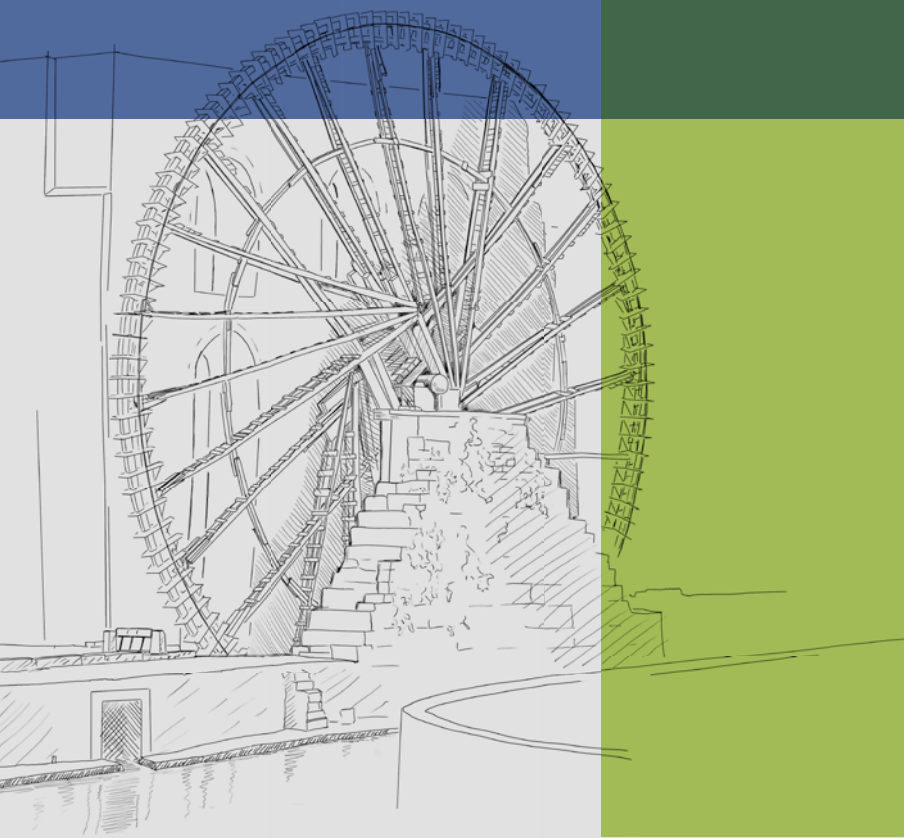


Water Management in Ancient Civilizations

Jonas Berking (ed.)



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BERLIN STUDIES OF THE ANCIENT WORLD

WATER AND ITS MANAGEMENT is a necessity for every society and each individual. This book compiles ancient approaches to water management from different times, places, and perspectives. In antiquity, a great variety of techniques for how to store, deliver, and also lift water had evolved, especially during the Hellenistic and Roman times.

This book examines the different governance structures, water management bodies, and relevant legislation that were developed to ensure that water was used and delivered in specific ways. These are explored utilizing examples from ancient Mesopotamia, Egypt, Spain, and Italy.

To prevent water from delivery problems, theft, and pollution, water was often conveyed via closed systems, which were sometimes subterranean in nature. Two respective closed system techniques are presented in this book: the Qanat-technology, with examples from the Iberian Peninsula, and the Roman Aqueduct, with an example from Sicily. Additionally, this book looks at how water has been used in societies as a way to display power, for leisure, to show technical hubris, or to simply harness its power, for example to document time passing, as was done via ancient water clocks.

Water Management in Ancient Civilizations

EDITED BY

Jonas Berking

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Jonas Berking

Water Management in Ancient Civilizations: Editorial

Summary

This volume brings together papers on Water Management in Ancient Civilizations. It envelops a great variety of ancient means to harvest, supply, distribute, and dispute water in all its forms. Contributions range in time period from the early means of water management in Mesopotamia and Egypt, to the Epochs of Hellenistic and Roman Eras, into medieval times and beyond. The fascinating momentum of ancient water management include not only the great solutions and applications that were already at hand thousands of years ago, but its implications and importance for present and future problems, since water is, was, and will continue to be the most precious resource for human wellbeing.

Keywords: water availability; water technology; social organization; irrigation strategies; water lifting devices; water economy; water legislation

Dieser Sammelband vereint Beiträge zum Wassermanagement antiker Zivilisationen. Er umfasst dabei die große Bandbreite antiker Methoden zum Wasser sammeln, zur Wasserversorgung, zur Verteilung oder zu Verteilungsproblemen. Die Beiträge reichen von den Anfängen des Wassermanagements in Mesopotamien und Ägypten, über die Hellenistische- und Römische Epoche, bis hinein in das Mittelalter und die Neuzeit. Das Faszinierende am antiken Wassermanagement sind dabei nicht nur die frühen Lösungen und Anwendungen, sondern insbesondere auch ihre Wirkung und Wichtigkeit bis in die Gegenwart und Zukunft, denn Wasser ist und bleibt die wichtigste Ressource für menschliches Wohlergehen.

Keywords: Wasserverfügbarkeit; Wassertechnologie; soziale Organisation; Bewässerungsstrategien; Wasser-Hebe-Systeme; Wasserwirtschaft; Wasserrecht

This study is part of the Key Topic *Watermanagement* within the Excellence Cluster 264 *Topoi – The Formation and Transformation of Space and Knowledge in Ancient Civilizations*. It brings together papers presented at the 2016 workshop on *Water Management in Ancient Civilizations*. The workshop further developed the topic of ancient and historical water management within the Excellence Cluster *Topoi*, after a first workshop on this topic in 2014 at the Freie Universität Berlin, Germany.

I Scope of the volume

Water is one of the most important ingredients in nature and daily life, and the study of this very common substance is a subject of many different disciplines.¹ The majority of modern water studies are concerned with issues of water management, including: water quality and quantity, the broad agenda of human agency, and institutions of water distribution and sanitation. This volume brings together papers presented at the 2016 workshop on *Water Management in Ancient Civilizations*. The workshop further developed the topic of ancient and historical water management within the Excellence Cluster *Topoi*, after a first workshop on this topic in 2014 at the Freie Universität Berlin, Germany.² The workshop in 2016 only encompassed part of this broad field of water studies and disciplines. The idea of the workshop was to bring together approaches from different disciplines that contextualize water management within a historical perspective. The outcome of this fruitful and multidisciplinary workshop is a compilation of contributions from geosciences, classical archaeology, ancient oriental studies, history, history of science, and legal studies in this volume.

Within much of the research in water management, there is a growing interest in how to bridge water research from different disciplines, since water has been a topic high on the political and scientific agenda for several decades now.³ Increasing effort is being put into the incorporation of different academic disciplines, so that their knowledge can help solve a diverse range of global water problems.

However, in historical, and especially archaeological approaches, water research has a long tradition that predates the popular discussion by several decades. The often claimed “hydraulic hypothesis” put forward by Karl Wittfogel in the 1950s,⁴ was one of these earlier approaches that combined the social and political consequences of controlling and managing water. Although the hydraulic hypothesis has been critiqued and rejected by many scholars since, it still forms the basis for many modern discussions.⁵ One of the main aspects of this hypothesis is that extensive water distribution for irrigation purposes produces the need for regulation (an institution), which in turn formulates a major aspect of cultural and social dimensions. As a far-reaching consequence of this, irrigation endeavors could have been a major aspect in the first marked transition in human history (the transition from hunter-gatherer to state-urban cultures), and maybe also in the establishment of social stratifications.⁶

Hence, any single deterministic view of water solely as a resource is misleading for water studies, especially when set against the background of this workshop about water

1 Mays 2010b.

2 Berking 2016.

3 Weisz et al. 2001.

4 Wittfogel 1957, 2–3.

5 Harrower 2009.

6 Hunt et al. 1976.

management in ancient civilizations. Such a view would eclipse the great variety of water in all its forms. That is to say, water management can be approached in several ways and thought about on a number of different levels.

2 Water management: aspects and approaches

However, since water management is such a broad term, there is no simple approach to it. The great variety of disciplines and agendas which deal with water management issues describe complex relations between natural environmental conditions and social, technical, governmental, and legal structures. A straightforward definition, according to Scarborough is: “[...] water management is the human interruption of the natural water cycle undertaken by a society”.⁷ This definition covers the three important aspects of water management, including: (a) the natural movement of water (water availability), (b) the redirection and collection of water (water technology), and (c) the social organization, displayed, e.g. in governance or legal structures.⁸

More generally, this means that:

(a) Water availability refers to natural water sources. The primary source is precipitation and the subsequently generated surface, or groundwater, run-off. It is important to note that the specific climatic conditions, hydrological regime, and landscape or catchment characteristics make water availability a dynamically changing and manifold process.

(b) Water technology refers to all technical measures of water management. Specifically these are: (i) wells and springs, (ii) open and closed canals, (iii) open and closed reservoirs, (iv) temporal and permanent dams, as well as (v) water lifting devices.

(c) The social organization with respect to water management refers to the way in which water is shared, provided, and used among individuals or groups. Often societies develop(ed) special governance structures to regulate water as a resource.

Water and water management have various other dimensions; for example, water can be classified and analyzed in terms of its function and purpose. Water is used as fresh water (domestic, drinking, tap, and portable water); for food production (water for irrigation and animal husbandry); fishery; navigation (transport); cult practices; energy (hydropower); status (political power); hygiene; and for the purpose of entertainment, protection, cooling, and recreation.⁹

Water management can also be seen through the lens of the prevailing climatic or hydrologic conditions and the chronological time period of a particular study. The pre-

7 Scarborough 1991, 1.

8 Berking et al. 2016.

9 Berking et al. 2016.

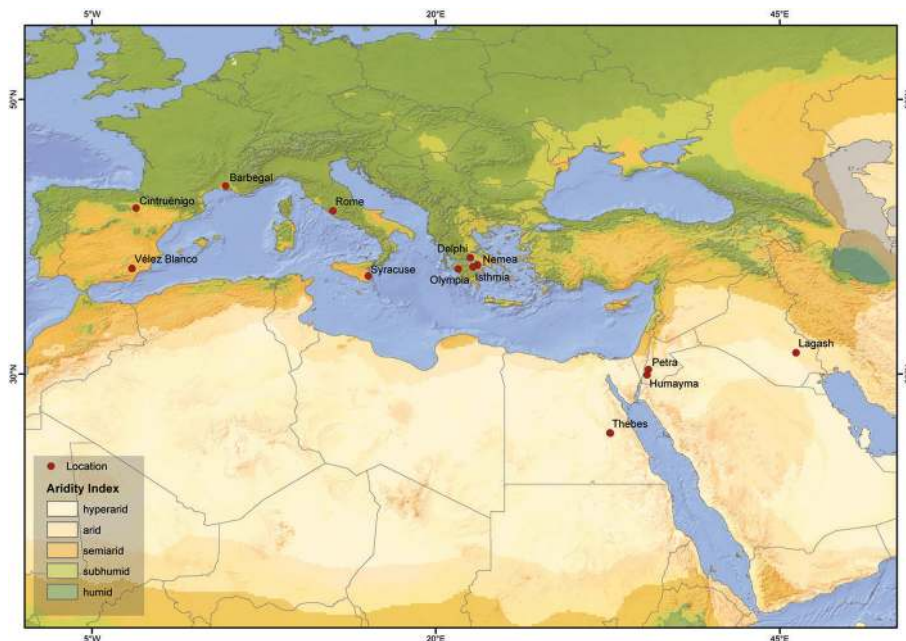


Fig. 1 Distribution of the main locations presented in this volume. Background colors represent the UNEP Aridity Index, indicating the climatic setting of the specific sites.

vailing landscape and climatic setting of a specific study site concerns the type of water management strategies applied in a particular case. For this volume, the geographic distribution and climatic classification of the contributions presented here are shown in Fig. 1.

The most common means with which to group historical studies is to classify them according to their chronology. The chronological framework for the contributions in this volume are illustrated in Fig. 2. Due to the very long timeframes of several of the studies, this chronological classification isn't used to organize this volume.

3 Organization of the Volume

The original thematic concept of the workshop is used to organize this volume, and, thus, the papers are grouped into four sections: (i) Water, Climate, and Society; (ii) Water Techniques and Legislation; (iii) Water and Economy; and (iv) Water Management in the Classical era. These present different aspects of ancient water management. It is not the claim of this volume, however, that it presents a comprehensive book about ancient

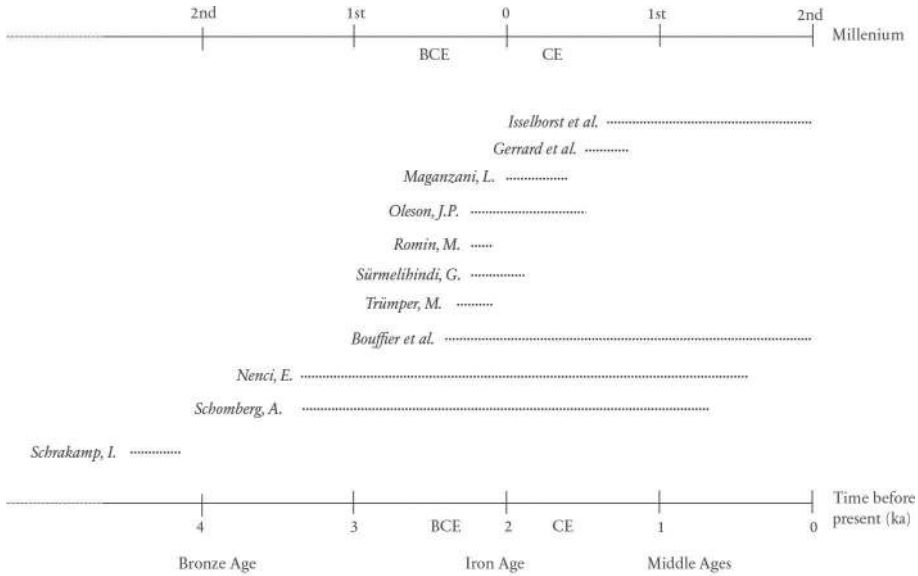


Fig. 2 Chronological order of the main periods presented in this volume.

water management, but it brings together single case studies with new and original research.

4 Sections

4.1 Water, climate, and society

Especially in arid and water scarce regions, water management is a fundamental need for humans and societies. These regions are prone to drought and are prime examples of the interactions between of water, climate, and society. One important aspect of coping with low water availability is presented by J. Oleson, namely the provision of a well-organized water distribution and storage system built on advanced technological knowledge. The climatic conditions, as well as the technical knowledge, are very well represented in the arid mountainous region of western Jordan, where the Nabateans evolved in the first centuries BCE, with their capital of Petra. As J. Oleson points out, satellite settlements, such as Harara (Humayma) to the south of Petra, were also characterized by a well-organized water distribution and storage system. The technical realizations in water technology from the Nabatean and later Roman times are still famous today.

4.2 Water techniques and legislation

As mentioned above, most types of water technology can be grouped into five categories. Whilst most of these technologies and techniques are well understood, it is sometimes difficult to be sure of their origin or where and when they first appeared.

It seems that many techniques evolved during the first millennia BCE in Mesopotamia, as well as in Egypt, especially in Alexandria in the first millennium BCE. G. Sürmelihindi, herein, undertakes a comprehensive overview of water technology throughout antiquity. The special focus of this contribution is on water-lifting devices, which sometimes were highly sophisticated machines. For example, the Roman *force pumps* and the *water mills* were milestones of antique water lifting techniques, often not contextualized with such a profound geoscientific background. Also, what is probably the oldest water-lifting device, the *shādūf*, plays a role in G. Sürmelihindi's paper, and is analyzed in much more detail by E. Nenci in his contribution. E. Nenci describes the *shādūf* from its first appearance in Egypt and follows its fast spread into different regions. The sophisticated technical details of this practical and easily recognizable technique are often neglected and it is only possible to date such devices by examining all existing records and sources as presented here.

The other major aspects of this chapter include water rights and water law, and their legislation. Here questions arise such as: Who owns the water? Is water a public or private good? What societal structures – states, cities, communities, or organizations – are in charge of this legislation? The best known example of a highly sophisticated system from antiquity presented in this volume, is the Roman water law. L. Maganzani presents excellent examples in her contribution, focusing on local irrigation systems organized by villages and communities in the Roman world and jurisprudential sources belonging to Justinian's Digest on the topic. The fact that joint water use generated disputes that were then addressed by jurisprudence, allows a perfect evaluation of the relationships between communities and their respective members concerning their water and irrigation needs. In a similar way, M. Ronin analyzes the problems Roman jurists had to cope with when facing problems related to water sharing and irrigation in the periphery of Rome. She argues that Roman jurists applied legal solutions that were directly linked with the development of the city of Rome itself, including the increasing competition for water resources due to economic and environmental reasons.

4.3 Water and economy

Water is vital for agriculture, and in most cases agricultural prosperity grows with the availability of fresh water. Hence, the economic value of water is often very high, especially in agricultural regions with hot and dry climates or a pronounced seasonality in

water availability.

A prime example of such a region is Middle and Lower Mesopotamia, where the hot and dry climate makes rain-fed irrigation nearly impossible. From here, I. Schrakamp introduces the oldest water management system presented in this volume. He focusses on the information provided by cuneiform inscriptions on the socio-economic and water management issues from the 3rd millennium BCE, focusing on the arid area around the Euphrates at Lagash.

In contrast to the riverine societies of Mesopotamia, which had little rain throughout the year, the Mediterranean regions typically have a rainy season in winter and hot, dry summers. Here, different techniques of groundwater tapping and distribution systems evolved that were especially important to provide water throughout the growing seasons during the summers months. Some especially well known and prominent examples of water distribution and irrigation strategies developed in the Iberian Peninsula at the end of the Classical era and with the beginning of medieval times. The *mélange* of Roman and Arabic influences at the time led to the development of special water management systems and irrigation techniques and communities, some of which are still in use today. One such technique is presented by C. Gerrard and A. Gutiérrez, providing new insight into the *qanat* technology in northern Spain, while Isselhorst et al. focus on water management strategies from Andalusia, of southern Spain, that partly still function today (Fig. 2).

4.4 Water management in the Classical era

During the Hellenistic and later Classical era, water management and water techniques flourished in a formerly unprecedented way. The societies that have flourished in the Greek territory since the last millennium BCE developed several sophisticated technical works.¹⁰ Some of these structures were related to water use. The application of hydraulic technology in combination with knowledge of processes, allowed the ancient Greeks to set up water supply and drainage systems, as well as flood protection, sanitary systems, and, maybe for the first time, recreational and sport facilities with water, such as pools or bath houses. This is the focus of the comprehensive study on Greek baths by M. Trümper, focusing mostly on the Peloponnese, but setting them into the context of the whole era of Greek baths throughout the Mediterranean.

When Rome later became the dominant power of the Mediterranean, they influenced vast regions through their large scale building projects and logistics. Roman construction and management of cities and settlements, and their way of exploiting and interacting with natural environments, especially water, was extensive and uncontested.

¹⁰ Mamassis and Koutsoyiannis 2010.

One aspect of water supply in Roman settlements that was probably rather new at the time was to provide large quantities of water with high quality. This was only possible through the usage of regularly available, relatively pure groundwater sources, which were tapped and canalized and often transported over long distances via aqueducts.¹¹ From the classical area, Bouffier et al. present the famous aqueduct of Syracuse, the Aqueduct of Galermi, which is still in good shape and restored.

Finally, the contribution of A. Schomberg opens up the field of water application and technology, which is important to a rather new area of research into the invention, distribution, and functioning of ancient water clocks. She evaluates how and when time measurement began to take place in antiquity; the important role of the complicated but practical water clock, starting with its origin in the 2nd millennium BCE in Egypt; and how they later spread during Roman times, until the era of the water clock ended with the invention of the mechanical clock during the Middle Ages.

11 Cf. Mays 2010a.

Bibliography

Berking 2016

Jonas Berking. "The Berlin 2014 Water Management Workshop". *Water History* 8.1 (2016), 41–42.

Berking et al. 2016

Jonas Berking, Brian Beckers, Daniel Knitter, and Brigitta Schütt. "Problems Concerning Ancient Water Management in the Mediterranean". *eTopoi. Journal for Ancient Studies. Special Vol. 6* (2016), 74–101. URL: <http://edition-topoi.org/articles/details/problems-concerning-ancient-water-management-in-the-mediterranean> (visited on 25/05/2018).

Harrower 2009

Michael J. Harrower. "Is the Hydraulic Hypothesis Dead Yet? Irrigation and Social Change in Ancient Yemen". *World Archaeology* 41.1 (2009), 58–72.

Hunt et al. 1976

Robert C. Hunt, Eva Hunt, G. Munir Ahmed, John W. Bennett, Richard K. Cleek, P. E. B. Coy, Thomas F. Glick, Russell E. Lewis, Bruce B. MacLachlan, William P. Mitchell, William L. Partridge, Barbara J. Price, Wolf Roder, Axel Steensberg, Robert Wade, and Imre Wellmann. "Canal Irrigation and Local Social Organization [and Comments and Reply]". *Current Anthropology* 17.3 (1976), 389–411.

Mamassis and Koutsoyiannis 2010

Nikos Mamassis and Demetris Koutsoyiannis. "A Web Based Information System for the Inspection of the Hydraulic Works in Ancient Greece". In *Ancient Water Technologies*. Ed. by L. W. Mays. Dordrecht: Springer, 2010, 103–114.

Mays 2010a

Larry W. Mays. "A Brief History of Roman Water Technology". In *Ancient Water Technologies*. Dordrecht: Springer, 2010, 115–137.

Mays 2010b

Larry W. Mays. *Water Resources Engineering*. 2nd ed. Hoboken, NJ, and Chichester: Wiley, 2010.

Scarborough 1991

Vernon L. Scarborough. "Water Management Adaptations in Nonindustrial Complex Societies: an Archaeological Perspective". *Archaeological Method and Theory* 3 (1991), 101–154.

Weisz et al. 2001

Helga Weisz, Marina Fischer-Kowalski, Clemens M. Grünbühel, Helmut Haberl, Fridolin Krausmann, and Verena Winiwarter. "Global Environmental Change and Historical Transitions". *Innovation: The European Journal of Social Sciences* 14.2 (2001), 117–142.

Wittfogel 1957

Karl A. Wittfogel. *Oriental Despotism*. New Haven: Yale University Press, 1957. URL: <http://archive.org/details/KarlAugustWittfogel-OrientalDespotism> (visited on 25/05/2018).

Illustration credits

1–2 J. Berking.

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Strategies for Water Supply in Arabia Petraea during the Nabataean through Early Islamic Periods: Local Adaptations of the Regional ‘Technological Shelf’

Summary

Excavation by the author at the site of al-Humayma, ancient Hawara, allowed detailed reconstruction of the water-supply system that supported this isolated settlement in the hyper-arid Hisma Desert of Southern Jordan. A re-evaluation of the regional water-supply systems in Arabia Petraea from the Nabataean through the Early Islamic phases, shows that some aspects of the systems at Nabataean sites, such as Petra and Hawara, had precedents in the technologies of the Late Bronze Age and Iron Age settlements in the region, while others can be traced to developments in the Hellenistic Aegean. Sites such as Petra, Hawara, Iram, and Hegra show that the overall flavor of the water-supply systems remain strictly regional, mostly due to climate, topography, and hydrology.

Keywords: Nabataeans; hydraulic technology; technological shelf; cistern; aqueduct

Die vom Autor geleitete Ausgrabung in al-Humayma, dem antiken Hawara, ermöglichte eine detaillierte Rekonstruktion des Wasserversorgungssystems, das die isolierte Stätte in der extrem ariden Hisma Wüste im südlichen Jordanien versorgte. Eine Neubewertung der Wasserversorgung in der Arabia Petraea von der nabatäischen bis in die islamische Zeit zeigt, dass die in nabatäischen Siedlungen wie Petra und Hawara gebräuchlichen Systeme technisch teils aus der regionalen Spätbronze- und Eisenzeit hervorgehen, teils in die hellenistische Ägäis zurückverfolgt werden können. Es kann gezeigt werden, dass der generelle Charakter der Systeme in Siedlungen wie Petra, Hawara, Iram und Hegra regional bleibt, hauptsächlich aufgrund von Klimabedingungen, Topografie und Hydraulik.

Keywords: Nabatäer; Hydrauliktechnologie; technologisches Repertoire; Zisterne; Aquädukt

A Survey and excavation conducted by the author between 1983 and 2005 at the site of Humayma, in the Hisma Desert of Southern Jordan, produced an enormous amount of data about the details of the water-supply system that allowed this isolated settlement to flourish in a hyper-arid environment.¹

Humayma, ancient Hawara, was founded by a Nabataean King, Aretas, either the third or fourth of that name, sometime in the first century BC. An oracle told his son Obodas to, “seek a place called ‘White’”; a punning reference to the literal meaning of the name Hawara, and the vision of a white camel led him to the site (Fig. 1).² Essentially a colony of Petra, Hawara was located at a spot on the King’s Highway in the Hisma Desert, which was well suited to pastoralism, agriculture, and trade, and the small Nabataean settlement continued to flourish under subsequent Roman, Byzantine, and Abbasid occupiers.

The regional water-supply system included 27 km of aqueduct, five reservoirs, 57 cisterns, and three containment dams, along with a few wadi barriers and terraced fields (Fig. 2).

A complete analysis of the local and regional water-supply system of Hawara for the first final report of the Humayma Excavation Project, published in 2010, made a full evaluation of the historical and technological context from the Nabataean through the Early Islamic periods possible. The regional system, in fact, is almost entirely Nabataean in origin, and the original design functioned almost without change across 800 years. This remarkable stability and effectiveness raises questions about Nabataean hydraulic technology. Was there a distinct repertoire of techniques and structures that is recognizably Nabataean? If so, did all these techniques originate with the Nabataeans themselves as they gradually sedentarized in the course of the second century BC? In particular, did this technology evolve at Petra, which seems early for it to have had special economic, religious, and political importance? Did engineers trained or experienced in some normative tradition of water supply carry this knowledge outward from Petra in the same way that much of the Nabataean painted fine ware was exported from that central place? Was there a Nabataean Vitruvius or Frontinus, some paragon of hydraulic engineering or administration who spread his ideas in written form? Finally, how do the chronology and technology of the water-supply systems at Hegra, or in the flourishing cities of the Negev, compare with the systems the core settlements of Arabia Petraea, such as Petra and Hawara. Naturally, I want to develop this discussion of Nabataean water-supply technology in a way that will contribute to the workshop theme of *Water Management in Ancient Civilizations*, and to the session theme of *Water, Climate, and Society*.

1 See the bibliography and account of the excavation in Oleson 2010.

2 Oleson 2010, 50–53.

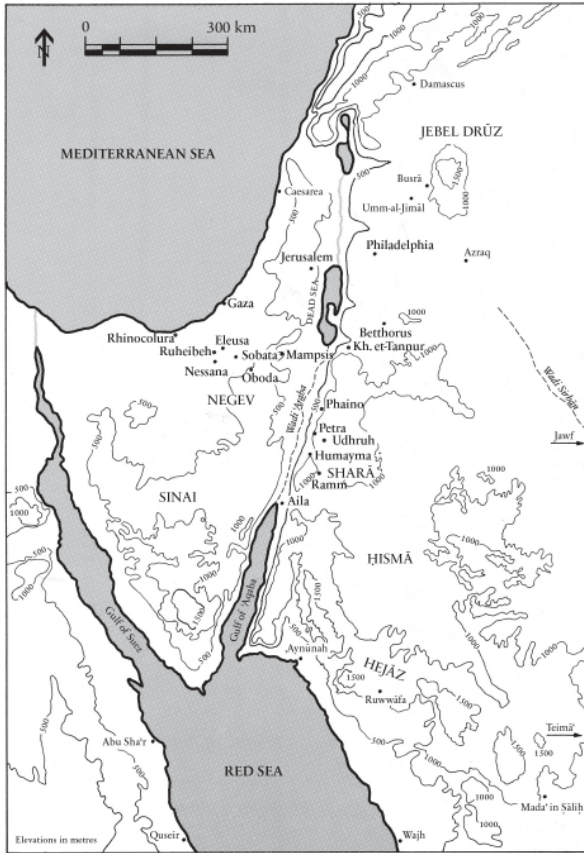


Fig. 1 Locator map of Humayma.

At the start, I have to emphasize that the variety of environmental conditions across Nabataean territory presents some problems for any hypothesis of a unitary Nabataean technology.³ The northern portion of the kingdom, which I can only touch upon in this context, was relatively well watered and well endowed with agricultural land. For these same reasons, this region was also rich in traditions of water management and water supply that originated as early as the Bronze Age, and were modified or supplemented by various regional cultures through the Hellenistic period. At present, the annual precipitation at Damascus averages 202 mm, which is below the threshold for grain production, but the Barada River, originating in the Anti-Lebanon mountains, has emptied into the al-Ghutah oasis since antiquity, on the edge of which Damascus was founded long before the Nabataean hegemony, allowing irrigation agriculture. The site of Bosra to the south, in contrast, receives only 150 mm of rainfall a year, and must rely on reservoirs

3 National 1984; Shehadeh 1985; al-Kurdi 2008.

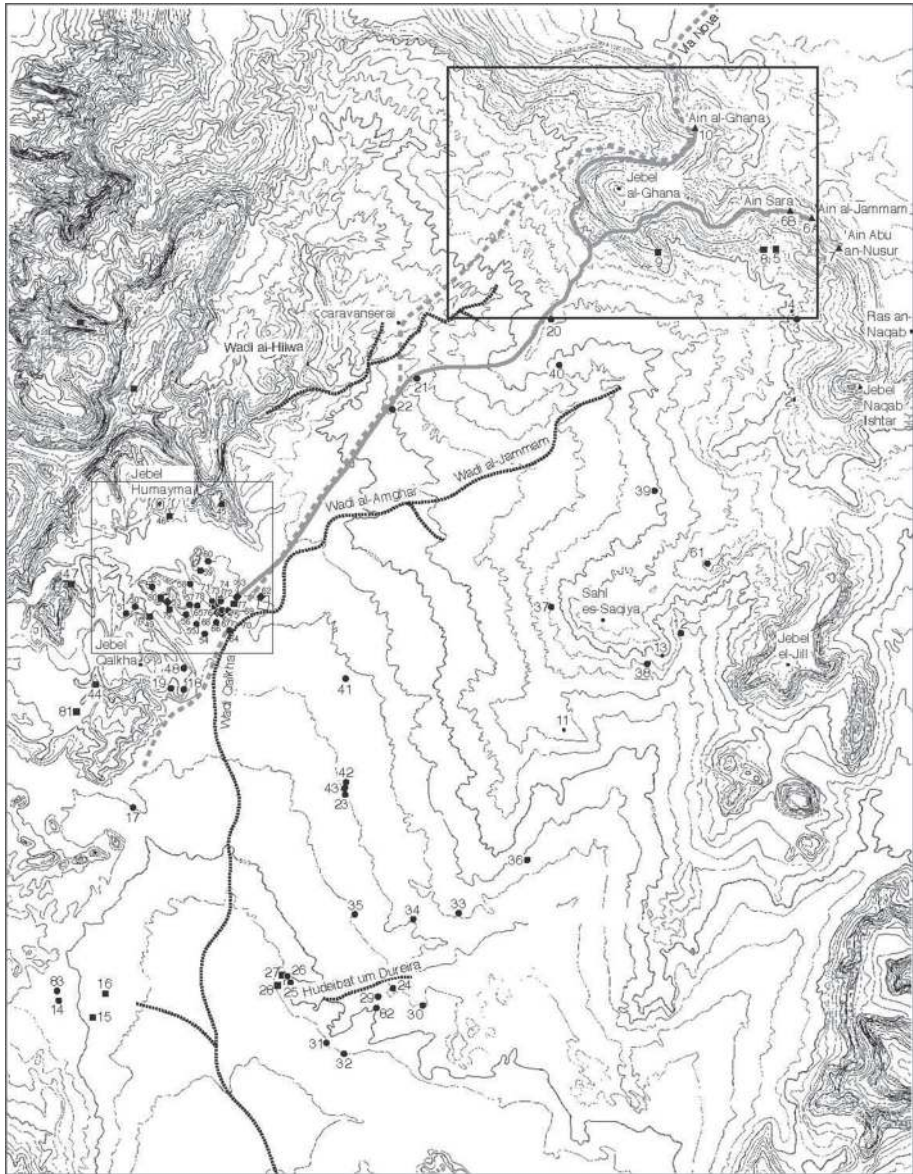


Fig. 2 Map of Humayma region with hydraulic installations.



Fig. 3 View of 'Ain Brak, Petra.

and cisterns to store the run-off. This run-off water was directed to reservoirs and agricultural fields by shallow earthen channels. The same goes for Umm el-Jamal and the other sites that flourished in the Hauran during the Nabataean period. All of these techniques were in use in the region since the Bronze Age.

Between Bosra in the north and Ras en-Naqb far to the south, on the high el-Sherah escarpment that forms the boundary of the Hisma Desert increased rainfall coincides with higher elevation. The settlements at the higher elevations, such as Jerash, Madaba, and Kerak and the lands around them receive between 200 and 400 mm of precipitation, sufficient for growing grain. The lower, dry steppe regions to the east receive between 100 and 200 mm, which allowed an active pastoral economy but restricted agriculture.

Farther south, the capital city of Petra gave its name to stony Arabia Petraea, but enjoyed water resources far exceeding those elsewhere in the region. The site of Petra receives only 40 mm of precipitation a year, but Wadi Musa higher up to the east receives 177 mm, and the run-off flows, for the most part, through Petra. In addition, the abundant spring of 'Ain Musa and several lesser springs flow from the high stratum of limestone down towards the settlement center (Fig. 3).⁴

Conditions to the southeast around the Jafr depression, to the south in the Hisma Desert, and in the Hejaz, qualify as hyper-arid, with more or less 50 mm of precipitation annually and very high evaporation rates. The cities of Nabataean origin in the Negev enjoyed both higher rainfall – between 100 and 300 mm annually – and more fertile soil than Arabia Petraea, although conditions were not as favorable as in the northern Nabataean territory.⁵ Nevertheless, despite all these regional anomalies, modern scholars often assume that all the settlements between Avdat and Bosra that shared in the Nabataean cultural veneer formed part of a unitary technological system. Was this really

4 Bellwald 2008; Oleson 2010, 417–446.

5 Evenari, Shanan, and Tadmor 1982, 95–119.



Fig. 4 Iron Age Cistern, Umm Biyara.

the case? What is the cultural flavor of hydraulic technology in this large and varied region, and what does it tell us about Nabataean culture in general? First, we must consider the origins of these techniques.

Many aspects of Nabataean hydraulic technology had precedents in the technologies of the Bronze Age and Iron Age settlements that later became part of the Nabataean kingdom.⁶

Cisterns are the most obvious example of this connection since they appear in large numbers at nearly every Bronze and Iron Age settlement, both cut into the bedrock and built of blocks. There are numerous Iron Age examples at Sela and at Umm Biyara above Petra (Fig. 4). The terracing of agricultural fields was another common and effective method throughout the eastern Mediterranean from at least the Late Bronze Age onward. This was a technique designed to capture both run-off water and eroded soil, and transform a difficult slope into a series of narrow but fertile horizontal fields.⁷ There are many examples of these throughout the Nabataean kingdom, including a large number around Petra. Dams are a more technically demanding type of structure, but even so, attempts were made to block the flow of run-off water by the Early Bronze Age at Jawa, and – to move somewhat outside the Nabataean cultural area – at Ugarit by 1300 BC, a masonry dam was put across a flowing stream near the Royal Palace. Earth or masonry dams were a typical method of water control for the Late Bronze Age cultures of Egypt and Mesopotamia.⁸ The Nabataeans made use of both techniques.

Earthen water channels were an essential part of the river valley cultures in the Bronze Age, but shallow, unlined earth channels were also used in dry regions in every period to carry run-off water, although they seldom survived. Rare examples can

6 Oleson 1992; Oleson 2001; Heemeier et al. 2008.

7 Oleson 1992, 890–891; Oleson 2001, 605–608; Oleson 2010, 479–481; Price and Nixon 2005.

8 Helms 1981; Garbrecht 1991; Oleson 1992, 890–891; Oleson 2001, 608; Philip 2001, 173–174.



Fig. 5 Late Bronze Age conduit blocks, Ugarit.

be seen at Nabataean sites such as Umm el-Jimal and Sobota.⁹ By the Late Bronze Age rock-cut conduit blocks were a well-known method that was used throughout the eastern Mediterranean and the Levant (Fig. 5).

These were essentially pre-fabricated channels that conducted the flow of water from springs or other water sources across open land or through settlement centers into water storage structures. The Nabataean conduit blocks are generally more neatly carved than their Bronze Age predecessors, but in terms of design and function, they are identical.¹⁰

9 Oleson 2000, 184–205; Oleson 2001, 467.

10 Oleson 2001, 608–610.

An alternative to the open earth channel or the open stone channel was the terracotta pipe, specially designed with male and female terminations to allow a tight-fitting conduit. Pipes were used from the Late Bronze Age onward where a closed flow was needed, as in removing sewage, protecting water quality, conducting water below ground level, or providing a pressurized head.¹¹ Pipelines appear at many Nabataean sites, notably Petra and Hawara, although they had the disadvantage of becoming easily clogged by debris or water-deposited calcium carbonate.

Other aspects of Nabataean hydraulic technology can be traced to developments in the Hellenistic Aegean. It is likely, for example, that Nabataean engineers or military personnel borrowed the idea of long-distance terracotta pipelines from an outside source, and applied specific principles to the conduits that brought spring water to Petra. Possible nearby models include the pipeline built in the early first century BC to serve the Hasmonean and Herodian Palace complexes at Jericho and Kypros, but these pipelines were buried, small in scale, and not easily seen. They were themselves most likely modeled on the long-distance terracotta pipelines built to serve the citadel of Pergamon in the third century BC. Since the Pergamon pipeline climbed the slope above ground, Nabataean merchants or mercenaries in the area could easily have noted the impressive hydraulic installation.¹²

A particularly striking example of Hellenistic techniques adopted by the Nabataeans is the built or rock-cut cistern roofed with slabs carried on cross-arches, which the Nabataeans adopted enthusiastically sometime in the first century BC. Philon of Byzantium describes this roofing technique in the third century BC in the context of military architecture, and sometime afterwards a clever engineer applied the system to roofing rectangular cisterns on the treeless, arid island trade center of Delos (Fig. 6).¹³

The technique is actually quite rare for cisterns elsewhere in the Hellenistic world, although it had the advantage of allowing roofing without the use of long timbers as supports. This was an obvious advantage for applications both on waterless Aegean islands and in the deserts of Nabataea. Nabataean merchants trading around the Aegean in the first century BC probably saw the design while visiting Delos and borrowed it for both cistern and house architecture at Petra. The design remained in use in the region through the early modern period for roofing both types of structures.

Are there any important methods of water supply already known in the Eastern Mediterranean in the pre-Nabataean period that the Nabataeans did not adopt? The only one that stands out due to its later popularity is the *qanat* system. This involves the

11 Jansen 2000, 104–110.

12 Garbrecht 1987; Netzer, Laureys-Chachy, and Meshorer 2001, 27, 31, 33; Meshel and Amit 2002; Oleson 2010, 489–490. For the presence of

Nabataeans in the Mediterranean world see Roche 1996.

13 Philon, *Mechanike Syntaxis*, pl. 87. 11–18; Oleson 2010, 481–487.



Fig. 6 Theater cistern, Delos, 3rd century BC.

tapping of a water source below ground by means of an excavated shaft, then digging a tunnel at a carefully regulated slope below a downward sloping ground surface, until the tunnel meets the surface and flows into the open to its destination. The surface indication of a *qanat* is a series of shafts that were used to plot the direction and depth of the channel, to remove the spoil from digging the tunnel – which forms characteristic mounds around the shaft openings – and to allow periodic access for maintenance.¹⁴ This technique probably first appeared somewhere in the area of Persia or eastern Anatolia in the early first millennium BC, and it seems to have arrived in the Levant by the Late Roman or Byzantine period. In my opinion, *qanats* only became common in the region in the Early Islamic period. Although dating a *qanat* is difficult, none so far can be connected with a documented Nabataean context. There are two *qanat* sites in the southern Nabataean homeland; the one at Yotvata is probably Early Islamic and the extensive *qanat* systems between Udhruh and Tahuna are Byzantine or Early Islamic in date. There are eight *qanat* sites in northern Jordan, some of which originated in the late Roman period, but with significant Early Islamic intervention. This technique was not taken up by Nabataean engineers in Arabia Petraea simply because the topography and hydrology usually did not allow it. In the north, it may not have been used during the Nabataean period because the other systems we have reviewed were sufficient.

From this repertoire of designs, or – as historians of technology call it – this technological shelf, Nabataean engineers developed a suite of techniques and materials appropriate for urban water-supply systems and rural run-off agriculture in the regions under their control. That this suite of designs seems so characteristically Nabataean results from the enthusiasm with which their engineers applied the various borrowed designs

¹⁴ Goblot 1979; Lightfoot 1997; Abudana and Twaissi 2010; Oleson 2010, 447.



Fig. 7 Aqueduct channel in the Siq, Petra.

to a uniquely arid and stony landscape in Arabia Petraea and the Hejaz, with transformative results. The dry environment and low population have also fostered remarkable preservation of the structural remains.

How does Hawara, ancient Humayma, fit into this system? Does it closely reflect developments at Petra, the central place of Nabataean culture, or did the inhabitants of Hawara develop their own strategy and techniques for water supply? Petra and Hawara are good test sites for the relationship between the cultural capital and a rural offshoot, since the water-supply systems at both have been thoroughly studied and published. We can then have a look at the more distant Nabataean settlements in the Hejaz and Negev. We have to examine Petra first.

By the mid-first century BC, and possibly more than a century earlier, the inhabitants of Petra enjoyed a sophisticated and adaptable water-supply system.¹⁵ The regional springs were harnessed to supply at least five separate conduits or pipelines, following a variety of routes, using a variety of techniques, and supplying drinking water to various parts of the settlement (Fig. 7).

The multiplicity of channels and routes reflects both the number of sources and the number of areas supplied, but this approach also provided redundancy in the event of renovations, natural disaster, or enemy action. In addition, there were numerous large and small cisterns in and around Petra filled by run-off water. These served a variety of ongoing public and private functions but also supplied back up in the event of the disruption of the aqueducts. Some of these cisterns were formed by blocking a large crevice or small wadi with a substantial barrier wall in order to retain a pool of run-off water. This type of arrangement saved most of the effort of excavating an entire cistern tank.

15 Bellwald 2008; al-Muheisen 2009, 31–129; Oleson 2010, 417–446.

The Nabataeans occasionally built diversion dams, as at the entrance to the Siq. Another type of blocking wall was apparently unique to Petra. Several dozen small dams block watercourses that drain into the Siq, the narrow passageway into Petra from the east, but they do not retain the water for use. There are discharge openings at the base of these dams that allow the water to run out slowly. In this way the small dams *detain* the water, rather than *retaining* it, preventing the sudden large rush of run-off that would fill the Siq and endanger people and property.¹⁶ This unique feature, now in use in many modern water-control systems, was produced by the special topography of Petra and local patterns of precipitation. Finally, the landscape in and around Petra was transformed by hundreds of terraces and wadi barriers that enhanced local agricultural productivity by holding back both soil and water.

How does this sophisticated and successful hydraulic technology relate to that found at Hawara? The very concept of a long-distance conduit fed by a spring, as seen at Petra, undoubtedly provided both the inspiration and the engineering skills that contributed to the construction of the Hawara aqueduct system sometime in the first century BC (Fig. 8).¹⁷

The same aqueduct technology was applied at both sites, with the exception of the long-distance terracotta pipelines, which were present at Petra but absent at Hawara.¹⁸ While short local pipelines were used within the settlement of Hawara, some of them apparently pressurized, they do not appear outside the settlement center. The much longer distances to be travelled, the lower average slope, and the lower output of the available springs were probably all factors that made use of a long-distance pipeline impractical. It is possible, however, that the occasional use of pipes within stone gutter blocks at Petra inspired the use of inverted roof tiles in the gutter blocks of the Jammam aqueduct in the fourth century AD, perhaps after the earthquake of 363.¹⁹ This curious and unparalleled modification, which involved the recycling of approximately 18 000 terracotta cover tiles taken from structures in the Roman fort at Hawara, probably was meant to solve a supply problem caused either by the settling of the foundations of the aqueduct, or a substantial decrease in the water flow from the springs (Fig. 9). The use of tiles may also have helped solve the problem of the build-up of sinter, calcium-carbonate deposits, in the aqueduct channel, since the tiles could be replaced or cleaned periodically without dismantling the aqueduct structure.

Although the Hawara aqueduct conduits were cut into the bedrock where that was possible, about 95 percent of the course was built of stone gutter blocks.²⁰

16 Bellwald 2008, 67–69; Bellwald and Ruben 2003, 71–76; Oleson 2010, 421–422.

17 Oleson 2010, 74–115, 386–394.

18 Oleson 2010, 181–187, 255–288, 330–331, 394–396.

19 Oleson 2010, 102–107, 112–115, 328–330.

20 Oleson 2010, 74–115.



Fig. 8 Nabataean aqueduct channel to Hawara.

Gutter blocks of the same design appear where necessary in the Petra system, but the main channels were often slightly larger than at Hawara, to accommodate the greater flow of the springs. In all the cases where the capacity of the conduits or pipelines serving Petra has been calculated, the potential maximum flow seems far in excess of the probable available spring flow. The calculated capacity of the conduits in the Siq alone (208 cum/hr), for example, is 34 times the recent discharge of the 'Ain Musa. The same disparity was noted for the Hawara aqueduct system as well (2.2–19.6 cum/hr), although only at a factor of 4.5.²¹ Since it is unlikely that either spring was correspondingly more abundant in antiquity, several technical explanations for this over-building are possible.

21 Oleson 2010, 365–368, 434–435.



Fig. 9 Nabataean aqueduct with inverted roof tiles added, Hawara.

First, the excess capacity gave the engineers greater leeway for errors in leveling and calculation of gradient when dealing with constantly changing slopes; a larger channel area made it less likely that poor leveling would cause an overflow of water that would damage the aqueduct structure. Alternatively, the excess capacity could have been meant to compensate for the formation of calcium carbonate deposits in the channels and pipes over the decades. Sinter seems to have been removed regularly from the Hawara conduits, since the deposits surviving in the conduits usually show only four to 10 annual growth rings, and chunks of discarded sinter are found there and along the course of the aqueduct. It was more difficult to clear pipes, and one pipeline in the Siq at Petra finally became so clogged with sinter that the pipes were broken open to allow unconfined channel flow.²²

In the 'Ain Musa system, it is likely that a distribution basin at the Zurraba reservoir allowed the flow from the spring to be directed to any one of the three outflow conduits as special needs arose in various parts of the city. Diversion of the entire spring discharge to a single channel, naturally required careful attention to capacity. Intentional over-engineering by individuals uncertain about flow rates, slopes, and levels is probably the most likely solution. Roman engineers, such as Frontinus, often took the same precautions in their calculations of water flow in the aqueducts.²³

There are other parallels between the Petra and Hawara aqueduct systems.²⁴ For example, both make use of occasional settling tanks within the flow regime to remove sand and silt. Both systems also provided draw tanks or drinking tanks isolated from the flow by short branch lines. Large stone basins with multiple exits and sluice gates allowing the diversion of water into various subsidiary channels have been found at both

22 Bellwald and Ruben 2003, 58, 87–90.

24 Oleson 2010, 444–446.

23 Hodge 1992, 215–245.



Fig. 10 Nabataean pool fed by aqueduct, Hawara.

sites. Both systems also fed reservoirs or pools that made the water directly available or serviced local pipe systems. The aqueduct system at Hawara discharged its water into a large shallow pool (27.6×17 m, depth 1.34 m) with a capacity of 629 cubic meters (Fig. 10).

The overflow water then spilled into a downstream conduit that supplied a bath building and possibly some cisterns in the town center. The pool was designed to display, rather than to store, the water or to make it accessible. It seems very likely that the Hawara pool was modeled on the Garden Pool complex in Petra, which was the centerpiece of a garden complex, a Near Eastern *paradeisos*. There was even an island in the Petra pool for banquets.²⁵ This comparison, however, has the remarkable implication that the major motive for the construction of the 27 km long Hawara aqueduct was royal or cultural prestige, meant as a dramatic proof of the Nabataean ability to control the desert. The intended audience may have been the caravans travelling the King's Highway, particularly those heading north through Hawara towards Petra. Many of the monuments in the Siq were also meant to impress visitors arriving by that entrance: the arched entrance, water basins, betyls, inscriptions, bas-reliefs of camel caravans, and the spectacular al-Khazneh tomb facade. Once inside the city, visitors might have gaped at the waterfalls at the termination of the 'Ain Brak and North Khubtha conduits, and at the *paradeisos* associated with the Garden Pool. Although compromised in quality, the overflow from both the Petra Garden Pool and the Hawara aqueduct pools was suitable for baths, industrial purposes, and agriculture.

The basic technology of the reservoirs and cisterns at Hawara also resembles the equivalent structures at Petra. At both sites most cisterns were cut down into a leveled rock surface and provided with slab roofs carried on cross arches (Fig. 11).

25 Oleson 2010, 181–187, 381–383, 439–443.



Fig. 11 Nabataean arch-roofed cistern, Hawara.

One disparity is that only one cistern and one reservoir at Hawara were provided with stairs into the pool to facilitate periodic cleaning, a feature that was common at Petra. It is possible that the settling basins commonly associated with cistern intakes at Hawara represent a local practice that made frequent cleaning less urgent. Settling basins were only rarely associated with cisterns at Petra.

A more striking anomaly at Hawara is the appearance in the settlement center of cylindrical cisterns built of blocks. In the Hawara center, cisterns and reservoirs had to be built of stone blocks rather than cut into the rock, because the bedrock was out of reach beneath the surface soil. It is no particular surprise to see the usual rectangular design constructed entirely of blocks. What is surprising is the appearance of seven built domestic cisterns with the typical arch supported roof, but with a cylindrical form (Fig. 12).²⁶

I have found no close parallels for this design in Nabataea or anywhere else in the contemporary Mediterranean world.²⁷ The design certainly makes sense, since the cylindrical shape not only provides more volume in proportion to the amount of masonry than rectangular plans, but it is also easier to waterproof and is better able to resist pressure from the surrounding soil. Did an innovative Nabataean engineer responding to the local situation possibly introduce the design to solve problems at Hawara? If this is the case, these cisterns provide striking evidence of the adaptability and sophistication of Nabataean hydraulic engineers, and their willingness to deviate from accepted designs. On the other hand, the fact that this design did not spread to other Nabataean

26 Oleson 2010, 199–202, 206–213, 377–378.

27 Bruneau and Bordreuil 1982, 499–502, record a circular well at Delos built of dry stone masonry, with three transverse arches that support a roof like a truncated cone. The design of this structure, how-

ever, is quite different from that of the arch-roofed cisterns at Humayma, and it is not a cistern. The adjacent stairwell suggests that it might have served as a ritual bath (*miqueb*) for the nearby synagogue. I owe this reference to Monika Trümper.

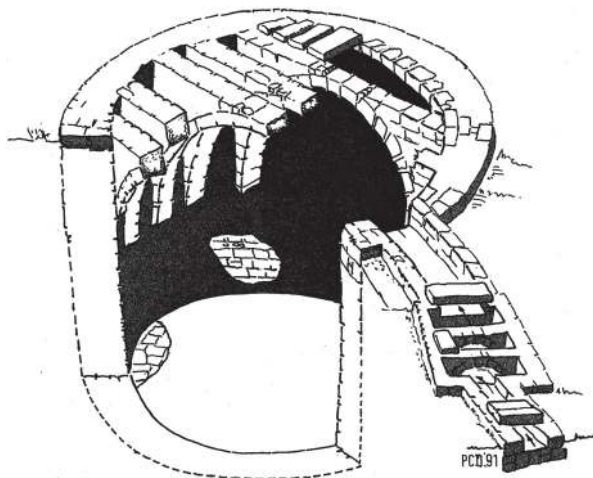


Fig. 12 Cylindrical arch-roofed cistern, Hawara, reconstruction.

sites may indicate that this engineer only worked locally, and the exchange of technical information was limited.

Another anomaly at Hawara is the rarity of agricultural terraces and wadi barriers in comparison with the hundreds seen at Petra.²⁸ The best soil around Hawara is found in the two depressions north and south of the settlement center, below the bedrock jebels, but very few traces of ancient wadi barriers survive there. Perhaps the flow of water in these wadis was either too violent for earth barriers to survive, or too intermittent for earth barriers to be of use for agriculture. Agriculture was practiced around Hawara, but, if the recent Bedouin practices preserve the ancient ones, near the foot of sandstone ridges or jebels that provided reliable and manageable catchments. The fields probably were furnished in antiquity, as today, with earthen barrier walls and conduits rather than with constructions of stone. Earthen features naturally were more likely to disappear over time, but Nabataean examples have survived here and there around Petra and at et-Telah in the Arabah.²⁹

There were at least three retention dams on the outskirts of Hawara, designed to hold back large pools of run-off water (Fig. 13).³⁰ The water would have been of low quality and probably used to water animals. This type of large open pool retained by a barrier wall does not appear at Petra, either because spring water sources were available, or because of the generally steeper topography.

There is a striking contrast between the agricultural practices at Hawara and those in the wadis around the Nabataean through Byzantine mining settlement of Phaino, 35 km

28 Oleson 2010, 161–169, 370–372.

29 Oleson 2010, 448–452.

30 Oleson 2010, 155–161, 372–373.



Fig. 13 Nabataean dam,
Hawara.

northwest of Petra in the Wadi Arabah. Although the function of the settlement was very different from that of Hawara, and much of the water supply in the Byzantine period was intended for use in processing ore, there are some similarities in topography and in soil and water resources. A recent survey catalogued a few structures similar in function to those at Hawara, but later in date and following the Roman design traditions: an aqueduct, reservoirs, a few cisterns, and two dams.³¹ The most prominent surviving remains of the water-supply system of Phaino are the numerous field boundaries built of water worn boulders, barrier walls with spillways, and earthen, stone framed water conduits built on and just above the wide, braided plane of the Wadi Faynan. Barrier walls diverted and guided the flowing water and delayed it so it could soak into the soil. The survey recognized 85 simple field systems, 10 complex field systems, and 6

31 Barker, Gilbertson, and Mattingly 2007.



Fig. 14 Aqueduct channel, Ramm.

side terraces. An area of at least 253 ha was prepared for agriculture in this manner, beginning in the Nabataean period. This irrigation system illustrates techniques that could have been applied at Hawara to make use of the braided flow in the wadis that pass by the site, but which apparently were not.

The well-known temple of Allat at Iram, modern Ramm, was built on a slope of scree at the foot of the precipitous cliffs characteristic of Wadi Ramm. The spring that served the site is tucked back into a recess in the west wall of the main wadi, framed by smaller wadis that climb into the cliffs to the north and south. Hawara lies 43 km to the north, but otherwise there were no Nabataean settlements of any size in the Hisma. The precise character of the sanctuary and settlement is still not entirely clear, but the water-supply system shows some striking parallels with that serving Hawara.³² The design of the spring-fed aqueduct is identical, as is the use of several branch lines to supplement

the main conduit, and the conduction of the water to a pool or reservoir (Fig. 14).

There were numerous arch-roofed cisterns and small dams in the region, as around Hawara, providing privately owned water. Although no one seems to have noticed, the modest Nabataean dam at al-Kharaza near Jebel Ratama, between Wadi Ramm and Hawara, may be the earliest well-documented vertical wall dam with an arched plan – a brilliantly innovative design that continues to be used throughout the world today.³³ This structure is also remarkable due to the presence of an inscription that provides both the owner's name and the date of construction: "Belonging to Seba, son of Eleh [this dam; J. O.] was prepared the year forty-one of Aretas [AD 32; J. O.], king of the Nabataeans, lover of his people."³⁴ Could this structure be another example of the innovative genius of the Nabataean engineer who designed the cylindrical cisterns at Hawara? Given the proximity of Hawara and Ramm, there were undoubtedly social, religious, and political bonds between them. In fact, Wadi Ramm may be the site of the oracular shrine referred to in the foundation story of Hawara, the oracle that told Obodas to "seek a place called 'white'".³⁵ Hydraulic engineers probably moved freely among Petra, Hawara, Ramm, and rest of the Hisma.

Although Hegra, modern Meda'in Saleh, lies 400 km south of Hawara, the two sites were connected by an active trade route. The topography of the sites is similar, and the amount of precipitation is approximately the same: 50–80 mm. Some parts of the site were served by rock-cut conduits with settling tanks, collecting run-off water for cisterns, but there are far fewer rock-cut cisterns at Hegra than at Hawara or Petra. Instead, the presence of ground water at a depth of only 18 m apparently fostered a water-supply system dependent on wells, which are not seen at Petra or Hawara.³⁶ The wells are very wide, up to seven meters in diameter, and seem to have served as a type of cistern fed by the percolation of ground water rather than by run-off.

The early stages of the Nabataean occupation of the Negev remain obscure, but the Nabataeans seem to have established trade routes across the region to emporia at ancient Gaza and Pelusium by the late fourth century BC. These routes attracted watchtowers and settlements possibly as early as the second half of the third century BC. Incense and other high value commodities imported from the Arabian peninsula and the Indian sub-continent were carried along this 'incense road,' and they contributed to the development of six main Nabataean settlement centers that by the Byzantine period may have had a total population of 20 000: Oboda, Sobata, Nessana, Mampsis, Elusa,

32 Oleson 2010, 452–456.

33 Farès-Drapeau and Zayadine 2001, 207–213; Oleson 2010, 456. A Roman dam with arch plan at Glanum in Southern France may have been constructed in the first century BC, but its design can no longer be

documented, and the date is approximate; Hodge 1992, 81.

34 Farès-Drapeau and Zayadine 2001, 212–213.

35 Oleson 2010, 50–53.

36 Nehmé et al. 2006.

and Ruheiba. The average annual precipitation around these settlements varies from 100–300 mm. To support the human and animal populations in this arid environment, sophisticated water-supply systems were developed that provide interesting parallels and contrasts with the Hawara system.³⁷

There are several problems in evaluating the relevance of the Negev archaeological evidence to the systems at Hawara and Petra. Most important is the question of chronology. The region remained well populated and prosperous through the seventh century AD, and it is often not clear to which period various water-supply structures such as wadi barriers belong.³⁸ Although the designs are often compatible with a first-century BC or AD Nabataean origin, it is very likely that many of the water-supply systems visible in the region today date to the Byzantine or early Islamic period. At Hawara, in contrast, the Nabataean aqueduct continued to serve the settlement well into the Byzantine period, and none of the five Byzantine churches built there were provided with a cistern. In the Negev, by contrast, nearly all the churches were provided with one or more cisterns fed by run-off from the roof and adjacent courtyard.

A second problem is that, although the Negev is arid, in many areas the soil is generally more extensive and better in quality than that around Hawara or the rest of Arabia Petraea. Furthermore, there are varying ways to calculate the amount of useable run-off generated by the hills, which are earth rather than bedrock.³⁹ As a consequence, even though the ancient cities of the Negev are often cited as close cousins to the Nabataean settlements of Arabia Petraea, the parallels are frequently only approximate and the chronologies are very different.

As in Arabia Petraea, both rural and ‘urban’ cisterns were an important part of the water-supply system in the Negev. Due to the regional geology, however, the most common design in the Negev was a regular or irregular tank carved in soft chalk bedrock, with a natural roof formed by a stratum of limestone. This technique was easier and generally more durable than building roofs over a rock-cut tank. The slab roof supported by cross-arches on block built walls occasionally appears on cisterns in the Negev, and it was ubiquitous for roofing houses.⁴⁰ The first-century cistern at Bor Nekarot on the ‘Incense Road’ looks particularly similar to the type seen at Hawara and Petra, perhaps because of its early date. Where cisterns are associated with houses in the Negev, they usually appear beneath the courtyard, as at Hawara, but they seldom have arch-supported roofs.

As at Petra and Hawara, dams were occasionally employed to retain water where the topographical circumstances allowed. A particularly impressive series of Nabataean dams survives at Mampsis.⁴¹

37 Oleson 2010, 460–478.

38 Shereshevski 1991.

39 Evenari, Shanan, and Tadmor 1982, 95–147,

179–219.

40 Oleson 2010, 464, 477–478.

41 Oleson 2010, 470–474.



Fig. 15 Stone piles, Sobata.

Reservoirs, usually unroofed because of their size, formed the largest part of the Negev water systems, occasionally built of blocks, but more often cut into the bedrock. Due to their exposure to the sun and wind-blown debris, the quality of the water was likely to have usually been poor. The water was collected from precipitation run-off, lifted from wells, carried in from dammed pools by porters or draft animals, and, in only one case, at Sobata, filled at least in part by an earthen aqueduct that carried in run-off from a nearby catchment. At Hawara, Petra, and Wadi Ramm, in contrast, the largest reservoirs were filled entirely by spring-fed aqueducts. In fact, the only long aqueduct in the Negev with engineering features, such as a built viaduct and distribution tanks, was the dirt channel at Sobata. Nothing has been found that resembles the ten to twenty kilometer long channels built of stone conduit blocks found in Arabia Petraea. Water channels made of stone gutter blocks very similar to those used at Hawara, can be seen in all the Negev settlements, but only to carry water short distances within a house, along a street, or between a reservoir and a bath. Stone distribution basins also appear in these same circumstances. Springs existed in the Negev, but inconveniently deep or distant from the site of the larger Nabataean settlements. Wells 40 to 70 m deep at Oboda, Ruheiba, and Nessana represent the typical regional solution to this problem. Wells were of no use at Petra or Hawara, where groundwater was either too deep or non-existent.⁴²

Despite the similarities in climate and cultural development, and despite a few superficial similarities, the water-supply systems serving the ancient settlements in the Negev are actually quite different from those at Petra and Hawara. Above all, the creation of fields at Oboda and Sobata through the terracing of wadis and the piling up of surface stones in regular patterns on hillsides to enhance run-off did not occur at Petra

(Fig. 15).

There are in fact stone piles on three slopes at Hawara, but not associated with fields suitable for agriculture. They may represent a failed experiment, or they may have had some sort of ceremonial or religious significance.⁴³ There may simply have been enough bedrock slopes in the vicinity of Hawara suitable for channeling water to agricultural fields that it was not necessary to enhance the run-off from a few slopes with rocky soil. The intensive agriculture in the Negev, particularly the bulk production of wine for export in the Byzantine period, was an extension of the needs of the adjacent Mediterranean economy. Arabia Petraea was too distant to have served this trade in bulk goods, and food production very likely was intended for local consumption.

Judging from its foundation story, the nearly exclusive use of ceramics from Petra, and the character of the water-supply system, Hawara was a political, cultural, and technological colony of Petra. Petra provides the closest and earliest parallels for all aspects of the water-supply system, although the system at Petra was more complex and monumental. The neighboring water-supply system at Ramm constitutes the one other close parallel to the arrangements at Hawara. The water-supply systems at the other sites of Nabataean origin differ from one another, since Nabataean engineers naturally responded to local variations in climate, topography, geology, and population. There were also differences in chronology, and possibly in engineering traditions as well.

There was no single methodology for supplying Nabataean settlements with water. There was an established repertoire of techniques, probably carried from place to place by engineers. It is unlikely, however, that any Nabataean Vitruvius or Frontinus composed a written compendium of engineering knowledge. Nevertheless, the cylindrical, arch-roofed cisterns in the center of Hawara are a testimony to the activity of at least one local genius, along with the nearby arch dam at al-Kharaza.

What does all this mean for the concept of Petra as a central place with an admired and imitated technological shelf? It seems likely that hydraulic engineers who worked at Petra also worked at or had some influence on the engineers who worked at Hawara and Ramm; so, here we see the projection of a central technology in a similar environment. Farther afield, however, the systems seem very different, in tune with varied local circumstances. Even allowing for their probable later chronology, the Negev settlements used water-supply strategies and designs different from those seen in the Petra region. The fall-off of central influence with distance did not, of course, imply a decline in effectiveness of the systems. There is much we still do not know about the processes of Nabataean technology. At Hawara and near Ramm, we find the apparently unique technological

42 Oleson 2010, 460–478.

43 Oleson 2010, 167–169. Kennedy 2012, 497–498, reports the presence of ca. 2000 similar cairns at a site

in northeast Jordan that have no apparent practical purpose and thus might have served some ceremonial need.

footprints of the strikingly innovative hydraulic engineer or engineers who created a new cylindrical cistern and an arch-walled dam. Other issues that remain unsolved are the sources of funding, planning procedures, surveying techniques, the composition and organization of the work teams, the local administration of water from springs, and the ownership of run-off flow from natural or enhanced catchments. We still need to throw light on the details of the hydraulic technology for which the Nabataeans were so famous in antiquity.

Bibliography

Abudanah and Twaissi 2010

Fawzi Abudanah and Saad Twaissi. "Innovation or Technology Immigration? The Qanat Systems in the Regions of Udhruh and Ma'an in Southern Jordan". *Bulletin of the American Schools of Oriental Research* 360 (2010), 67–87.

Barker, Gilbertson, and Mattingly 2007

Graeme Barker, David Gilbertson, and David Mattingly. *Archaeology and Desertification: The Wadi Faynan Landscape Survey, Southern Jordan*. Oxford: Oxbow Books, 2007.

Bellwald 2008

Uli Bellwald. "The Hydraulic Infrastructure of Petra – A Model for Water Strategies in Arid Land". In *Cura Aquarum in Jordanien*. Ed. by C. Öhlig. Siegburg: DWHG, 2008, 47–94.

Bellwald and Ruben 2003

Uli Bellwald and Isabelle Ruben. *The Petra Siq: Nabataean Hydrology Uncovered*. Amman: Petra National Trust, 2003.

Bruneau and Bordreuil 1982

Philippe Bruneau and Pierre Bordreuil. "Les Israélites de Délos et la juiverie délienne". *Bulletin de Correspondance Hellénique* 106 (1982), 465–504.

Evenari, Shanan, and Tadmor 1982

Michael Evenari, Leslie Shanan, and Naphtali Tadmor. *The Negev. The Challenge of a Desert*. 2nd ed. Cambridge, MA: Harvard University Press, 1982.

Farès-Drapeau and Zayadine 2001

Saba Farès-Drapeau and Fawzi Zayadine. "Preliminary Report on the Fourth Season of the Wadi Iram Epigraphical, Geographical, and Archaeological Survey". *Annual of the Department of Antiquities of Jordan* 45 (2001), 205–216.

Garbrecht 1987

Günther Garbrecht. "Die Wasserversorgung des antiken Pergamon". In *Die Wasserversorgung antiker Städte*. Mainz: Philipp von Zabern, 1987, 13–47.

Garbrecht 1991

Günther Garbrecht, ed. *Historische Talsperren 2*. Stuttgart: Konrad Wittwer, 1991.

Goblot 1979

Henri Goblot. *Les qanats: Une technique d'acquisition de l'eau*. Paris: Mouton Éditeur, 1979.

Heemeier et al. 2008

Benjamin Heemeier, Mathis Hamann, Arno Patzelt, and Matthias Grottker. "Tall Hujayrat al-Ghuzlan – Das wasserwirtschaftliche System einer prähistorischen Siedlung in SüdJordanien". In *Cura Aquarum in Jordanien*. Ed. by C. Öhlig. Siegburg: DWHG, 2008, 119–513.

Helms 1981

Svend W. Helms. *Jawa. Lost City of the Black Desert*. Ithaca, NY: Cornell University Press, 1981.

Hodge 1992

Alfred Trevor Hodge. *Roman Aqueducts and Water Supply*. London: Duckworth, 1992.

Jansen 2000

Gemma C. M. Jansen. "Urban Water Transport". In *Handbook of Ancient Water Technology*. Ed. by Ö. Wikander. Leiden: Brill, 2000, 103–125.

Kennedy 2012

David Kennedy. "The Cairn of Hani: Significance, Present Condition and Context". *Annual of the Department of Antiquities of Jordan* 56 (2012), 483–505.

al-Kurdi 2008

Othman al-Kurdi. "The Water Situation in Jordan". In *Cura Aquarum in Jordanien*. Ed. by C. Öhlig. Siegburg: DWHG, 2008, 11–20.

Lightfoot 1997

Dale R. Lightfoot. "Qanats in the Levant: Hydraulic Technology at the Periphery of Early Empires". *Technology and Culture* 38 (1997), 432–451.

Meshel and Amit 2002

Zeev Meshel and David Amit. "The Water-supply Systems of Cypros Fortress." In *The Aqueducts of Israel*. Ed. by D. Amit, J. Patrich, and Y. Hirschfeld. Journal of Roman Archaeology Supplement 46. Portsmouth, RI: Journal of Roman Archaeology, 2002, 313–329.

al-Muheisen 2009

Zeidoun al-Muheisen. *The Water Engineering and Irrigation System of the Nabataeans*. Irbid: Yarmouk University, 2009.

National 1984

Jordan National Geographic Centre. *National Atlas of Jordan 1: Climate and Agroclimatology*. Amman: National Geographic Centre, 1984.

Nehmé et al. 2006

Laila Nehmé, Isabelle Sachet, Thomas Arnoux, Jean-Claude Bessac, Jean-Marie Dentzer, Alain Ker-morvant, Jean-Baptiste Rigot, and Laurent Tholbecq. "Mission archéologique de Mada'in Salih (Arabie Saoudite): Recherches menées der 2001 à 2003 dans l'ancienne Hijra des Nabatéens." *Arabian Archaeology and Epigraphy* 17 (2006), 41–124.

Netzer, Laureys-Chachy, and Meshorer 2001

Ehud Netzer, Rachel Laureys-Chachy, and Ya'akov Meshorer. *Hasmonean and Herodian Palaces at Jericho. Final Reports of the 1973–1987 Excavation. Vol. 1: Stratigraphy and Architecture*. Jerusalem: Hebrew University, 2001.

Oleson 1992

John Peter Oleson. "Water Works." In *Anchor Bible Dictionary*. Ed. by D. N. Freedman. Vol. 6. New York: Doubleday, 1992, 883–893.

Oleson 2000

John Peter Oleson. "Irrigation." In *Handbook of Ancient Water Technology*. Ed. by Ö. Wikander. Leiden: Brill, 2000, 183–215.

Oleson 2001

John Peter Oleson. "Water Supply in Jordan through the Ages." In *The Archaeology of Jordan*. Ed. by B. MacDonald, R. Adams, and P. Bienkowski. Sheffield: Sheffield University Press, 2001, 603–614.

Oleson 2010

John Peter Oleson. *Humayma Excavation Project, 1: Resources, History, and the Water-Supply System*. Boston: American Schools of Oriental Research, 2010.

Philip 2001

Graham Philip. "The Early Bronze I–III Periods." In *The Archaeology of Jordan*. Ed. by B. MacDonald, R. Adams, and P. Bienkowski. Sheffield: Sheffield University Press, 2001, 162–232.

Price and Nixon 2005

Simon Price and Lucia Nixon. "Ancient Greek Agricultural Terraces: Evidence from Texts and Archaeological Survey." *American Journal of Archaeology* 109 (2005), 665–694.

Roche 1996

Marie-Jeanne Roche. "Remarques sur les Nabatéens en Méditerranée." *Semitica* 45 (1996), 73–99.

Shehadeh 1985

Numan Shehadeh. "The Climate of Jordan in the Past and Present." In *Studies in the History and Archaeology of Jordan*. Ed. by A. Hadidi. Studies in the History and Archaeology of Jordan 2. Amman: Department of Antiquities, 1985, 25–37.

Shereshevski 1991

Joseph Shereshevski. *Byzantine Urban Settlements in the Negev Desert*. Beersheva: Beersheva University, 1991.

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Gül Sürmelihiindi

Palaeo-Environmental Condition Factor on the Diffusion of Ancient Water Technologies

Summary

Thales of Miletus wisely declared that water is the vital element for life. Being the core substance for human survival, the management of water has always been an important matter. Early attempts to improve water-lifting devices for agricultural endeavors have been detected in Hellenistic Alexandria. However, aside from the limitations of the different devices, variations in geology also limit the use of some of these machines in specific areas. Some of these devices were used daily, whereas others remained impractical or were of minor importance due to their complicated nature, and some were even forgotten until they were later rediscovered. Water also became a basic power source, providing energy, e.g. for cutting stone or milling grain, and such applications constituted the first attempts at Roman industrialization.

Keywords: ancient water technologies; Hellenistic science; diffusion; geology; geography; Roman; aqueduct

Bereits Thales von Milet erklärte Wasser zum wichtigsten Element allen Lebens. Entsprechend kam dem Management dieser Ressource schon immer große Bedeutung zu. Erste Versuche, Wasser-Hebesysteme in der Landwirtschaft einzusetzen, lassen sich im Hellenistischen Alexandria nachweisen. Die Nutzbarkeit solcher Hebesysteme war eingeschränkt einerseits durch ihre individuelle Konstruktion, andererseits durch die Geologie vor Ort. Während dabei einige dieser Wasser-Hebesysteme täglichen Einsatz fanden, blieben andere ungenutzt oder gerieten auf Grund ihrer geringen Bedeutung oder ihrer Komplexität bis zu ihrer Wiederentdeckung in Vergessenheit. Wasser wurde damals auch als Energiequelle eingesetzt, wie zum Beispiel beim Schneiden von Steinen oder beim Mahlen von Korn. Solche Anwendungen stellen gleichsam den Anfang der antiken römischen Industrialisierung dar.

Keywords: antike Wasserstrukturen; Hellenistische Wissenschaft; Diffusion; Geologie; Geographie; römisch; Wasserleitung

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If only there is water, there will be life... and water always finds its way. (G. S.)

1 The short history of human adaptation to nature

The history of the relationship between *Homo sapiens* and the nature in which they lived, was reshaped about 10 000 years ago during the Holocene period. A constantly growing population in North Africa made it necessary for the people to develop a reliable water supply for multiple needs, such as preparing agricultural lands to provide food for the people. One of the first places where the transition from hunting-gathering to cultivation happened was the Middle East, about 10 000 to 9 000 BP. Thereafter, Central Europe began cultivation, with a delay of at least a thousand years, due to severe cooling periods and a strong advance of glaciers. This transition period, from nomadic to farming, was a fruitful turning point for *Homo sapiens*, since it created food security and stopped the long tradition of following wild herds.

Global warming during the Holocene finally opened the way for building advanced civilizations. At the onset of the Holocene, nomadic hunters started to build fixed settlements where water management was necessary. They benefited from the power of the available natural resources.¹ The traces of the structures of these fixed settlements can be found associated with irrigation and drainage channels in the Near East and early mining sites. Subsequently, gravity driven aqueducts and water and animal driven mechanisms were invented to provide bathing facilities and increase food production to satisfy the growing human population.

The first more advanced civilization formed during the mid-Holocene period was called the Atlantic; this was a warm and long period that provided the foundation for the development of the complex human cultures of the Phoenicians, Carthaginians, Greeks, and finally the Romans.² This is also the time when enhanced task-division was first apparent, making life easier, as people worked by means of a division of labor, working as merchants, soldiers, engineers, and craftsmen.³

1 Roberts 2014.

2 Perry and Hsu 2000.

3 Behringer 2009.

The techniques used to make tools were improved and, subsequently, people started to use these tools in their daily life. Seafaring was improved through the development of wooden sailing ships to make discoveries overseas. This brought together new ideas and technologies that people had observed in foreign lands during their travels. This travel also helped to build cultural connections and trade while climatic conditions were stable. Aside from trading goods such as ivory, pottery, and wine, the people also observed how those from different lands dealt with water and land management issues on a daily basis. After the first optimistic and unsatisfactory attempts to use these same technologies in their own areas, the people began to realize that some things worked differently in other geographical settings; this was the decisive point where innovation processes took place and different types of machinery and structures were constructed.

First, building a waterproofed cistern or digging a well in a private garden became a common and simple way of solving the water problems of individual citizens, although the latter required a technique to lift the water to the ground level, where the water was needed. Meanwhile, others had the idea to transport water over short distances via conduits, which was followed by the tapping of water sources from even further away by opening channels and constructing tunnels or building high-level bridges with channels or pipes. Early examples include the Minoan Aqueducts of Crete, the aqueduct of archaic Samos with the famous Eupalinus Tunnel, and Athens and Syracuse and the aqueducts and well-houses of Megara.⁴ The technique of building aqueducts was not very common until the Roman era, since it was quite an expensive solution, even though it involved water being driven in a natural way by gravity, without any additional labor. In most cases, well or cistern technology fulfilled the daily needs of the people, although the simple lifting mechanism of a bucket and rope system did not always answer their needs, since in some areas, a well could be more than 90 m deep. Therefore, this practical way of obtaining a regular water supply had to be improved through the innovation of water-lifting techniques, which are discussed in this contribution.

2 Hellenistic science, technology, and the first attempts to diffuse them

Looking at history, it is curious that most of the ancient large civilizations emerged at about the same latitude: the Mediterranean, Mesopotamia, Iran, China, and India, and in the southern hemisphere, Peru. The most common aspect of all these countries was a climate that was not overwhelmingly hot, nor one with a cold Nordic atmosphere.

4 Angelakis, Savvakis, and Charalampakis 2007; Kienast 1995; Koutsoyiannis et al. 2008; Crouch 1993;

Tölle-Kastenbein 1990.

The favorable conditions of having a moderate climate and fertile land led local people to be at the center of the technological improvements connected to irrigation. Presumably for this reason, Hellenistic Alexandria was the birthplace of important scientific innovations.

The Alexandrian school of engineers in Hellenistic Egypt triggered a breakthrough in natural philosophy between the 3rd and 1st century BC. Early scientists were encouraged to concentrate on the development of mechanisms to lift great masses, resulting in lever, pulley, and cogged wheel systems being developed, and the invention of the first practical equipment to increase the harvest.

In fact, Egyptians triggered the first agricultural work in the Nile Valley. This may have been driven by a sudden population increase, the largest human population in any area until that time, and growing based on the controlled use of the clay-rich, abundant water of the Nile.⁵

Meanwhile, in another Hellenistic city, Syracuse, the inventor of many theorems and practical devices, Archimedes (287–212 BC), was working along the same lines to understand how things work in nature. Although his invention of the catapult was relatively destructive in the hand of others, the common use of the *Archimedian screw* he developed is a good example of his lasting inventions.

Two additional Greek engineers worth mentioning by name are Ctesibius (285–222 BC) and Heron of Alexandria (AD 10–70), who are known until today as the fathers of pneumatics. Nevertheless, their inventions, such as water-clocks, a steam-powered engine, and an automatic door opener, were not practically used for a long time. They were also criticized by many scholars of their time as being nothing more than toys to entertain and amuse the public.⁶ The early written sources on the lever and pulley system demonstrated their use in daily life,⁷ but scholars did not show the same attention to Hero's (Heron of Alexandria) labor saving cogged wheel mechanism perhaps because it was not used widely for some time. The force-pump, however, is an exception that after several modifications was distinguished from other inventions by being a life-saving device that was utilized as a fire-extinguisher and also for its practical application in lifting water to a higher elevation. Otherwise, most of these first inventions of Greek engineers from the Alexandrian School were either only locally in use or seen as nothing more than scientific experiments.

The innovation process of the force-pump and many other mechanisms was not a coincidence; it coincided with the date when the Romans started to create written records of history. The Romans ruled the Mediterranean region for more than five hundred years and made great improvements in all aspects of life; therefore, some big

5 Butzer 1976, 76–92.

7 Pleket 1967, 39–40.

6 Granger 1931.

changes took place in the practical use of the inventions mentioned above. Starting from this point, diffusion of the machines increased consciously by the Romans, who improved these machines, allowing them to shift from only purely scientific inventions to becoming applied devices in their time. However, why and how Romans became involved in the diffusion of water technology is a curious issue that needs to be examined in order to understand the needs of the people of that time and ancient trade policies.

Plato (427–347 BC), in his *De Re Publica*, indicated that “love of money” was a characteristic of the Phoenicians and Egyptians. This was seen as the main difference they had from the Greeks, who were seen as having a “love of knowledge”.⁸ The love of making money might have also been a dominant character of the Romans and their trade policies. Certainly, the contribution of Romans to technology and engineering issues was mainly in the field of practical application.⁹ During the Roman era, not only practical technologies were in common use, additionally, entertainment machines were well diffused and available almost everywhere throughout the Empire. They were a top request of Roman nobles and land owners for their new villas, such as a force-pump to spray a water jet from a pool to where they were reclining and dining on couches to impress their guest, or raising water for their gardens or opening a temple door automatically, using the principle of Hero’s pneumatics. These devices played an important role in showing Roman prosperity to the rest of the world, and led others to admire the Roman lifestyle. More importantly, the diffusion process and common use of water technologies was part of the growing Roman economy. A number of waterwheel remains from mining sites in Hispania, Britannia, and Dacia and the watermill complexes for grinding flour to provide *annonae*, proved their common application for industrial use. The Roman military played a powerful role in the diffusion of ancient water technologies and the widespread use of water-powered machines by means of their strong military organization and colonial administration.¹⁰

In the following, I discuss these technologies and the important features that played a role in their diffusion, other than the palaeo-environmental conditions.

3 Comparison of ancient water technologies

3.1 Water-lifting devices

People needed to raise water for various applications. Water-lifting was indispensable for mining sites and for extinguishing fires. After simply digging wells to reach the ground-

8 Griffith 2000.

9 Landels 2000.

10 Spain 2002, 51.

water level, people constructed a rope and bucket as the first mechanism for lifting water to the surface level. However, as wells got deeper, more efficient devices were needed as deeper wells would require longer ropes, which were in turn much heavier, resulting in it being much more laborious to obtain water from the deeper wells. Several types of water-lifting devices were invented, which are compared below.

3.1.1 *Shādūf*

The device known as *shādūf* in Arabic, *kelōneion* in Greek, is also called *tolleno* or *swipe*. It is one of the simplest and earliest water-lifting systems, and was invented even earlier than the Hellenistic period, during the Early Bronze Age. It is still in use in Egypt and many areas in North Africa and the Middle East today. This crude mechanism involves only a bucket, or something similar to a bag, and a rope; however, it is different from a bucket-rope arrangement, as it also includes a heavy counterbalance bound to a wooden arm and a supporting skeleton. There are no historical remains at the archaeological sites, due to its perishable nature, but there are illustrations of the *shādūf* on frescoes, mosaics, and vases; e.g., the example of a wall painting from Thebes, depicting the use of a *shādūf* from 1300 BC.¹¹ This system was not an ambitious one, but was rather modest in nature, and was only meant to raise water from a river or a ditch for agricultural purpose. The *shādūf* is a low-lift device, but nevertheless has a relatively high discharge volume, providing up to 6 m³/hour at a height of 3 m.¹²

The biggest advantage of the *shādūf* is its low-cost and simple nature. It can also raise water from narrow shafts, and this made it one of the most practical devices available for lifting water. However, the *shādūf* can only raise water over short distances due to the limited height of its beam, and its capacity is also low compared to other water lifting mechanisms.¹³

3.1.2 *Waterwheels with a compartmented body (tympanum or tympanon/drum) and compartmented rim*

Waterwheel technologies were powered by natural resources, such as water, wind, animals, or manpower. The *tympanum* or *tympanon* (drum) in Greek is the oldest known complex water-lifting mechanism, which even inspired Archimedes in his invention of the water-screw.¹⁴ It was a machine composed of a closed wheel with openings that allowed water to enter at the bottom of the wheel and let it escape again at the top. The Latin word *tympanum* was first mentioned in *De Architectura* by Vitruvius (70–15 BC) as

11 Oleson 2008, 350.

12 Oleson 1984, 369.

13 Oleson 2000, 227.

14 Oleson 1984, 298.

a device to lift water for irrigation purposes or for supplying the needs of salt works.¹⁵ It is clear that the *tympanum* has a few advantages over *Archimedes' screw*, due to the simplicity of its construction; however, it is only able to lift water to a height of two thirds of the wheel's diameter, limiting its use. Another disadvantage was related to problems with clogging. Additionally, its torque was not as efficient as that of the water-screw.

The waterwheel, with its compartmented rim, was a similar mechanism to the *tympanum*, but using the rim of the wheel only. Waterwheels were first mentioned in Apollonius' treatise (262–190 BC) of about 240 BC.¹⁶ The invention of both types of waterwheel, with compartmented rim and body, dates back to the mid-third century BC. The earliest known evidence of an animal-driven wheel for lifting water was at Perachora, Greece from the 3rd century BC.

3.1.3 *Water-screw or cochlias (Archimedean screw)*

The water-screw can be found under the name *cochlias* in Greek literature. It was allegedly invented especially for one area, the Nile Delta and its surrounding terrain, and is known as the Egyptian or *Archimedean screw (tambour)*, since its invention during the 3rd century BC is mostly credited to Archimedes (Fig. 1). Some scholars believe that it was already in use before Archimedes' visit to Egypt, but he saw its value and worked on a design to improve it for the needs of the Egyptian farmers. It has a quite simple construction: a large helix open at both ends in a cylinder with water scooped at the end of the helix. It was low-lift, with a constant rise, but still effective and easy to handle. Moreover, its most important advantage in comparison with the force-pump or *tympanum* was its low susceptibility to clogging, which is a real problem in the Nile Delta, where alluvium-rich fields with solid matter such as mud, sand, silt, and gravel were subject to draining. Aside from these considerable advantages, a high level of friction reduced the efficiency of the water-screw. The advantage of raising quite large amounts of water was overshadowed by its low-lift nature – not as high as a waterwheel – which limits its use in some fields.

Archaeological finds and textual sources indicate that the screw was used for irrigation purposes, mostly in Egypt, along with draining water from mines and dewatering bilge-water from ships. The earliest known evidence for its use in a ship was a screw designed by Archimedes for Hieron II of Syracuse in the third century BC.

On the map of diffusion of water technologies, we can see widespread use of the water-screw in Spanish mines, due to its capacity to assist in effective drainage (Fig. 2). Posidonius (135–51 BC) noted that it can drain a great amount of water with relatively minor labor.¹⁷ Although most examples date back to the Imperial Age, a depiction of

15 Oleson 1984, 113.

17 Oleson 1984, 89.

16 Wilson 2002, 7.



Fig. 1 A reconstructed Archimedean screw in Israel. This low-lift device has the advantage of draining quite a reasonable amount of water by a simple manual system. In antiquity, the device was turned with the feet. Photograph and reconstruction work, Yeshu Dray.

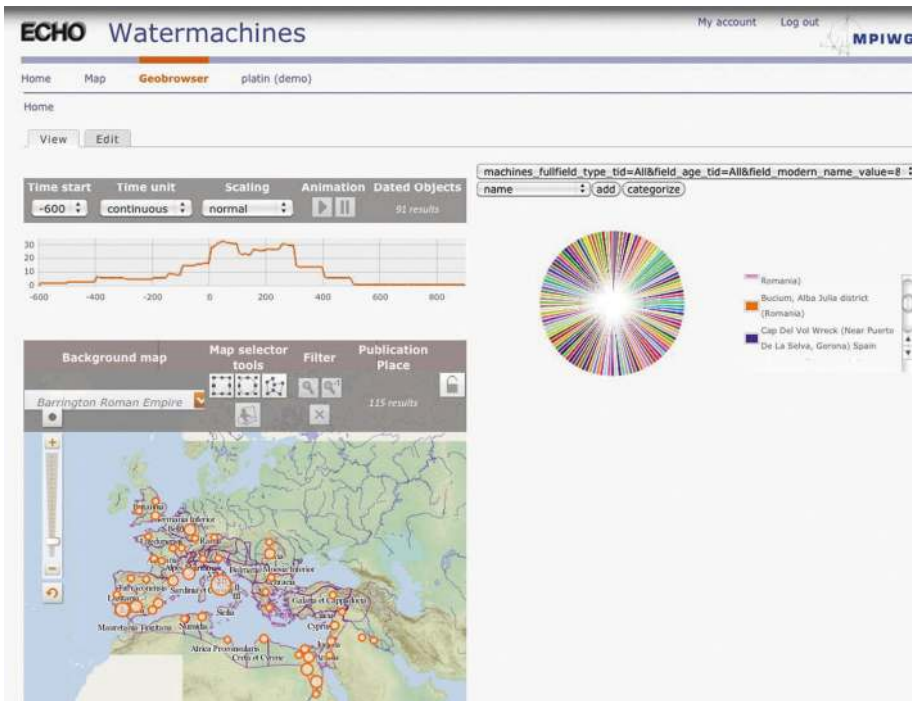


Fig. 2 Diffusion map of water machines for lifting and draining water and providing power for milling activities. The database is online and has a dynamic map that covers the Mediterranean and Western European examples.



Fig. 3 a) Wooden force-pump found in Bertrange, Luxembourg. The pump dates back to AD 270 and was found in the Roman fort. The original remains are in the National Museum of History and Art in Luxembourg. b) This example of a force-pump is made of bronze and was used in the Sotiel Coronada copper mine in southwest Spain, either as a fire-extinguisher or to spray cold water on rocks to fragment them. This force-pump dates back to the Imperial Roman period and is housed at the National Archaeological Museum in Madrid.

one water-screw operating on Egyptian agricultural land was found in the Casa dell' Efebo, Pompeii, proving its use before AD 79.¹⁸ Another screw from Ciudad Real was discovered in a mining site in Spain that dates back to the post-Roman period.

3.1.4 Force-pump

Vitruvius' comment in his treatise *De Architectura* on, "useless objects that flattered the senses by amusing the eye and ear",¹⁹ was most likely a criticism of the water-organ or similar *automata* mechanisms. However, when he describes all the water-lifting machines in his treatise, he provides a separate chapter for force-pumps, emphasizing their practical use and clever invention by the Greek engineer Ctesibius of Alexandria (Fig. 3). In fact, Vitruvius is the only scholar who attributed the invention of the force-pump to Ctesibius and, therefore, the device is referred to by some people as the *Ctesibica machina*. This exceptional machine is, "extremely useful and necessary"; according to Vitruvius' account.²⁰

Compared to all the others, the force-pump was the most advanced water-lifting mechanism. The mechanism was originally made of bronze and consisted of pistons working in two vertical cylinders connected by transverse pipes that led pressurized water to a central delivery pipe. The water was locked in under the force of gravity by one-way valves at the base of the delivery pipe. The lower part of the pump was submerged into a water body. The literary sources mainly mentioned the bronze force-pump as a fire-extinguisher and it was used to spray fresh perfumed water during games in theaters

18 Oleson 1984, 241.

19 Oleson 1984, 24.

20 Oleson 1984, 124.

or amphitheatres, as it was a portable mechanism.²¹ There are some rare examples, such as the bronze, portable pump from the Sotiel Coronado mine in Spain, which was used as a fire-extinguisher or, more interestingly, to spray a cold water stream on top of heated rocks to fragment them for mining.²² These special applications were related to the advantageous features of the pump: being portable and also providing a jet of pressurized water.

There are some other recorded uses of the force-pump, e.g. for raising water for an orchard in a Roman villa and for kiln-production. Of all of the water machines, the force-pump had the most delicate nature and was relatively expensive to build and maintain. These features played an important role throughout its diffusion process to the provinces of the Roman Empire. Nevertheless, after the first century BC, some radical innovations established a new design where wood replaced the original bronze; this process helped the force-pump become more affordable and easier to produce and maintain. After this adaptation process, the force-pump became more widespread and appeared in several areas with several different applications, as a multitask machine for gardening and for raising drinking water from the wells in villas or on rich farms. Another advantage of this adaptation, was that the wooden apparatus was less affected by water than the bronze ones, and this led them to remain preserved at their original locations; broken bronze pumps could be recycled for their metal value, while broken wooden ones would have no value, and would be left in place. The 20 known examples from domestic areas are mostly wooden, but also include eleven bronze pumps and one lead example.²³

The force-pump was also commonly used as a bilge-pump in ships after the 1st century AD. In fact, there were a number of other possibilities to drain bilge water from the hold of a ship, such as the *chain-pump* and water-screw. The *chain-pump* had properties of both bucket-chain and force-pump and consisted of a series of wooden disks on a rope that were pulled through a cylinder. This was allegedly more effective than the water-screw, since the screw might be handicapped by its low lift and required horizontal placement. The *chain-pump* also shared the same advantages of the *Archimedean screw*, in that it did not need any maintenance for cleaning muddy water and was more stable under the pitching and rolling conditions of the ship at sea than the screw installation.²⁴

3.1.5 *Bucket-wheel*

The design of the bucket-wheel machine (*polykadia* ‘multi-bucket’ in Greek) was forgotten for centuries and only rediscovered in the Middle Ages. It is similar in its reappearance to the force-pumps.²⁵ It is known to be the simplest of the ‘higher-head’ devices. In contrast

21 Stein 2014, 21, 31.

22 Stein 2014, 24.

23 Stein 2014, 34–35.

24 Wilson 2011, 42.

25 Landels 2000, 67.



Fig. 4 Bucket-chain installation reconstructed for the Roman bath of the local inn at the Xanten archaeological site in the ancient Roman town of Colonia Ulpia Traiana in Northern Rhine-Westphalia.

to the previous devices, the bucket-wheel was apparently driven by animal power in Greek speaking communities in Egypt. The bucket wheel consists of a series of buckets fixed around the rim of a wheel. The buckets were probably wider at the bottom, so they could scoop up a reasonable amount of water and lift it to a narrow opening at the top level.²⁶

3.1.6 *Bucket-chain*

The bucket-chain, or *halysis* in Greek, is another type of 'high-head' water-lifting mechanism, most likely the improved model of the bucket-wheel (Fig. 4). It consists of a tread-mill on a horizontal axle with two parallel endless chains where the buckets are fixed to the chains at relatively equal intervals. Since the buckets are bound to the chain and due to the elaborate nature of the iron-work, this device was likely to be more expensive to build than the bucket-wheel. However, in some places where there was not

26 Landels 2000, 67.

enough space to build a bucket-wheel, it was a preferable device. The advantage of the device was related to its working principle being independent from its diameter. Moreover, the percentage of spillage was reduced to a minimum by the rapid turning of the buckets only after reaching the axle. Nevertheless, if the water amount was not high enough, there was the problem of the chain slipping around the axle due to the heavy weight of the chains and buckets.

It is most likely that the bucket-chain was used more often in small-scale settings, such as a villa or for a farm, where the water would be used for drinking, cleaning, and other needs of a household.

3.1.7 *Noria (Egyptian wheel) and Sāqiya (Persian wheel) or wheels of pots*

The word *sāqiya* is often used to describe a water-lifting mechanism using ceramic pots, although it actually refers not to a water-lifting machine but to the driving mechanism (*sāqiya* gear) that drove it, usually powered by an animal (Fig. 5).²⁷ The earliest known example is from Alexandria, in a fresco representation that dates back to the 2nd century BC.²⁸ It basically consists of a pair of cog-wheels oriented at right angles to one another, designed to transfer the rotation of a vertical shaft driven by an ox into a more easily applied horizontal motion. The *sāqiya* with a bucket-chain wheel was very common in Fayyum, Egypt. Several *sāqiya* examples were continuously in use for up to one hundred days along the Nile River, to irrigate farms outside the period of the annual Nile flood.

The *noria* has many similar features as the *sāqiya*, although it is usually driven by water-power. The gear-driven *noria* examples have a short shaft and were commonly used in the Iberian Peninsula and Morocco.²⁹ Its application was generally for irrigation purposes, just as the *sāqiya* was. The first known example of the *noria* is a representation of a mosaic in Apamea, Syria from the 2nd century AD.³⁰ Their common appearance in Spain, especially during the Arab conquest, may be due to their simplicity and efficiency, which helped their widespread distribution, resulting in their use becoming a tradition.³¹ A nice example of a hydraulic *noria* is situated along the Orontes River near Hama, Syria³² and another example from the Islamic period has recently been restored in Córdoba, Spain (Fig. 6).

3.1.8 *Relations of water lifting devices*

Like the *shādūf*, the *sāqiya* and *noria* are examples of relatively crude water machines. According to many scholars, their widespread distribution was related to their simplic-

27 Oleson 2000, 267–272.

28 Oleson 1984, 382.

29 Schiøler 1973.

30 Oleson 2008, 42.

31 Wilson 2003, 141.

32 Oleson 2000, 236–238.



Fig. 5 A reconstructed medieval *sāqiya* example from Alcázar of Córdoba. This machine was powered by manpower to lift water from the cistern below, and was used to irrigate the garden.



Fig. 6 This typical example of a *noria* (water-wheel) was reconstructed on the Guadalquivir River in Córdoba. Possibly, it was originally built by the Romans and modified in medieval times to provide water for Alcázar de los Reyes Cristianos (a medieval castle) for gardening and for milling grain. This *noria* was powered by the river.



Fig. 7 An ideal deep rectangular shaft for a sizeable bucket-chain in Pompeii, the main installation for the Stabian Baths. The carbonate incrustations can be clearly seen along the left side wall. The original wheel driving the installation was positioned in the room behind the modern fence. The onset of the arc, visible in the back wall of the shaft, held the bucket chain installation.

ity.³³ They functioned according to the same principle, although the *noria* was driven by water-power, whereas the *sāqiya* was powered by an animal. The most practical feature of the *sāqiya* is its ease of use, even without practical knowledge. The large number of *sāqiya* and *noria* that were found in countries such as Egypt and Spain, and in North Africa shows that they were used in connection with agriculture, and indicates the ease with which they could be installed and used.

The bucket-chain, the most applied of all the water-lifting machines, raised water from deep shafts (wells); however, its large structure required a wide, usually rectangular space (Fig. 7). The compartmented waterwheels, the *noria* and *tympanum*, also required special room for their installation. These waterwheels were also some of the most commonly used machines to lift water. Here, however, the limitation was due to their structure, since the lower part of the wheel must be immersed in the water body to carry water to the higher level, which could not exceed the top of the wheel.³⁴ The same set-up is needed for a water-screw; placing its lower part within a water body limits the height to which water can be lifted. Therefore, unlike the force-pump and bucket-chain, they are unable to lift water from a narrow and deep shaft. Conversely, the force-pump had the disadvantage that it could only move small volumes of water, which limited its application; however, the biggest advantage of the force-pump was not only its ability to raise water from a deep and narrow shaft, but also that it could produce jets of water under pressure. This led it to be classified as a more ingenious but elaborate device than the other mechanisms, and expanded its application to be used as a fire-extinguisher or fresh water or perfume sprayer.³⁵

33 Schiøler 1973.

34 Oleson 1984.

35 Stein 2014, 32.

3.2 Comparison of watermills

The invention of the watermill allowed converting the natural power of flowing water in order to utilize it for mechanical work. The idea of the watermill wheel was not different from the wheel used for raising a heavy volume of water to higher levels, and one may have influenced the other. Later on, however, the contribution of the watermill to establish the mass production of flour was a landmark for the advancement of the Roman economy. There were also other types of mechanical systems utilized; for example, quite simple ones like the trip-hammer, which work with the power of the water. There was no way to use the trip-hammer for continuous production; hence, it remained part of a small-scale farmer's economy.³⁶ The water-driven pestle was also an alternative way to pound and pull grain. Its common use in Italian provinces was pointed out by Pliny the Elder (NH 18.97). However, none of these methods were appropriate for a larger population and larger-scale production. Thankfully, the invention of the watermill, helped to solve the problem of discontinuity in mass production and it also helped to increase *per capita* productivity with its great output.³⁷ The similar shape of different watermill models may even mean that one was invented from the shape of the other. Two types of mills are briefly discussed below.

3.2.1 Norse and Greek mills (*horizontal-wheeled mills*)

The Norse and Greek mills were presumably simple, inefficient types of mills from a primitive model that involved low capital investment.³⁸ The biggest advantage of mills using the horizontal-wheeled system was the ease of construction, since there was no gearing involved. The water comes in as a jet with a very high speed and is used to turn the paddles via the sharp slope of the millrace or with a drop-tower installation for producing a fast water flow. The mills were commonly used in Northern Europe, in particular after the Middle Ages; the term 'Norse mill' presumably originated from its find location.³⁹ Since it is the simplest mechanism of the mills, it was probably invented as a first watermill mechanism, while the other types of watermills were probably derived from it.⁴⁰ It was not known to have been installed for industrial purposes, as no archaeological evidence has come to light yet.

The geographical setting played a crucial role when choosing a wheel type. Most examples of the horizontal-wheeled mills were located in areas with limited amounts of water, but also at locations where a high velocity jet of water could be produced by a sufficiently high hydraulic head, particularly in mountainous areas.⁴¹ The known

36 Wikander 2000, 406–407.

37 Wilson 2002, 30.

38 Wikander 2000.

39 Lucas 2006, 34.

40 Wikander 2000, 395.

41 Forbes 1964.

examples are mainly from the Southern and Eastern Mediterranean, such as Algeria, Palestine, Jordan, Naxos, and some others. These examples with drop-tower (*arubah*) installations, where water was stored at a higher level to provide pressurized water for turning the mills, were common in North Africa; a typical example is Oued Mellah in Algeria.⁴² An example of a related type of mill (helix-turbine) from Roman times was found in Chemtou and Testour with a remarkably extended size, with three waterwheels at each mill, is worth mentioning.⁴³

3.2.2 Vertical wheel (*undershot-overshot*)

The vertical wheel mill can only be used with a right-angled gearing system, which can convert the water-power from the vertical rotation of the mill wheel to the horizontal rotation needed for the millstones. Due to the complicated nature of the gear mechanism, it was probably developed later than the Norse (Greek) mills. There are some criteria that determine the type of vertical wheel to be used, overshot or undershot, such as meteorological, geological, and topographical conditions in the subject area. The overshot wheels can be optimal for a limited water supply and a high hydraulic head. For overshot mills, which are the most common types, an aqueduct that can provide water-power would have been the best option, since it can be easily regulated for maintenance work. Overshot mills were more efficient mills, although their construction needed much more work than undershot mills. Undershot mills are mostly fed by a river with a larger water supply and a lower head and are, therefore, easier to build, since there is no need for a hydraulic arrangement. However, they can only work when there is a strong and rapid water flow, such as from a river.

4 The role of geological settings and other factors on the diffusion of water technologies

A database was set-up in collaboration with the Excellence Cluster *Topoi* and the Max Planck Institute for the History of Science to see the geographical distribution of ancient water technologies. In the following section, the discussion concentrates mainly on the outcome of this “diffusion of the ancient water technologies” database, and the resulting interpretations.⁴⁴

42 Wikander 2000, 377.

43 Wilson 1995, 503.

44 The “diffusion of the ancient water technologies” database can be visited under following link: <https://drupal.mpiwg-berlin.mpg.de/watermachines/> (visited on 25/05/2018).

The database has a dynamic map where the distribution of water machines is shown.

4.1 Water-lifting devices

The geological setting played a significant role in the diffusion process of water technologies and structures, and it is, therefore, surprising that it has not been discussed in detail before elsewhere. People were aware of natural resources and the importance of their power, like ores and water. This can be clearly seen if one looks at the ancient settlements of Greek colonies in Sicily or Italy. For example, the important settlements of ancient Athens (Greece), Nîmes (Southern France), Syracuse (Sicily), and many others were chosen because they were especially close to springs where a perennial, continuous source of water was present;⁴⁵ even today, some of these sources are still in use. Greece is dominated by a limestone geology, where ancient Greeks benefited from groundwater sources, without needing to make investments to bring the water from greater distances, e.g. in Athens and Corinth. The main reason behind this choice was that a karstic system would not reflect the extreme seasonal variation in rainfall, since groundwater sources are generally well-mixed and provide a continuous water supply. Hence, Greek tribes also looked for a similar geological setting wherever they settled elsewhere. An example is Empúries in Northeast Spain, where the ancient Greek city was built on top of a karstic source, covering the people's water needs. In Sicily, the conditions were similar, in that Agrigento and Syracuse were located where Greek colonies benefited from the same type of karstic geology as found in their home towns, and they applied the same methods to supply water for their settlements.⁴⁶ The Greek founders of Syracuse originated from Corinth and specifically settled there due to the similar geology, climate, and natural water sources available in the cave settings. The geology of both areas consist of penetrable rocks that overlies a layer of impermeable clay, where Corinthians could benefit from their experience and know-how from their homeland, and could apply the same technologies here for water management. Therefore, until the population climbed up the hills of Syracuse, due to a significant growth of the city, people were satisfied with the water supply, only taking water from cisterns and wells, lifting the water by using simple lifting mechanisms and *hydrias*. There was, therefore, no need to build an aqueduct until the 3rd century BC.

Another factor that may have played a significant role in the diffusion process of water-lifting machines, suggested by a number of scholars, was the complexity of some machines that discouraged people of North Africa and the Middle East from using them in their daily life.⁴⁷ This might be one of the reasons that played a role in the widespread use of some of the crude machinery, such as the *sāqiya* and *shādīf* in these arid areas. Large-scale farming activities must have required a continuous production of water with

45 Crouch 1993, 71-72.

46 Crouch 1993, 83-90, 96-99.

47 Murphey 1951.



Fig. 8 Wooden fragments of the large tread wheel with compartmented rim from the Rio Tinto copper mine from Huelva, Spain. The water-wheel was used to drain water from the mine site. The water-wheel dates back to the 1st to 2nd century AD. It is presently displayed in the British Museum, London.

minimal expense and the lack of a water source to feed a gravitational aqueduct supply in many semi-desert regions gave rise to the common use of these simple machines. Meanwhile, there are very few finds of mechanical irrigation systems in use in rural areas in Italy. This was probably due to the abundance of small farms, which were unable to carry the expense of organizing animal or manpower to power the water-lifting system and the system's maintenance.⁴⁸

Another powerful and relatively expensive installation is the tread-wheel with a compartmented rim, driven by animal or manpower. These are located mostly in ore rich geological settings with lead, silver, and gold deposits, in mining areas where slave power was also available (Fig. 8).

Force-pumps were mostly found at archaeological sites in Western Europe, where precipitation is relatively abundant throughout the year. Even though water scarcity was never dramatic in these areas, most of the eighteen force-pumps found in the wells were defective, most likely due to the decreasing of the ground water level after years of drought.⁴⁹

Although the more advanced devices were presumably invented at a very early age, their diffusion took a long time. There are three main factors behind this delay worth mentioning, though other factors should also be considered. The first factor might have been the expensive and laborious construction of machines such as the waterwheel and force-pump. Aside from the expense of building and installing those machines, operating them by means of slave or animal power added additional expenses, and postponed

48 Hodge 2002, 248.

49 Stein 2014, 31.

their diffusion and widespread use. For many agricultural sites, it was not possible and often not necessary to incur such expenses due to the small size of the plots.

A second factor in the delay of diffusion was the complicated nature of some of the devices like the force-pump, which was temperamental in some ways and required a reasonable knowledge of the technology used. There was always a danger that it would stop working due to its complicated nature, and it was difficult to maintain and repair, something that was unlikely to be done by simple farmers without know-how.

The last, but not least, factor was the amount of water that could be lifted, which was relatively low for some mechanisms. Some of the technologies were limited in their capacity, with the total amount of water they could raise being related to their diameter, as with the *tympanum*.

4.2 Watermills

Another issue in taking advantage of natural sources is the application of water mills. Mills were used earlier than the Classical period but were especially common during the Roman era, when they became a part of early industrialization. The water machines that were driven by water-power required a reliable water source for economic profit, since the machinery could turn without interruption, with the added possibility to control the activity. Therefore, these water-powered machines were consciously located in geographical settings where the precipitation is almost year round, providing a continuous water source. Wikander, however, explains in a plausible way, that there was not really a geographical constraint on the diffusion of mills.⁵⁰ Indeed, in the Mediterranean, there seem to be many areas with reasonable sources that have a continuous water supply that would have been suitable for mills. Although no earlier watermill examples have yet been found by archaeologists, one well-known watermill for grinding flour was identified in Ephesos that dates back to the early Byzantine period, and a saw-mill was identified at Hierapolis that dates back to the 3rd century AD.⁵¹ Both of these examples are from Asia Minor. It might, in fact, have been an even larger problem to obtain a water supply from the rivers of Western Europe, where there is usually a problem with flooding of the rivers, which might have caused an interruption in flour production and even damage to the installations. As a consequence, the limitation issue regarding environmental conditions should be regarded skeptically, taking poor archaeological remains into account.

Most examples of watermills for industrial use were overshot wheels that usually had a connection with a costly aqueduct supply; the water moved continuously through the

50 Wikander 2000, 378.

51 Wikander 2000, 378.



Fig. 9 Undershot wheel installation of a reconstructed Byzantine water mill at the river Nahal Tananim. This structure is a good example of ancient water-mills that still function.

channels and chutes to the waterwheels, which turned the paddles. The Barbegal water-mill complex in Southern France was one of the best examples of this kind of expensive and large-scale arrangement.⁵² Being part of an ambitious setup, water machines driven by water-power from aqueducts needed to be located in a specific geographical setting, located on a top slope where aqueducts brought the water from a higher position to turn the wheels by gravity. Until today, some of the locations where overshot wheels were located in archaeological sites benefited from similar topographical setting for grinding flour as at Barbegal: the Janiculum,⁵³ the Baths of Caracalla in Rome,⁵⁴ Venafro,⁵⁵ Saepinum in Southern Italy,⁵⁶ and the Agora of Athens in Greece.⁵⁷ Fortunately, some of these watermill installations preserved their carbonate incrustations: this has helped researchers to determine the design and size of the watermill structures and to improve our understanding of the activities of these machines through their working period, such as their upkeep, which indirectly contributes to our knowledge of the Roman economy.⁵⁸

The second type of watermill, the undershot wheel, also required a continuous water supply, although these mills could be located directly in rivers or streams where water could turn the paddles. Most present-day examples come from tidal rivers in England, where the current can move the paddles in both directions. The Mediterranean climate is a typical bimodal one, where rainfall amount varies quite dramatically throughout a year due to the only serious precipitation taking place during the winter. The lack of powerful perennial rivers in the Mediterranean basin, due to seasonal precipitation,

52 Leveau 2006; Sellin 1981; Hodge 1990.

53 Wilson 2001.

54 Schiöler and Wikander 1983.

55 Reynolds 1983, 34.

56 Guendon 2007.

57 Parsons 1936.

58 SürmeliĻhindi et al. 2018.

may have played a role in the paucity of undershot mills in this basin. A rare example consists of the Byzantine mills at Nahal Taninim in Israel (Fig. 9).

5 Adaptation processes

Ancient water mechanisms changed in nature as “one species turns into another”, due to geographical advantages or disadvantages, analogous to “natural selection”, as described by Charles Darwin (1809–1882), but driven deliberately by the people of that time. A number of adaptations were made by engineers or workers, to amend the disadvantages of some water-lifting devices, such as the wheels with compartmented rim and the force-pump, to make them more practical, cheaper, and finally, more applicable to people’s needs and circumstances. For example, the wheel with compartmented rim was equipped with inexpensive pots, another innovation process helped increase the common use of the *sāqiya* in Egypt and North Africa as well. Probably between the 1st and 3rd centuries AD, terracotta pots replaced wooden buckets, since this was more affordable due to the local scarcity of wood.⁵⁹ Finally, for many waterwheel applications, it was a tradition to use available material for their construction. Therefore, the examples of terracotta pots found were generally from Egypt, whereas in Western Europe, wooden buckets were commonly in use.⁶⁰

The force-pump was probably the most altered by innovation processes. The remains of all found force-pump examples from wells were wooden in design and, therefore, the adaptation process from bronze to wood most likely took place because bronze pumps could have decayed more easily under water and very quickly gone out of order. Here, the advantage was not only about making devices more practical, but also making them cheaper.

The three types of watermills discussed above, with three different designs, were chosen due to their functionality in their geographical location. The horizontal-wheeled mills were replaced by either overshot or undershot ones, due to their low level of water capacity in some areas.⁶¹ Another study also discussed the more common use of undershot wheels, even though overshot ones were more efficient;⁶² the reason for this lies in the availability of the geographical setting. The overshot mills required a large head (2–10 m) and were more often located in steep areas where supplementary construction was necessary, such as a millrace, pond and shaft, and sluice, which requires a significant patronage to finance the expenses. On the other hand, the advantages of undershot wheels were numerous, as they could operate with a low head of less than 2 m, which

59 Oleson 2008, 352–353.

60 Wilson 2002.

61 Wikander 2000, 378.

62 Denny 2004.

made their diffusion more widely applicable and practical in areas close to the population centers, utilizing small brooks or streams in any flat area with a relatively less ambitious output.

6 Comparison of the factors of diffusion of aqueducts, *qanats*, and water-lifting devices

An aqueduct was a symbol for prosperity, a luxurious life, and a so-called ‘civilized community.’⁶³ Public latrines and big bathhouses projects were difficult to build without economic support, and were a way of winning a large number of supporters and an important position or concrete power for a tyrant or an emperor. If one traces the locations of the Roman aqueducts, one can recognize their extensive distribution in the Western provinces of the Empire.⁶⁴ These provinces were Romanized over time, especially through Roman invasions. There is a general postulated opinion about the aqueducts in the Near East that these were built mainly for Roman soldiers to provide them with a Roman-approved life style, and not to attract the local population.⁶⁵ Natives of the invaded lands kept using their traditional technologies to raise water from wells and cisterns and to irrigate their land.⁶⁶

There is a common underestimation of the nature and science perception of Graeco-Romans.⁶⁷ Hodge remarks, “[t]here is no evidence of any real or systematic geological understanding of the ancients.”⁶⁸ Nevertheless, ancient Greeks consciously and successfully sought karstic locations for a place to settle. Such locations can easily be recognized due to the weathering of the limestone. Apparently, the Greeks knew about the presence of water in this setting, and probably also knew how to extract it.⁶⁹ There are several example sites that support this idea, but one well-known site is the Greek colony of Émpurias (Ampurias), Spain, where an installation, possibly a bucket-chain, lifted water for a bath.⁷⁰ This installation worked for a considerable time, as can be seen from the floor, which has carbonate incrustations from the carbonate-rich groundwater. This incrustation was due to the location of the ancient city on top of karstic geology, where there would have been enough water due to the abundant water storage in karstic caves under the city. Despite the growing population during the later Roman epoch, people never needed to build an aqueduct on this site.

63 Hodge 2002, 51.

64 See for example www.romaq.org (last accessed 25/05/2018).

65 Hodge 2002, 252.

66 Wittfogel 1956.

67 Hodge 2002, 51.

68 Hodge 2002, 51.

69 Crouch 1993, 83–99.

70 Buxó 2008, 9–16.

The common distribution of *qanats* in the Middle East and North Africa were associated with specific geological settings too. Most desert regions in Syria and North Africa supported the widespread use of *qanats* because of the advantageous geological setting formed by impervious layers of calcium carbonate and quartz. Moreover, there is a strong correlation between the location of *qanat* sites with the amount of rainfall and evapotranspiration in relation to topography and geology.⁷¹

How force-pump installations were diffused is difficult to track because many bronze examples were likely recycled. One possible explanation for their seeming non-existence in the Near East is likely related to the unreliable climatic conditions where the groundwater level was subject to change. The representation of the *Archimedean screw* examples from Egypt maybe also provide proof that people of this time understood that the silty plains of the Nile Delta were not an ideal place to use delicate mechanisms such as a force-pump. Also, there were no mills with undershot wheel mechanisms, as the famous flooding of the Nile River might have destroyed a fixed installation.

7 Conclusions

The importance of population dynamics in the evolution of tool and machine technology is nowadays a well-accepted fact. The East African Rift Valley was a center of innovation because *Homo sapiens* populated this dry land, where the production of food and water was a primary concern. The breakthrough of scientific innovations and developments of water technologies during the 3rd century BC by Hellenistic scientists was driven by the Ptolemy Dynasty's desire to increase the food production and make advances in water management. However, some scientific inventions stemming from this time remained without a practical application for many centuries until the Romans came to power. The Romans triggered the advances that resulted in these devices being applicable to daily life, and also helped diffuse these technologies throughout the Empire, even involving the Roman army in their distribution. The diffusion process of water technologies not only helped the Romans to have more comfort in activities of every-day life but also brought about economic benefits through the trade of these machines. Although the diffused ancient water machines were well-developed and elaborate, people recognized some of the disadvantages and limitations of the different machines and how those related to the paleo-environmental conditions of the working areas. Therefore, especially in the ancient settlements of the Middle East and North Africa, people commonly continued using the same techniques from their own tradition that they had learned long ago from their ancestors, instead of applying new techniques.

71 Lightfoot 1996.

Moreover, some of the water-lifting devices, with their limited water capacity, remained small-scale applications and were never part of ambitious irrigation projects, as far as is known today. The best example of this are the force-pump installations.

Another disadvantage with a force-pump or a wheel with compartmented rim is that they were quite elaborate to build, operate, and maintain, along with the capital expenses involved. Following the progress of innovative work, the force-pump was used for a number of applications, some of which were very important tasks (done by the bronze ones): fire-fighting, bilge-pumping for dewatering a ship, and more casual, luxury tasks, such as spraying fresh perfumed water in the Roman theater and amphitheaters to cool the air. Especially in the Western provinces of the Roman Empire, changing the original bronze apparatus of pumps to a wooden design triggered their common use for lifting water from wells for drinking and gardening. By using wood, some disadvantages were solved; wood, was more commonly available in Western Europe and was less subject to decay under water, in comparison to bronze pumps. Nevertheless, the number of pumps in use may have been quite limited compared to other water-lifting devices that had a higher capacity and were cruder, such as the *noria*, the *Archimedean screw*, and the *shādūf*, for large-scale irrigation. Especially the water-screw has a big advantage, with its robust nature, that allowed its use in coarse-grained and gravel-rich settings, such as draining a mine or using it on a river bank, although no actual remains of the latter have been found. The tread-wheel, with compartmented rim, was also limited to specific areas, in particular, to the mining sites. In this respect, the most important issue was to drain high quantities of water from the mines by means of machine power, and to use them for the ore crushing.

From the archaeological remains, it is plausible that the diffusion of water-powered mills started by the 1st century AD, matched with the first serious attempts at industrialization. Generally speaking, the ambitious watermill installations of the Roman world were located close to reliable springs or river sources, far from any dramatic water level changes, and where there was a lot more capital involvement, an expensive aqueduct supply was built. The diffusion of the two main designs of undershot and overshot wheeled mills depended on the features of the different geographical settings, profiting from the power of streams and rivers in relation to changes in local paleo-environmental conditions, or connected to a gravity driven aqueduct. A few examples of the ancient water technologies that have been mapped are still in use today, such as the *Archimedean screw*, *norias*, and gear-driven wheels with a compartmented rim. This means that even after almost three millennia of history, and the accordant technological progress that took place during the time, these mechanisms are still satisfying people's needs in rural areas today.

Bibliography

Angelakis, Savvakis, and Charalampakis 2007

Andreas N. Angelakis, Y. M. Savvakis, and G. Charalampakis. "Aqueducts During the Minoan Era." *Water Science and Technology: Water Supply* 7 (2007), 95–102.

Behringer 2009

Wolfgang Behringer. *A Cultural History of Climate*. Cambridge: Polity, 2009.

Butzer 1976

Karl W. Butzer. *Earl Hydraulic Civilization in Egypt: a Study in Cultural Ecology*. Chicago: The University of Chicago Press, 1976.

Buxó 2008

Ramon Buxó. "The Water-Management in an Ancient Greek-Roman City (I): An Example in the North-East Spain". In *Water Culture and Water Conflict in the Mediterranean Area*. Ed. by M. El Moujabber, M. Shatanawi, G. Trisorio-Liuzzi, M. Ouessar, P. Laureano, and R. Rodríguez. Options Méditerranéennes: Série A. Séminaires Méditerranéens 83. Bari: Centre International De Hautes Études Agronomiques Méditerranéennes, 2008, 9–16.

Crouch 1993

Dora P. Crouch. *Water Management in the Ancient Greek Cities*. New York: Oxford University Press, 1993.

Denny 2004

Mark Denny. "The Efficiency of Overshot and Undershot Waterwheels". *European Journal of Physics* 25 (2004), 193–202.

Forbes 1964

Robert Jacobus Forbes. *Studies in Ancient Technology*. Vol. IX. Leiden: Brill, 1964.

Granger 1931

Frank Granger. *Vitruvius, De Architectura*. Loeb Classical Library Books 251. Cambridge, MA: Harvard University Press, 1931.

Griffith 2000

Tom Griffith. "The Republic". In *Cambridge Texts in the History of Political Thought*. Ed. by G. R. F. Ferrari. Cambridge Texts in the History of Political Thought. Cambridge, MA: Cambridge University Press, 2000.

Guendon 2007

Jean-Louis Guendon. "Les Concrétions Du Canal D'Amenée D'Eau Au Moulin: Examen Pétrographique". In *Énergie Hydraulique Et Machines Élévatrices D'Eau Dans L'Antiquité*. Ed. by J. P. Brun and J. L. Fiches. Aix-en-Provence: Aix Marseille Université, CNRS, 2007, 131–135.

Hodge 1990

Alfred T. Hodge. "A Roman Factory". *Scientific American* 263.5 (1990), 106–111.

Hodge 2002

Alfred T. Hodge. *Roman Aqueducts and Water Supply*. London: Duckworth, 2002.

Kienast 1995

Hermann J. Kienast. *Die Wasserleitung des Eupalinos auf Samos XIX*. Bonn: Habelt, 1995.

Koutsoyiannis et al. 2008

Demetris Koutsoyiannis, Nikos Zarkadoulas, Andreas N. Angelakis, and George Tchobanoglous. "Urban Water Management in Ancient Greece: Legacies and Lessons". *Journal of Water Resources Planning and Management* 134 (2008), 45–54.

Landels 2000

John G. Landels. *Engineering in the Ancient World*. Oakland, CA: University of California Press, 2000.

Leveau 2006

Philippe Leveau. "Les Moulins De Barbegal (1986–2006)". *Traianus* (2006), 1–21.

Lightfoot 1996

Dale R. Lightfoot. "Syrian Qanat Romani: History, Ecology, Abandonment". *Journal of Arid Environments* 33.3 (1996), 321–336.

Lucas 2006

Adam Lucas. *Wind, Water, Work: Ancient and Medieval Milling Technology*. Leiden: Brill, 2006.

Murphey 1951

Rhoads Murphey. "The Decline of North Africa Since the Roman Occupation: Climatic or Human?" *Annals of the Association of American Geographers* 41.2 (1951), 116–132.

Oleson 1984

John P. Oleson. *Greek and Roman Mechanical Water-Lifting Devices: The History of a Technology*. Toronto: University of Toronto Press, 1984.

Oleson 2000

John P. Oleson. "Water-Lifting?" In *Handbook of Ancient Water Technology*. Ed. by Ö. Wikander. Technology and Change in History. Leiden: Brill, 2000, 217–302.

Oleson 2008

John P. Oleson. *Handbook of Engineering and Technology in the Classical World*. Oxford: Oxford University Press, 2008.

Parsons 1936

Arthur W. Parsons. "A Roman Water-Mill in the Athenian Agora?" *Hesperia* 5.1 (1936), 70–90.

Perry and Hsu 2000

Charles A. Perry and Kenneth J. Hsu. "Geophysical, Archaeological and Historical Evidence Support a Solar-Output Model for Climate Change?" *Proceedings of the National Academy of Sciences* 97.23 (2000), 12433–12438.

Pleket 1967

Henri W. Pleket. "Technology and Society in the Graeco-Roman World?" *Acta Historiae Neerlandica* 2 (1967), 1–25.

Reynolds 1983

Terry S. Reynolds. *Stronger Than a Hundred Men. A History of the Vertical Water Wheel*. Johns Hopkins Studies in the History of Technology 7. Baltimore, MD: John Hopkins University Press, 1983.

Roberts 2014

Neil Roberts. *The Holocene: An Environmental History*. Oxford: Wiley-Blackwell, 2014.

Schiøler 1973

Thorkild Schiøler. "Roman and Islamic Water-Lifting Wheels?" *Acta Historica Scientiarum Naturalium et Medicinalium* 28.48 (1973), 16–20.

Schiøler and Wikander 1983

Thorkild Schiøler and Örjan Wikander. "A Roman Water-Mill in the Baths of Caracalla?" *Opuscula Romana* 14 (1983), 47–64.

Sellin 1981

Robert H. J. Sellin. "The Large Roman Water-Mill at Barbégal (France)." *La Houille Blanche* 6 (1981), 413–426.

Spain 2002

Robert Spain. "A Possible Roman Tide Mill?" *Kent Archaeological Society* 5 (2002), 1–64.

Stein 2014

Robert Stein. *The Roman Water Pump*. Monographies Instrumentum 48. Montagnac: Editions Monique Mergoïl, 2014.

Sürmelihiindi et al. 2018

Gül Sürmelihiindi, Philippe Leveau, Christoph Spötl, Vincent Bernard, and Cees Passchier. "The Second Century CE Roman Watermills of Barbe-gal: Unraveling the Enigma of One of the Oldest Industrial Complexes?" *Science Advances* 4.9 (2018), eaar3620.

Tölle-Kastenbein 1990

Renata Tölle-Kastenbein. *Antike Wasserkultur*. Munich: C. H. Beck, 1990.

Wikander 2000

Örjan Wikander. *Handbook of Ancient Water Technology*. Technology and Change in History 2. Leiden: Brill, 2000.

Wilson 1995

Andrew Wilson. "Water-Mills in North Africa and the Development of the Horizontal Water-Wheel?" *Journal of Roman Archaeology* 8 (1995), 499–510.

Wilson 2001

Andrew Wilson. "The Water-Mills on the Janiculum?" *Memoirs of the American Academy in Rome* 45 (2001), 219–246.

Wilson 2002

Andrew Wilson. "Machines, Power and the Ancient Economy". *Journal of Roman Studies* 92 (2002), 1–32.

Wilson 2003

Andrew Wilson. "Classical Water Technology in the Early Islamic World". In *Technology, Ideology, Water: From Frontinus to the Renaissance and Beyond*. Ed. by C. Bruun and A. Saastamoinen. Acta Instituti Romani Finlandiae, 31, Rome: Institutum Romanum Finlandiae, 2003, 115–41.

Wilson 2011

Andrew Wilson. "Developments in Mediterranean Shipping and Maritime Trade from the Hellenistic Period to AD 1000". In *Maritime Archaeology and Ancient Trade in the Mediterranean*. Ed. by D. Robinson and A. Wilson. Oxford Centre for Maritime Archaeology Monographs. Oxford: Oxford University Press, 2011, 33–59.

Wittfogel 1956

Karl A. Wittfogel. "The Hydraulic Civilizations". In *Man's Role in Changing the Face of the Earth*. Ed. by L. Th. William Jr. Chicago: University of Chicago Press, 1956, 152–164.

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Elio Nenci

The Water Lifting Devices and the Origin of Ancient Mechanics: *Shādūf* and Pulley

Summary

Scholars have not paid much attention to the *shādūf* and they often describe it without studying the historical developments of the mechanical principles upon which its functioning is based. However, this water lifting device plays a very important role in the emergence of some basic concepts of mechanics: equilibrium and the law of the lever. This paper looks at the history of these concepts in relation to the use of the *shādūf* and pulley. It allows us to identify a set of basic principles that we can find both in theoretical works (the oldest surviving text is the Pseudo-Aristotelian *Mechanical Problems* 300 BC) and in books more focused on the practical applications of such principles.

Keywords: mechanics; hydraulic machinery; simple machines; lever; pulley

Dem *shādūf* zollt die Forschung im Allgemeinen wenig Aufmerksamkeit, und wenn, werden oft historischer Kontext und mechanische Grundlagen dieser Technik vernachlässigt. Dabei spielt gerade diese Wasser-Hebevorrichtung eine herausragende Rolle bei der Entstehung wichtiger Grundbegriffe der Mechanik: dem Gleichgewicht und dem Gesetz des Hebels. Dieser Beitrag versucht, die Geschichte der beiden mechanischen Konzepte in Bezug auf die Verwendung des *shādūf* und des Flaschenzugs nach zu vollziehen. Dabei ist es möglich, eine Reihe von Grundkenntnissen zu identifizieren, die sich sowohl in theoretischen Werken wiederfinden (ältestes Beispiel ist ein Text über die Pseudo-Aristotelischen *Mechanischen Probleme*, um 300 v. Chr.), als auch in stärker praxis-bezogenen Büchern.

Keywords: Mechanik; hydraulischen Maschinen; einfache Maschinen; Hebel; Wellrad

Most studies on ancient hydraulic machines treat the *shādūf* only very briefly (κηλώ-
 νειον in Greek, *tolleno* in Latin).¹ The reason may be the fact that this machine, which
 is thousands of years old, does not seem to have undergone any substantial changes
 up to our time. Therefore, it has almost always been groundlessly assumed that only
 one type of this machine existed, and it was described without studying the mechanical
 principle that it's based upon, a principle that began to be discussed in 300 BC in the
 Pseudo-Aristotelian *Mechanical Problems*.

I shall try here to show that the first assumption is misleading and that it is not
 possible to understand correctly the working of this machine without keeping in mind
 the developments of the theory of the simple machines. I will not use the method of
 research followed by many scholars, who have often neglected the idea of investigating
 this development in later periods (the Middle Ages and the Renaissance). Instead, I will
 make a wide ranging use of all of the documents available to me from these later periods.
 These are often directly connected with the ancient writings on the subject, and which
 are moreover of a great help for understanding the working and the construction of
 many mechanical devices, since they belong to a stage in the development of technology
 when the differences from the ancient practices were not so marked as later on.

The *shādūf* is a very simple machine made of two wooden beams, a weight, and a
 bucket for water that is tied to a rope or to a staff. The first beam is thrust straight into the
 ground, and works as a support for the other beam, which is placed crosswise along the
 upper part of the first beam and rotates around its support. This support is not placed
 under the middle point of the crosswise beam, but is placed at a point that divides the
 crosswise beam into two different parts, one of which is much longer than the other. The
 bucket hangs by the rope or by the staff from the end of the crosswise beam that is more
 distant from the support, whereas the weight is tied at the other end of this beam. This
 machine is placed near a river, a canal, or a well and is usually operated by a single man
 who draws the rope or the staff with the empty bucket downwards so that the bucket
 is lowered towards the surface of the water; once the bucket has been filled with water,
 the man lifts it with the help of the counterweight, and then he pours the water out.

I think that the first true depiction of the *shādūf* is found in the frescoes of the
 tomb of Apy at Thebes (tomb no. 217) (Figs. 1–2). In the past it was believed that the
shādūf was represented on an Akkadian cylindrical seal, which is going back to the year
 2300 BC, and in an Egyptian tomb discovered at el-Amarna (18th dynasty), but these
 identifications appear to be strained and hypothetical.² In the tomb of Apy (19th dynasty
 about 1300 to 1180 BC), on the other hand, we can see three complete representations of

1 Humphrey, Oleson, and Sherwood 1998, 309; Oleson 2000, 225–229; Wilson 2008, 350–351.

2 For a description of the seal, see Ward 1910, 146–

147; Laessøe 1953, 12; Salonen 1965, 250–251; Bagg 2000, 76 and pl. 17b. For the Egyptian tomb at el-Amarna, see Davies 1903, 41–42.



Fig. 1 Tomb of Apy at Thebes, left-hand side of the fresco.

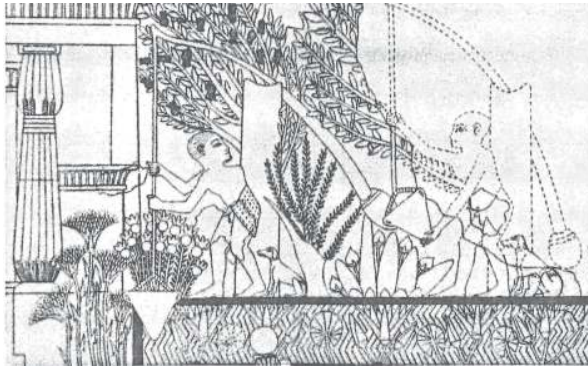


Fig. 2 Tomb of Apy at Thebes, right-hand side of the fresco.

the machine, together with the men who operate it.³ The support, the crosswise beam, the counterweight, and the bucket are clearly depicted, and the men who are about to lower the buckets towards the water or to lift them from the water are shown at the beginning or at the end of their effort. A fragment behind the figure on the right shows a hand that is about to pour the water that had been picked up with another *shādūf* that is no longer visible.

Though these representations show the whole of the machine, not all of the questions concerning its means of operation are solved. On the contrary, from what can be seen in the frescoes and in the other representations on the tomb of Nefer-hotep (tomb no. 49, Fig. 3), the arrangement of the crosswise beam would turn out to be completely unfavorable for the proper working of the machine, since in all these representations the part of the beam between the support and the counterweight appears always to be longer than the part between the support and the rope or the staff attached to the bucket. In this arrangement the beam would turn out to be a lever with the moving power placed

3 For literary evidence of the existence of this water lifting device in old Babylonian period, see Laessøe

1953, 12–13.

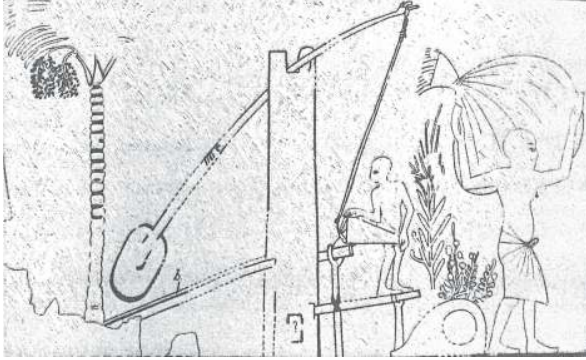


Fig. 3 Tomb of Nefer-hotep at Thebes.

near the fulcrum, and with the weight, which is to be movable, placed far away from the same fulcrum. This arrangement would make it difficult both to lower the bucket and to raise it, since the bucket would not be raised by a slow lowering of the counterweight, but the worker would have to apply a force in a direction contrary to that in which the force was applied for lowering the bucket.

We are here facing a real mechanical problem that should have immediately drawn the attention of those who have described and analyzed these representations, but such a problem does not appear to ever have been considered. A proper consideration of this problem was probably prevented both by the observation of the various *shādūf* that are still used along the Nile, and by the modern mechanical theory of the machine: these facts favored an interpretation of those representations that was distorted by ideas derived from more recent developments of technology; whereas it would have been more useful to explain those representations on the basis of the description of the object represented.

If we want to try to explain the way in which the machine is depicted in the representations I have described, without assuming that the Egyptian artists were not capable of correctly depicting the real machine used in their time, we must try to understand the reason for the particular arrangement of the parts of the machine. To do that, we must assume that the way in which it was operated was useful for raising the water without great effort. Now, in all these representations of the *shādūf*, no fixed connection between the vertical support and the horizontal beam is ever shown: this suggests the possibility that this beam was able to slide forwards and backwards (Figs. 1–2). The lack of the fixed point around which the beam could rotate, however, would seem to hamper the continuous operation of raising and lowering the bucket, unless the curved shape of the beam together with the width and the hollow shape of the top part of the vertical support could compensate for the unfavorable arrangement.

It is, therefore, possible that when the machine was operated, the crosswise beam

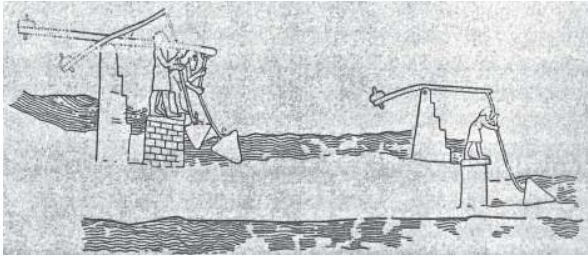


Fig. 4 Drawn from a bas-relief from the palace of Sennacherib at Niniveh.

was placed almost at an equilibrium on the support and then was made to oscillate on it; this movement being helped by its curved shape, which would have prevented the crosswise beam from sliding forwards, while the possible lateral shifting would have been avoided because of the curved shape of the top of the support. If this hypothesis is correct, then the man who was operating the machine would have first drawn the beam towards himself, so that the distance between the support and the rope or the staff which was holding the bucket would increase, after which, he would keep the beam in that position while the bucket was lowered and lifted. It would have been difficult for a single man to empty the bucket, though, because the beam would have had the propensity to slide back towards the side of the counterweight.

The lack of a fixed connection between the support and the crosswise beam would have made the working of the machine more complicated, slowing down operation, and, in the end, diminishing the quantity of water raised in a day. Perhaps the machines depicted in those ancient documents were not up to the task of supplying irrigation, which could mean that those unfavorable conditions were not considered very important.

All of these difficulties seem to disappear all together with the types of *shādūf* depicted in a bas-relief from the palace of Sennacherib at Niniveh, going back to the 7th century BC. Here, the machine is represented according to its classical form, with the crosswise beam almost always straight or slightly curved; with the weight attached to the end of the beam nearer the support; and with the bucket placed at the other end, more distant from the support. Even the connection between the vertical support and the horizontal beam seems clearly represented. This arrangement is not, to be true, visible in all the types of *shādūf* represented in the bas-relief, but it is clearly visible in one of them. The machine is arranged so that it can function with the greatest efficiency, and the workers engaged in raising the buckets could raise a great quantity of water from one level to other, so it could go to the places where it would later be distributed in smaller quantities (Fig. 4).

Let me summarize: the mural paintings of some tombs in Thebes show a device that is partially different from that which is portrayed in a bas-relief of Sennacherib's Palace



Fig. 5 Representation of a *shādūf* using a movable counterweight.

at Nineveh. As a matter of fact, the lack of a stable connection between the pivot and the transversal beam in the Egyptian reproductions, implies that the way in which the machine was operated was fundamentally different from how it worked later on, and raises many problems from a mechanical point of view. The effectiveness of the machine depends on the different ratio in the lever between the weight and the bucket, therefore, the more distant the weight is from the pivot, the more difficult it would be to operate the machine to lower the bucket.

The result obtained by using a fixed point of rotation offers a great advantage when one has to repeat the same operation, but the versatility of the use of the machine is lost. No wonder, then, that in the Greek-Roman world we find the *shādūf* with a crosswise beam that is not fixed. It is surprising, however, that a variation is introduced in the relation between the weight, the fulcrum, and the power by using a movable counterweight (Fig. 5). This arrangement appears reproduced on a vase that shows the description of a satyr and another man who operates the *shādūf*, waiting for two women near a well. Here, the smaller length of the crosswise beam on the side of the rope attached to the bucket makes up for the weight being nearer to the support. Another device is shown in a mosaic floor from a house at Oudna, now in the Museum of Bardo at Tunis (Fig. 6), where we can notice another beam that is similar to the support of the *shādūf*, but a bit shorter, to prevent the part of the crosswise beam with the counterweight from getting completely lowered down, making it easier to lift.

As I said, the working of this machine had been analyzed in the most ancient Greek treatise on mechanics that has survived, the Pseudo-Aristotelian *Mechanical Problems*. In it, the author tried for the first time to base the explanation of the workings of 'simple machines' (such as the lever, the windlass, the wedge, and the pulley) on a single mathematical principle, and to solve a series of questions that could be answered by referring

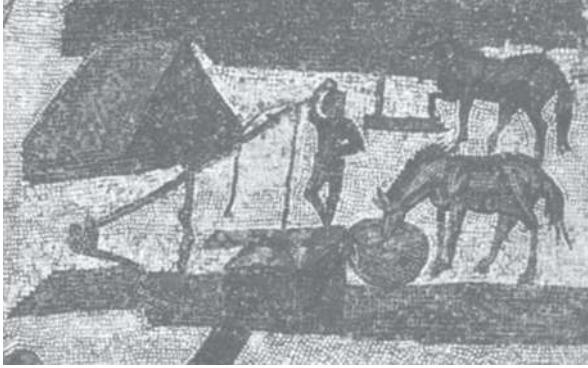


Fig. 6 Mosaic floor from a house at Oudna, now in the Museum of Bardo at Tunis.

to that same mathematical model. The starting point of the whole treatise was the astonishment roused by the operations carried out by means of a lever, such as the lifting of great masses that man was unable to move without that instrument. An even greater astonishment was roused by the fact that, by adding weight to weight, that is the weight of the lever to the weight that had to be lifted, the whole thing could be moved more easily.

For it is strange that a great weight can be moved by a small force, and that, too, when a greater weight is involved. For the very same weight, which a man cannot move without a lever, he quickly moves by applying the weight of the lever.⁴

This fact upset the obvious relationship between the force needed to move a certain body and its weight; in fact the experience clearly shows that things ‘weighing less’ are easier to move than things ‘weighing more.’

The author of the *Mechanical Problems* moved on to discover the principle that was able explain this remarkable fact: This principle was directly related to the movement of the lever, so that the working of the machines was reduced to the circle. He also considered it remarkable that the circle is an even more astonishing figure, since it is made up of opposites, a fact that becomes obvious when the circle is generated by a rotating line fixed at one end:

1. The generation of the circle is made by what is stationary, i.e. one end of the radius, and by what is moving, i.e. the other parts of the radius which move round and produce the surface of the circle.

4 Aristot. *mech.* 847b11–15.

2. The circle includes at the same time the concave, inside the circumference, and the convex, outside the circumference.
3. The rotating circle moves simultaneously in opposite directions, for it moves simultaneously forwards and backwards.
4. The circle is generated by the movement of one line drawn as a radius from the center, but no two points on that line travel at the same pace, but that which is further from the fixed center travels more rapidly.⁵

Having explained why the point more distant from the center travels more quickly than the point closer to it, though impelled by the same force, the author of *Mechanical Problems* moved on to explain in Question 3 why small forces can move great weights by means of a lever.⁶

The discussion of the lever, referring back to the paradox pointed out at the beginning of the treatise, not only explains the way this instrument works by relating it to the movement of different points of the radii of a different length than the lever, but tries at the same time to establish some sort of connection between the weight, the power needed to move it, and their relative distances from the fulcrum. This is an utterly new aspect of the problem that is not discussed in the later questions; certainly not in the case of the κηλώνειον-*shādūf* (Question 28), which could have been seen as a special form of lever. On the contrary, when this appliance is being discussed, the principle that explains how the different velocities of the points of the radius that generate the circle, is also totally ignored. Here, no reference of any sort is made to the theory of the lever, and the whole chapter is focused on the operation of drawing water, which is analyzed in the two essential movements of lowering the empty bucket (by raising the counterweight) and lifting the bucket full of water (by lowering the counterweight).

Why do men make swing-beams at wells in the way they do? For they add the weight of the lead to the wooden beam, the bucket itself having weight whether empty or full. Is it because the machine functions in two stages (for it must be let down and drawn up again), and it can easily be let down whereas it is difficult to draw up? The disadvantage, then, of letting it down rather more slowly is balanced by the advantage of lightening the weight when drawing it up. The attachment of lead or a stone at the end of the swing-beam produces this result. For thus, when one lets down the bucket by a rope, the weight is greater than if one let the bucket down alone and empty; but when it is full,

5 Aristot. *mech.* 847b15–848a19.

6 Aristot. *mech.* 850a30–850b9.

the lead draws it up, or whatever weight is attached to it. So that on the average the two processes are easier than they would be in the other case.⁷

The structure of the machine is assumed to be known to the reader, and so the author ignores a whole series of specific details that must be known to assure that the working of the appliance would be favorable for the man who has to draw the water. The relation of the distances and of the weights with the bucket full of water should produce a state of almost equilibrium, for if the counterweights weigh more heavily, the entire operation would be less easy. Those who were constructing such appliances, and probably some of those who were using them, must have somehow been aware of this fact, but it does not seem that this basic knowledge of mechanical principles resulted in pointing out the fundamental geometrical principle of the inverse proportion between the weights and the distances from the fulcrum.

Let us now analyze the mechanical operation accomplished by the *shādūf* and compare it with other operations generally employed for lifting weights, both with the help of machines and without them. The use of special technical devices for raising water from wells must have started very early in the history of mankind: the need of increasing the quantity of water drawn up was probably the cause of inventing such devices. The increased dimensions of the bucket involved an increased effort necessary to lift it, and this needed the employment of several workers, the use of animals, or the construction of specific contrivances for helping the men to bear more and more weight, and at the same time making it easier to lift that weight. The placement of those who had to perform this task was determined by the operation that they had to execute, but required that they should be near the water. There was also a difference in respect to the lifting of solid weights: in our case it was impossible for one who was lifting the weight to put himself under it. The fact that the machines used for both operations showed aspects that were partly similar and partly dissimilar seems not to have ever been clearly pointed out.

Drawing water from above using only a bucket tied to a rope requires a remarkable effort, since during the lifting the entire weight of the bucket must be borne for a short time by one hand only. Drawing water from wells and rivers with the help of the *shādūf* was less difficult and required less effort. This was also true when one used the *trochlea*, a wheel placed above the well that could rotate about an axis, with a rope wound round its circumference and tied to the bucket. Instead of a wheel, any cylinder could be used with a rope wound around it several times.

On the contrary to what I pointed out for the *shādūf*, in the *Mechanical Problems*, the analysis of the workings of the *trochlea* (Question 9) is related both to the general

7 Aristot. *mech.* 857a34–857b8.

mechanical theory treated in that work, and to that which had been reported in the first Question concerning bigger and smaller weighing machines. Since the shape of a wheel is directly related to the circle, the wheels rotating around their pivot actually behave like balances; so, bigger wheels move and lift the weights with greater ease and more quickly than smaller wheels.

Why is it that we can move more easily and quickly things raised and drawn by means of greater circles? For instance larger pulleys work better than smaller ones and so do large rollers. Surely it is because, the distance from the centre being larger, a greater space is covered in the same time, and this result will still take place if an equal weight is put upon it, just as we said that larger balances are more accurate than smaller ones. For the cord is the centre and the parts of the beam which are on either side of the cord are the radii of the circle.⁸

This way of explaining the working of a wheel was an immediate application of what had been said at the beginning of the *Mechanical Problems*: the reason for the presumed greater ease with which the bigger *trochleae* were operated was once more seen in the greater velocity of the points that were more distant from the center. In this case, the ease with which the weight was lifted was related to speed; this assumption was sharply criticized in the 16th century. In the Pseudo-Aristotelian treatise, the *trochea* was discussed from a general point of view, and was not in any way related to its possible use in lifting a bucket full of water from a well: this specific function was left to the κηλώνειον-*shādūf* alone. In the *Mechanical Problems*, neither the use of cranks attached to wheels nor the use of windlasses (Question 13 where their use is strictly related to the theory of the axle in the wheel) were treated in connection with our subject.

Why are the larger handles more easy to move round a spindle than smaller ones, and in the same way less bulky windlasses are more easily moved than thicker ones by the application of the same force? Is it because the windlass and the spindle are the centre and the parts which stand away from them are the radii? Now the radii of greater circles move more quickly and a greater distance by the application of the same force than the radii of smaller circles; for by the application of the same force the extremity which is farther from the centre moves more. This is why they fit handles to the spindle with which they turn it more easily; in the case of light windlasses the part outside the centre travels further, and this is the radius of the circle.⁹

8 Aristot. *mech.* 852a14–22.

9 Aristot. *mech.* 852b11–21.

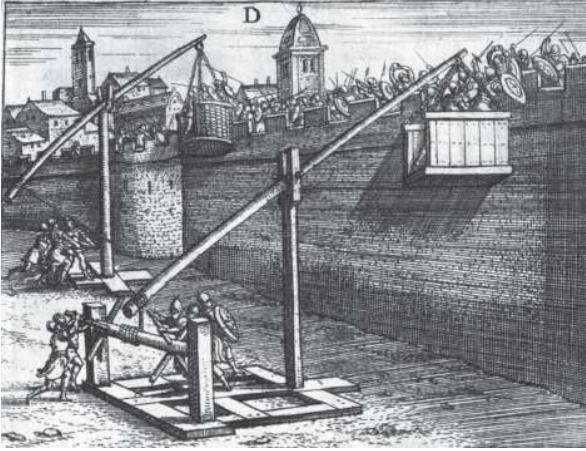


Fig. 7 Representation of a *tolleno*.

From Pliny's *Naturalis Historia*, we learn that in the Latin world the specific function of the *shādūf* seemed to be known: the *tolleno*, as well the *trochlea* and the pump, was used as a device to be placed near a well for the irrigation of the gardens of country houses.¹⁰

However, in late Antiquity the word *tolleno* was used to indicate a machine that worked like a normal lever; this lever, by having a very tall support, would have lifted the soldiers to the height of the walls of the city (Fig. 7).¹¹

The *tolleno* had become an instrument in the hands of soldiers: without a counterweight, it seemed to have lost any connection with the κηλώνειον-*shādūf*, and with the original function of a machine for raising water. In this case also, things are not so simple as they look. In a painting of an Egyptian scene found during the excavation at Ercolano, a device for raising water from a cistern is represented that works in a way very similar to the *tolleno* used during a siege (Fig. 8).

The later works on theoretical and practical mechanics produced in the Greek-Roman world do not seem to have paid any attention to these two mechanical devices. We had to wait until the *Mechanical Problems* were rediscovered at the beginning of the 16th century and were later studied and commented upon for finding a renewed interest for the κηλώνειον-*shādūf*, together with attempts to integrate the Pseudo-Aristotelian text. Lacking a direct connection with the general mechanical principle of that work or with the treatment of the lever, the question concerning this machine seemed to be somehow incomplete to many authors who studied that book. Nicolò Leonico Tomeo (AD 1486–1531), the author of the Latin translation that most helped to make the work to be known for centuries, felt the need of adding an important specific commentary

¹⁰ Plin. *Nat.* XIX, 60.

militaris IV, 21.

¹¹ Flavius Vegetius, 4th to 5th century AD, *Epitoma rei*



Fig. 8 Representation of a device for raising water found in Ercolano.

that actually related the device to the balance with the support placed underneath the pivot, a particular kind of balance discussed in the second mechanical problem.¹² This trend was followed decidedly by Alessandro Piccolomini (AD 1508–1578), the author of a *Paraphrase* of the Pseudo-Aristotelian work, in which for the first time, the mechanical reason for the advantage offered by the *shādūf* in the operation of raising water was pointed out and explained.¹³ Finally, in the work *In Mechanica Aristotlis Problemata Exercitationes* (Mainz, AD 1621), written by Bernardino Baldi (AD 1553–1617), the mechanical operation performed by this machine was studied more deeply by pointing out the role played by the weight of the body of the person who was involved in the action of the lifting. He noticed in the first place, that in order to draw water by means of the κηλῶνειον-*shādūf* one had to reverse the way in which the effort was normally applied with the use of only the hands. He wrote:

Truly, with a hand, by means of a rope, the empty bucket can be easily lowered, but it is lifted with difficulty when it is full, whereas by using the κηλῶνειον the things are reversed. The worker who lowers the bucket is helped by the weight of his body, while the one who lifts the bucket by means of a simple rope is hampered by the weight of his own body; certainly the help given by the weight of the body make it much easier to lift the bucket.¹⁴

This observation is very important, since it makes us better understand the dynamics of the various moments of the lifting of a weight, and it makes it possible to compare the operation made by hand, with that performed by means of the *trochlea*.

The use of a pulley has the advantage mentioned at the end of the passage I quoted: in this case, “the person who draws the water, by adding the weight of his own body to his forces, finds it easier to lift the bucket full of water”.

All of these considerations make us reach a deep understanding of the working of this very ancient machine, which in its relative simplicity contained a complicated series

12 Aristot. *Quaestiones Mechanicae*, 51.

13 Piccolomini 1547, 60–61.

14 Baldi 2010, 331.

of applications of the law of the lever. It seemed that the working of the *shādīf* was at last recognized as different from that of the common lever, but the similarities were still considered very strong, even by Baldi. At the conclusion of his discussion of the problem, he did not hesitate to state: “the machine used in the war that is called *tolleno*, is not at all different from the κηλώνειον both for its form and for its way of operating”.¹⁵

The discovery of all the documents concerning the ancient machines helped to attain a high level of theoretical investigation that took advantage of the recovery of Archimedes’ work containing the law of the lever. What happened to the basic knowledge of mechanical theory during the previous centuries, though? The medieval works on the *scientia de ponderibus* are silent on this point, but that knowledge was not completely lost; something of it remained under the unexpected form of an esopic tale contained in the Roman de Renart.

This poem, written toward the end of the 12th century, was translated into many languages during the Middle Ages and has been very popular until our own time. In the fourth ‘branch’ or chapter (verses 151–364), it is told that a fox who had jumped into a bucket placed on top of a well, caused it to go down to the bottom of the well, raising at the same time the bucket tied to the other end of the rope. Not knowing how to get out of this situation, she managed to tell a wolf, who had just arrived near the well, that there was food at the bottom of the well. By persuading the wolf to jump into the bucket that was at the top of the well to go down to reach the food, the fox managed to raise the bucket that was at the bottom and therefore to save herself.¹⁶ The basic idea of this tale seems to have very ancient origins, and is probably related to a traditional comment on some biblical passages of the Talmud.¹⁷ Aside from the problem of the historical origin of the tale, its interesting point is the description of the use of the *trochlea*, or of a turning cylinder, which exploits the weight of the empty bucket that goes down, to make it easy to lift the full bucket. This trick reminds us of the function played by the counterweight in the *shādīf* and show us that the base knowledge of mechanics acquired in the second millennium BC was never lost, but was maintained in the popular memory through both the use of mechanical devices and moral tales, very different from the texts usually studied by historians of science.

15 Baldi 2010, 333.

16 See <http://gallica.bnf.fr/ark:/12148/btv1b52505725s/>

f84.image (visited on 07/05/2018).

17 Varthy 2000, 245–248.

Bibliography

Ancient Authors

Aristot. *mech.*

Aristotle. "Mechanical Problems". In *Minor Works. On Colours. On Things Heard. Physiognomics. On Plants. On Marvellous Things Heard. Mechanical Problems. On Indivisible Lines. The Situations and Names of Winds. On Melissus, Xenophanes, Gorgias*. Ed. by W. S. Hett. Loeb Classical Library 307. Cambridge, MA: Harvard University Press, 1936, 327–411.

Aristot. *Quaestiones Mechanicae*

Aristoteles. "Quaestiones Mechanicae". In *Aristotelis Stagiritae Parva Quae Vocant Naturalia. De Sensu & Sensili. De Memoria & Reminiscencia. De Somno & Vigilia. De Insomniis. De Divinatione per Somnia. De Animalium Motione. De Animalium Incessu. De Extensione & Brevitate Vitae. De Juventute & Senectute, Morte & Vita, & De Spiratione. Omnia in Latinum Conversa, Et Antiquorum More Explicata a Nicolao Leonico Thomaeo. Eiusdem Opuscula Nu-Per in Lucem Edita. Item Eiusdem Dialogi, Quotquot Extant*. Ed. by N. Leonico Tomeo. Paris: Apud Simonem Colinaeum, 1530.

Secondary Literature

Bagg 2000

Ariel Bagg. *Assyrische Wasserbauten. Landwirtschaftliche Wasserbauten in Kernland Assyriens zwischen der 2. Hälfte des 2. und 1. Hälfte des 1. Jahrtausends v. Chr.* Baghdader Forschungen 24. Mainz: Philipp von Zabern, 2000.

Baldi 2010

Bernardino Baldi. "In Mechanica Aristotelis Problemata Exercitationes". In *In Mechanica Aristotelis Problemata Exercitationes. Vol. I. Testo Latino Riveduto E Corretto Con Traduzione Italiana a Fronte*. Ed. by E. Nenci. Milan: Angeli, 2010, 47–385.

Davies 1903

Norman de Garis Davies. *The Rock Tombs of El Amarna. Part I. The Tomb of Meryra*. Archeological Survey of Egypt 13. London: Oxford University Press, 1903.

Davies 1927

Norman de Garis Davies. *Two Ramesside Tombs at Thebes*. Publication of the Metropolitan Museum of Art Egyptian Expedition 5. New York: The Metropolitan Museum of Art, 1927.

Davies 1933

Norman de Garis Davies. *The Tombs of Nefer-hotep at Thebes*. Publication of the Metropolitan Museum of Art Egyptian Expedition 9.1. New York: The Metropolitan Museum of Art, 1933.

Gauckler 1896

Paul Gauckler. "Le domaine des Laberii a Uthina". In *Monuments et Mémoires publiés par l'Académie des Inscriptions et Belles-Lettres*. Ed. by G. Perrot and R. de Lasteyrie. Fondation Eugène Piot. Monuments et Mémoires publiés par l'Académie des Inscriptions et Belles-Lettres 3. Paris: Leroux, 1896, 177–229.

Humphrey, Oleson, and Sherwood 1998

John W. Humphrey, John P. Oleson, and Andrew N. Sherwood. *Greek and Roman Technology: a Sourcebook: Annotated Translations of Greek and Latin Texts and Documents*. London and New York: Routledge, 1998.

Laessøe 1953

Jørgen Laessøe. "Reflexions on Modern and Ancient Oriental Water Works". *Journal of Cuneiform Studies* 7 (1953), 5–26.

Layard 1853

Austen H. Layard. *A Second Series of the Monuments of Nineveh: Including Bas-Reliefs from the Palace of Sennacherib and Bronzes from the Ruins of Nimroud; From Drawings Made on the Spot, during a Second Expedition to Assyria*. London: Murray, 1853.

Le Antichità Di Ercolano 1789

Tommaso Piroli. *Le Antichità Di Ercolano. Pitture. Tomo I.* Rome, 1789.

Lipsius 1596

Justus Lipsius. *Poliortecicon Sive De Machinis, Tormentis, Telis Libri Quinque.* Antwerp: Ex officina Plantiniana apud Viduam et Ioannem Moretum, 1596.

Oleson 2000

John P. Oleson. "Water-Lifting." In *Handbook of Ancient Water Technology*. Ed. by O. Wikander. Technology and Change in History 2. Leiden: Brill, 2000, 217–302.

Pfuhl 1923

Ernst Pfuhl. *Malerei und Zeichnung der Griechen. Vol. III: Verzeichnisse und Abbildungen.* Munich: Bruckmann, 1923.

Piccolomini 1547

Alessandro Piccolomini. In *Mechanicas Quaestiones Aristotelis Paraphrasis Paulo Quidem Plenior.* Rome: Apud Antonium Bladum Asulanum, 1547.

Salonen 1965

Armas Salonen. *Die Hausgeräte der alten Mesopotamier.* Helsinki: Suomalainen Tiedeakatemia, 1965.

Varthy 2000

Kenneth Varthy. "The Fox and Wolf in the Well: the Metamorphoses of a Comic Motif." In *Reynard the Fox: Cultural Metamorphoses and Social Engagement in the Beast Epic from the Middle Ages to the Present.* Cultural Diversities and Intersections 1. New York and Oxford: Berghahn Books, 2000, 245–256.

Ward 1910

William H. Ward. *The Seal Cylinders of Western Asia.* Washington: Carnegie Institution, 1910.

Wilson 2008

Andrew I. Wilson. "Machines in Greek and Roman Technology." In *The Oxford Handbook of Engineering and Technology in the Classical World.* Ed. by J. P. Oleson. New York and Oxford: Oxford University Press, 2008, 337–366.

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1 From Davies 1927, detail of pl. 28. 2 From Davies 1927, detail of pl. 28. 3 From Davies 1933, detail of pl. 46. 4 From Layard 1853, detail of pl. 15. 5 From Pfuhl 1923, fig. 276. 6 From

Gauckler 1896, detail of pl. 22. 7 From Lipsius 1596, 34. 8 From Le Antichità Di Ercolano 1789, pl. 47.

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Lauretta Maganzani

Irrigation Communities in the Roman World Through Epigraphic Sources and Justinian's Digest

Summary

This paper deals with local irrigation systems organized by villages and communities that existed in the Roman world. It will examine some epigraphic and literary texts and relevant jurisprudential sources belonging to Justinian's Digest on this topic. In all these cases, the need for joint water use led to the development of at least initial forms of 'associations' among so called *rivales*. These 'associations' dealt with different matters such as: a) the distribution of water; b) the regulation of the hydraulic work, such as digging and maintenance; and c) the arbitration of possible disputes between users. For their part, the juridical texts provide a good insight into the 'legal status' of these communities, namely how internal relationships between *rivales* were considered.

Keywords: water; irrigation; communities; epigraphic sources; Justinian's Digest

Dieser Aufsatz präsentiert Beispiele lokaler Bewässerungssysteme und Dorfgemeinschaften aus Römischer Zeit. Untersucht werden zu diesem Thema sowohl epigraphische und schriftliche als auch relevante juristische Quellen, die zu *Justinian's Digesten* gehören. In allen untersuchten Fällen entwickelte sich aus dem gemeinschaftlichen Wasserverbrauch Formen der Gerichtsbarkeit zwischen den Gemeinschaftsmitgliedern, in Bezug auf a) Wasserzuteilung, b) Wartung, etwa durch Kanalarbeiten oder Instandhaltungsmaßnahmen und c) Schlichtung von Streitfragen zwischen Nutzerinnen und Nutzern. Die juristischen Quellen geben einen guten Einblick in den ‚Rechtsstatus‘ dieser Gemeinschaften und beschreiben, wie interne Beziehungen zwischen *rivales* gehandhabt wurden.

Keywords: Bewässerung; Dorfgemeinschaften; epigraphische Quellen; Justinianische Rechtsprechung

English translation by Francesca Scotti.

I Introduction

Today, as in the past, water resources play a key role both in the organization and occupation of territory and in the economic and social structuring of groups. A fundamental distinction can be made between general irrigation systems, as in the Nile Valley or Mesopotamia, and local irrigation systems.¹ In this paper I will cover local irrigation systems, organized by villages and communities, with particular reference to the Roman world (but also with a look to our most recent past).

The topic of irrigation communities in the Roman world has only become a matter of interest for classical scholars in recent times, in particular after the publication of the 2006 edition of the so-called *Lex rivi Hiberiensis* by Francisco Beltrán Lloris.²

After this edition, other inscriptions that have already been edited (for example the famous Tabula of Lamasba, the plans of Aventine and Tivoli, and so on) and some literary texts concerning these types of communities have been re-evaluated.³ Through this work, it has become clear that these forms of communities were quite widespread in the Roman world.⁴

In all these cases the common element was the provision of rules regarding the rights of the various water *rivales*, as well as the associated obligations (like cleaning and maintaining the channel, etc.). The distribution of the water used to take place at different times and in different quantities depending on the size of the ground to be irrigated. There were also measures to prevent or solve the frequent disputes between beneficiaries that would arise. Those disputes were so frequent that the Italian word ‘rivali’, derived from the Latin *rivales*, refers to individuals who argue and contradict each other.

It is also notable that some material relating to the existence and organization of these local communities for the joint exploitation of canals for irrigation still exists in various parts of the world. For example, they are widely present in South Tyrol, Vingschau (Fig. 1), and in the Swiss Alps, where you can still find kilometers of canals for the irrigation of the Alpine region. They are also widely present in Spain, in the Valencia region. Here, from time immemorial, there was also a special water court used to solve disputes between beneficiaries. Even in these cases, rules are usually given to the community for all its members and every individual has to provide for the maintenance and cleaning of the channel, without which, the flow of water would inevitably

1 Oleson 2000, 184–215; Bédoucha 2009, 476–478.

2 Beltrán Lloris 2006, 147–197.

3 Maganzani 2014b; Maganzani 2012a, 103–119; Maganzani 2012d, 121–124; Maganzani 2012b, 171–

185; Maganzani 2012e, 195–213; Leone 2012; Ronin 2012; Beltrán Lloris 2010; Debidour 2009; Bannon 2009.

4 Bernigaud et al. 2014.



Fig. 1 Archaeological findings of water channels used between the Bronze Age and AD 50 (hill of Ganglegg above Schludern, Vingschau).

be interrupted. In addition, it is often possible to find measures to prevent or solve the frequent disputes between beneficiaries.⁵

Antiquarians have generally taken no interest in such material remains, considering them a medieval legacy rather than a Roman one.⁶ In light of new epigraphic evidence, which I will speak about in a moment, it cannot be excluded that there might be a continuity between the organization of such communities in the Roman period and those communities whose remains are still visible on the ground; for example, Francisco Beltrán Lloris and Anna Willi recently demonstrated this for the Valencia region.⁷ Even in the Alpine region, we could be surprised by the similarity between some archaeological findings of water channels used between the Bronze Age and AD 50 (for example, those found in Vingschau above Schludern on the hill of Ganglegg; Fig. 1), and channels built at least at the end of the 18th century, like the one in Val d'Ultimo near Merano (Fig. 2).⁸

All these new data invite me to investigate this topic with a special regard towards Roman law and Roman classical jurisprudence. In recent years, following the publication of the *Lex rivi Hiberiensis* by Francisco Beltrán Lloris in 2006, the theme of irrigation communities has become a subject of interest for the Roman Law doctrine.⁹ However, as far as I know, this topic is still alien to Roman private law scholars:¹⁰ in fact, they have largely studied water servitudes on the basis of the fragments of Justinian's *Corpus*

5 Beltrán Lloris 2011; Bodini 2002.

6 Beltrán Lloris 2011.

7 Beltrán Lloris 2011.

8 Bodini 2002, 11–12.

9 Nörr 2008, 108–187; Capogrossi Colognesi 2014, 75–91; Capogrossi Colognesi 2012, 151–160; Buzzacchi 2015; Buzzacchi and Maganzani 2014; Buzzacchi 2013; Platschek 2014; Torrent Ruiz 2014; Torrent

Ruiz 2013a; Torrent Ruiz 2013b; Torrent Ruiz 2012; Maganzani 2014b; Maganzani 2014a; Maganzani 2012a, 103–119; Maganzani 2012d, 121–124; Maganzani 2012b, 171–185; Maganzani 2012e, 195–213; Mentxaka Elexpe 2009, 1–46.

10 But see Capogrossi's remarks in Capogrossi Colognesi 2012, 151–158 and Capogrossi Colognesi 2014.



Fig. 2 Channel built at least at the end of the 18th century, Val d'Ultimo near Merano.

Juris Civilis dealing with these easements,¹¹ but they have rarely connected this research to the archaeological and epigraphic findings on irrigation communities. Now that the knowledge on this topic has expanded, thanks to recent discoveries, it is my opinion that even indirect references to Justinian's sources become clearer and show that Roman jurists did not ignore the legal issues related to the community's use of water *ad irrigandos agros* at all. On the other hand, I think that these juridical texts can be better understood not only in the light of the inscriptions, but also with regard to the material remains available today that can help us better understand the problems discussed by the jurists in their concrete contexts.

This is the reason why in this paper I am going to study not only the most important epigraphic and literary texts on this subject, but also some jurisprudential sources

11 Gardini 2013; Vallocchia 2012, 17–33; Basile 2012; Möller 2010, 78–90; Tuccillo 2009; Fiorentini 2003,

51–197; Cursi 1999; Capogrossi Colognesi 1966. See also Bannon 2001, 34–52; Bannon 2009.

belonging to Justinian's Digest and in my opinion connected to the topic of irrigation communities.

2 Some epigraphic, literary, and juridical sources on irrigation communities in the Roman world

Epigraphic remains of Roman irrigation communities come from different parts of the Roman Empire, such as Spain, Africa, and Italy.¹²

The inscription of the Hadrian era, known as Agon bronze or *Lex rivi Hiberiensis*, is particularly significant (Fig. 3).¹³ It was discovered in 1993 in the town of Agon, about 50 km from Zaragoza, and since then it has been kept in the city's archaeological museum. It concerns an irrigation community that includes three villages located on the right bank of the Ebro River: the *pagi Gallorum* and *Segardenensis* belonging to the colony of *Caesaraugusta* (Zaragoza) and the *pagus Belsoninensis* belonging to the Latin *municipium Cascantum*. This inscription contains the regulation of the individual duties of the community members. They exploited a long artificial canal diverted from the river Ebro and obtained water for their farms through locks placed along the canal. That is why they had to provide for the periodic maintenance and cleaning of the canal and the locks. The *magistri pagi*, who used to hold this office for one year starting from the calends of June, were liable for the good administration of the *rivus*. For this purpose, they were authorized to impose fines and seize the *rivales* assets. Moreover, in the five days following their appointment, they had to convene an assembly to accomplish the annual operation of emptying and cleaning out the channel with the community members. If the landowners did not perform these works, the *magistri pagi* could delegate the local publicans to carry them out instead.

Another significant example is offered by the Lamasba Table,¹⁴ an inscription of the time of Elagabalus (AD 218–222) from Roman Africa.¹⁵ It is a regulation partially preserved on the table drawn up by an arbitration committee (of which a certain Valentinus

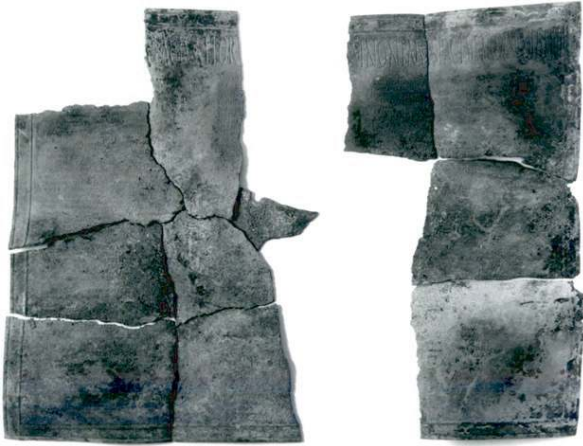
12 Maganzani 2014b, 225–231.

13 *Editio princeps*: Beltrán Lloris 2006; cfr. *L'année épigraphique* 1993, 1043; Beltrán Lloris 2006, 676; Beltrán Lloris 2010, 634. – See also Crawford and Beltrán Lloris 2013, 233; Maganzani and Buzzacchi 2014 (texts of Beltrán Lloris, Capogrossi Colognesi, Hermon, Lagóstena Barrios, Torrent, Platschek, Maganzani, Buzzacchi); Buzzacchi 2015, 49–66; Buzzacchi 2013; Tarpin 2014, 265–272; Torrent Ruiz 2013a; Torrent Ruiz 2013b; Torrent Ruiz 2012; Ronin 2012; Beltrán Lloris 2011; Nörr 2008, 108–187; Le Roux 2009, 19–44; Mentxaka Elexpe 2009, 1–46; Castillo

García 2009; Castillo García 2008; other bibliography in Maganzani 2012b, 184–185; Beltrán Lloris 2010, 33–34.

14 *Corpus inscriptionum Latinarum* VIII.4440e. 956; VIII.18587e. 1780–1782; *Ephemeris Epigraphica* V.1279; VII.788; *Inscriptiones Latinae selectae* 5793; Pachtere 1908, 373–405; Maganzani 2012e, 195–213.

15 Leone 2012; Maganzani 2012a, 103–119; Maganzani 2012e, 195–213; Ronin 2012; Debidour 2009; Meuret 1996; Trouset 1986; Shaw 1982; Shaw 1984; Pavis d'Escurac 1980.

Fig. 3 *Lex rivi Hiberiensis*.

is a member). The commission was established on the basis of a decree enacted by the *ordo decurionum* and the residents of Lamasba. The table shows the resolution of a conflict between members of the community regarding the distribution of the water that was coming from a perennial source or from an aqueduct (called *Aqua Claudiana*).

This is an arid region, with irregular precipitation that usually falls from October to April. These winter rains, however, could also be delayed until January, which would irreparably ruin the harvest. To avoid the catastrophic consequences of a possible winter drought, the farmers of Lamasba created a system of irrigation which would begin on September the 25th and perhaps end in late March. These rules, surely common to other agricultural areas, were probably passed down orally, at least in the arid parts of the empire. In this case, the regulation was written down as a result of a dispute that arose between community members.

The land to be irrigated was worked into *scalae*, i.e. terraces. The water had to be carried through small channels, which started from a larger horizontal channel, called *matrix*. This main channel ran along each terrace and was fed by a catchment basin or a tank, connected to the perennial source cited above, called *Aqua Claudiana*.

The available text, divided into columns, contains a list of the water recipients and indicates the name of each of them, the duration and the date of irrigation and the amount of the water attributed, expressed in K, a unit of uncertain meaning. On the basis of the number of K to which he was entitled, every owner would obtain the water for a specified period of time, measured in hours and half hours.

Speaking of Italy, I would like to mention in particular the so-called Priorate or Aventine Plan, belonging to the Augustan Age.¹⁶ It concerns a *distributio aquaria* for the

¹⁶ Corpus inscriptionum Latinarum VI.1261;

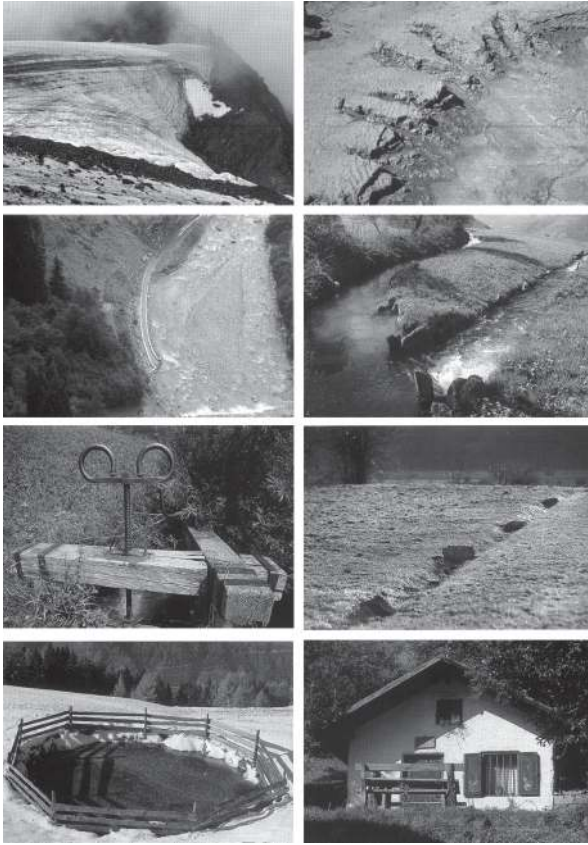


Fig. 4 An irrigation channel in Vinschgau from the beginning to the end: it starts from the mouth of the Glacier then proceeds with deviations and locks passing by both the catchment basins and the lodge of the person assigned to control the channel.

irrigation of an area of land in the vicinity of Rome. It is probably the deviation from a city aqueduct made through a channel with small bridges and tanks. The original text has gone missing. Here we see a reproduction of a work by Raphael Fabretti (1680), entitled *De aquis et aquaeductibus*. The plan shows two arms of a channel or an aqueduct on whose sides there are both the names of the water beneficiaries and the irrigation timetable.

The so-called Plan of Tivoli is very similar to the one just discussed and equally interesting.¹⁷ It is a marble table divided into two sections. Each part describes the irrigation system of land, whose owner is indicated by name: the *fundus Domitianus* belonging to a certain *M. Salluius* or *Saluius* and *Fundus Sosianus* belonging to a certain *Primus*.

VIII.4440.448; Maganzani 2012c; Rodríguez-Almeida 2002, 23–27.

VIII.4440.448; Maganzani 2012c; Rodríguez-Almeida 2002, 23–27.

17 *Corpus inscriptionum Latinarum* XIV.3676;

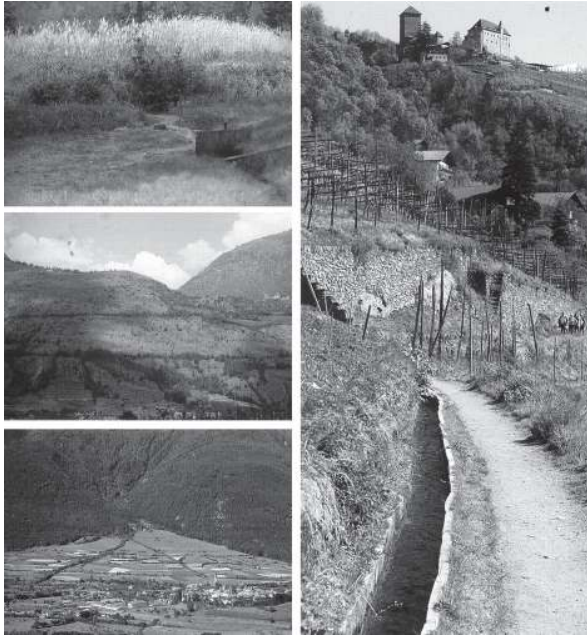


Fig. 5 One can see the water overflowing a wheat field. Then, the presence of irrigation channels is noticeable in the bushy landscape in the form of soft almost horizontal lines that finally reach the valley floor near the vineyards. Here, a service trail is clearly visible and it is also used as a comfortable biking trail.

Another example is the *Tabula aquaria* of *Amiternum* in L'Aquila.¹⁸ It is an inscription dating back to the first century BC that deals with the course of the local water. It shows the *castella*, i.e. the water reserves, and the distances between them indicated in feet. At the end of the text, there is the full extent of the path, 8670 feet, about 2564 meters. Inside the title, the first letters have gone missing: if the integration 'Purgatio' is correct it should refer to the works necessary to clear the path of the aqueduct.

The existence of irrigation communities in the Roman world is confirmed by other sources (both legal and literary). Frontinus speaks about the existence of a secondary channel of the *Aqua Iulia*, called *Aqua Crabra*, excavated by Agrippa in favor of the *Tusculani possessores*, and says: "It is the water that all villas in the area receive in turn, with a distribution according to shifts and established quantities."¹⁹ Cicero refers to the same *aqua Crabra*, stating also that there was an obligation to pay a vectigal to the city of *Tusculum* for this service.²⁰

Another example is offered by the Plinian description of the oasis of Tacape, corresponding to the modern Gabes (NH 18188–18189) that even today is irrigated by a

18 *Corpus inscriptionum Latinarum* I².1853; I² Add. III. 1049; Suppl. It. N.S. 9.50; Maganzani 2012d, 121–124; Segenni 2005, 603–618.

19 Frontin. *Aqu.* 9.5.

20 Cic. *Fam.* 16.18.3; *Leg. Agr.* 3.2.9.

source embedded in the rock: according to the author, this is a striking example of multiple cropping, as grain, legumes, and forage crops follow one after the other under date palms and shrubs all year long. The reason for the extraordinary fertility of the soil is precisely the abundance of water distributed to each of the inhabitants for a specified number of hours.

The final legal source to be mentioned here is a constitution of the emperors Marcus Aurelius and Lucius Verus, reported by jurist Papirius Iustus, that regulates the division of water for irrigation between neighboring owners.²¹ The water had to be apportioned according to the width of the land to be irrigated unless someone proved to have a greater right.

3 The ‘legal status’ of irrigation communities in the Roman world: preliminary clarification

It is interesting to think about what the ‘legal status’ of these communities might have been, that is, how they were structured and how internal relationships between *rivales* were considered. I think that it is possible to find some information about this in the texts of Justinian’s Digest. However, this survey requires some preliminary clarifications.

From a legal point of view, we must first distinguish between the derivation of water from a river or a public channel by the holder of a riparian plot of land and the conduction of water derived from the same river or canal in favor of one or several private terrains bordering the riparian one. Furthermore, in this second case, we must distinguish further between water that traverses public land and water that traverses on private land. In fact, the derivation of water from the river – which was usually carried out through the barrage of its course with so-called *saepta* and the creation of an *incile*, which is an inlet – was generally free. Ulpian, a jurist of the 2nd century AD, expressly says so in two texts of Justinian’s Digest.²² Only when a common citizen (*a quivis de populo*) asserted before the ‘praetor’ that the water derivation was detrimental to the public interest or that of the neighbors could the ‘praetor’ intervene, using his authority with the so-called ‘interdicta’ in order to prohibit or order something. For example, when it

21 Papirius Iustus D.8.3.17 (1 *De Const.*).

22 D.43.12.1.12 (Ulp. 68 ad ed.): *Non autem omne, quod in flumine publico ripave fit, coerces praetor, sed si quid fiat, quo deterior statio et navigatio fiat* (“The praetor does not absolutely prohibit any work being done in a public river, or on the bank of the same”, translation by L. M.); D.8.3.3.3 (Ulp. 17 ad ed.): *ad flumen autem publicum idem Neratius eodem libro scribit iter*

debere cedi, haustum non oportere et si quis tantum haustum cesserit, nihil eum agere (“In the case of a public stream Neratius states in the same book that the right of passage to it must be granted, but the right to draw the water is not necessary and where anyone grants only the right to draw water the grant will be void”, translation by L. M.). See Fiorentini 2003, 59–157.

was claimed that the derivation of the river prevented navigation and the use of public banks, or that it damaged neighbors by altering the course of the river making it dry, etc., the *praetor*, after a brief examination of the matter, could prohibit the derivation and order the removal of the respective works.²³

On the other hand, those who had a plot of land far from the river and wanted the water to reach their plot through a canal had two options, depending on whether the land on which the *rivus* was to be placed was public or private. In the first case, a public grant had to be claimed by asking the *princeps* – Paul says in D.8.1.14.2 (15ad Sab.): *ut per viam publicam aquam ducere sine incommodo publico liceat*, namely, “to conduct water across a highway in such a manner as to cause no inconvenience to the public.” In the second case, an easement of aqueduct (*servitus aquaeductus*) had to be constituted on the riparian plot of land starting from the so-called *caput aquae*.

If we try to relate this information to the concrete world described by the *Lex rivi Hiberiensis* and the other sources mentioned above, we can understand that the mechanism described above, while simple in theory, in practice often had to be integrated into complex systems. For example, in Agón, there was a big public irrigation channel deriving from the river Ebro, from where the water entered smaller private channels through locks. From here – as Capogrossi Colognesi recently argued²⁴ – the water had to be further distributed to the surrounding farms through a scheme of praedial servitudes; this could take place either through a single private channel connected to the perennial source (that was common to the various owners to whom it brought water) or through a channel from which the water flowed into a basin (*lacus*). From this basin, many other private channels set off to bring water to each landowner. While the *Lex rivi Hiberiensis* does not explicitly say this, both the legal texts and the many examples still present on the ground (in South Tyrol, Switzerland, Valencia, etc.) allow us to make this assumption (Figs. 4–5).

All of this means that public and private channels, public and private regulation, public grants to run water, and praedial servitudes probably coexisted within a single large community irrigation system (like the one of Agón).

Inscriptions – considering their purpose and their recipients – usually inform us about the public law aspects of irrigation communities; however, the texts of Roman jurists in particular deal with issues related to relationships between private individuals. In the next sections, I will make some references to these jurisprudential discussions.

23 See for example D.43.12.1*pr.*, 8, 12, 15, 19; D.43.13.1 *pr.*-1; Signorini 2014; Basile 2012; Möller 2010, 86–90; Fiorentini 2003, 159–275.

24 Capogrossi Colognesi 2012, 151–160; Capogrossi Colognesi 2014.

4 Legal relationships between rivaies

First of all, Roman jurists specify that it often happened that several neighboring owners in need of water obtained the right to conduct it from a perennial source located on the servant farm.²⁵

As we can see in the inscriptions (for example, in the *Lex rivi Hiberiensis*), community members usually reached an agreement about the cleaning and maintenance of artifacts, such as *fistulae* put in the channel, so that each individual had to carry out the maintenance and cleaning needed in his own section of the channel.

The Roman *praetor* also protected anyone who was prevented from repairing or cleaning an aqueduct, canal, or reservoir, with a specific interdict whose words are reported by the jurist Ulpian: *Praetor ait: rivos specus septa reficere purgare aquae ducendae causa quo minus liceat illi, dum ne aliter aquam ducat, quam uti priore aestate non vi non clam non precario a te duxit, vim fieri veto.*²⁶ This, as Ulpian says in *Dig.* 43.21.3.3 (70 *ad ed.*), was granted for the cleaning of a basin from which the water was conducted to several beneficiaries.²⁷

Through this common channel, each owner could use water at the same time or, if this was not enough, the use of water could be divided into days or hours – *diversis diebus et horis*²⁸ or by measurement (*mensuris*).²⁹

At this point, I am mainly interested in showing through some examples from Justinian's Digest: (a) how jurists qualify the legal relationships between the irrigation community members and the servant farm owner, (b) how Roman jurists consider relationships among the irrigation community members who at least partially use the same channel, and (c) if there was any special provision about private irrigation communities in the edict of the Roman Praetor.

(a) On the first issue, a useful indication can be drawn from a text of Proculus, a jurist of the Augustan Era. The following describes the case:

25 Arg. ex D.8.3.35 (Paul. 15 *ad Plaut.*).

26 Ulp. *Dig.* 43.21.1 *pr.* (70 *ad ed.*). "I forbid force to be employed against anyone to prevent him from repairing or cleaning any aqueduct, canal, or reservoir, which he has a right to use for the purpose of conducting water, provided he does not conduct it otherwise than he has done during the preceding summer without the employment of violence, or clandestinely or under a precarious title" (translation by L. M.).

27 Masuelli 2009, 149–183.

28 D.8.3.2.1–2 (IV reg.): 1. *Aquae ductus et haustus aquae per eundem locum ut ducatur, etiam pluribus concedi potest: potest etiam, ut diversis diebus vel horis ducatur.* 2.

Si aquae ductus vel haustus aquae sufficiens est, potest et pluribus per eundem locum concedi, ut et isdem diebus vel horis ducatur ("1. The right to conduct or draw water over the same place can also be granted to several persons; and this can be done on different days, or at different hours. 2. Where the water-course or the supply of water to be drawn is sufficient, the right may be granted to several people to conduct the water over the same place, on the same days, or during the same hours"; translation by L. M.).

29 Ronin 2015; Ronin 2012, 219–242; Cursi 2014, 55–57; Zuccotti 2004; Zuccotti 1994; Fiorentini 2003, 140–140; Cursi 1999, 157–202.

*Aquam quae oriebatur in fundo vicini, plures per eundem rivum iure ducere soliti sunt, ita ut suo quisque die a capite duceret, primo per eundem rivum eumque communem, deinde ut quisque inferior erat, suo quisque proprio rivo.*³⁰

Therefore, an irrigation community was organized with a first channel of common property, followed by a series of minor channels belonging to individual landowners placed on their respective farms. This was probably a very common situation, and perhaps it took place in Agón as well. The jurist continues, *Unus statuto tempore, quo servitus amittitur, non duxit.*³¹ This raises the problem of whether the other *rivales* acquired the right that he had lost, namely, if they were entitled to receive water on the days and times allocated to him or whether that right was lost for all *rivales* and the water intended for him ‘returned’ to the servant farm holder. Proculus provides this answer: *Existimo eum ius ducendae aquae amisisse nec per ceteros qui duxerunt eius ius usurpatum esse: proprium enim cuiusque eorum ius fuit neque per alium usurpari potuit.*³²

The jurist continues, *Si plurium fundo iter aquae debitum esset.*³³ He says, *per unum eorum omnibus his, inter quos is fundus communis fuisset, usurpari potuisset.*³⁴

In the case examined, however, there is a common channel used by several landowners: therefore, several different water easements. The jurist repeats:

*Item si quis eorum, quibus aquae ductus servitus debebatur et per eundem rivum aquam ducebant, ius aquae ducendae non ducendo eam amisit, nihil iuris eo nomine ceteris, qui rivo utebantur, adcrevit idque commodum eius est, per cuius fundum id iter aquae, quod non utendo pro parte unius amissum est: libertate enim huius partis servitutis fruitur.*³⁵

Then, on the basis of this text, we can state that in a private irrigation community each member had his own water servitude, even if the water channel was totally or partially

30 Proculus D.8.6.16 (1 epist.). “A number of men were accustomed, as of right, to channel water, which had its source on a neighbor’s estate, along the same watercourse. The arrangement was that each man, on his appointed day, channelled the water from its source, first of all along the afore said watercourse, which they used in common, and then, according to the distance of his land from the head of the course, along a channel of his own” (translation by L. M.).

31 “In this context one of the men failed to channel any water throughout the prescribed period, the lapse of which results in the loss of a servitude” (translation by L. M.).

32 “My opinion is that the rivalis has lost his right to channel water and the other *rivales* cannot encroach on it. The fact is that the right belongs to each one

of them as his own and neither of the *rivales* can encroach on it” (translation by L. M.).

33 “It would have been different if the right to the watercourse had been attached to an estate owned by several men” (translation by L. M.).

34 “In this case the servitude would have been the same for all co-owners and the portion of water not used by one of them could have been taken by the others” (translation by L. M.).

35 “Here if one member of the private irrigation community loses his right by failure of exploiting it, no right will accrue to the others; instead, the benefit of the right lost by a non-user will belong to the landowner from whose farm water comes: the landowner will enjoy freedom from this part of the servitude” (translation by L. M.).

common. This means that each servitude holder was protected by the *praetor* against anyone who prevented him from conducting water. This protection was offered by an interdict (D. 43. 20) and on the other hand by a civil action called *vindicatio servitutis*. At the request of a servitude holder, the *praetor* could promulgate an interdict by which he administratively and urgently prevented a third party from exercising the servitude, and in the case of a dispute between two *rivales*, Ulpian adds that the *praetor* would give a mutual interdict.³⁶ This means each *rivalis* could ask for the protection offered by the *praetor* against each other. The action, however, was later brought by the servitude holder to affirm the existence of his right and to condemn those who had hampered the exercise of the servitude to pay damages.

(b) The second problem concerns the legal classification of the relationships among *rivales*. One particular jurisprudential text can provide some information on this matter. This is a text of Julianus, a jurist of Hadrian's age, who presents the following case:

*Tria praedia continua trium dominorum adiecta erant: imi praedii dominus ex summo fundo imo fundo servitutem aquae quaesierat et per medium fundum domino concedente in suum agrum ducebat.*³⁷

I would like to draw attention to the Latin expression *domino concedente*, translated into English with the words, "with the consent of its owner". The jurist continues:

*Postea idem summum fundum emit: deinde imum fundum, in quem aquam induxerat, vendidit. quaesitum est 'numimus fundus id ius aquae amisisset, quia, cum utraque praedia eiusdem domini facta essent, ipsa sibi servire non potuissent.'*³⁸

And this was the answer:

[...] *negavit amisisse servitutem, quia praedium, per quod aqua ducebatur, alterius fuisset et quemadmodum servitus summo fundo, ut in imum fundum aqua veniret, imponi aliter non potuisset, quam ut per medium quoque fundum duceretur, sic eadem servitus eiusdem fundi amitti aliter non posset, nisi eodem tempore etiam per medium fundum aqua duci desisset aut omnium tria simul praedia unius domini facta essent.*³⁹

36 Ulp. Dig. 43.20.1.26 (70 ad ed.).

37 Julianus D.8.3.31 (Iul. II ex Minic.). "Three estates which were the property of three owners respectively were situated next to one another. The owner of the lowest estate acquired a servitude giving the right to take water for it from the highest estate and, with the consent of its owner, he channelled water across the middle estate to his own land" (translation by L. M.).

38 "Later the owner of the lowest land purchased the

highest estate and then he sold the lowest estate on which he had channelled the water. The question asked is: had the lowest estate lost its right to take water? In fact, as each of the two estates had become the property of the same man, there could be no servitude between two such estates" (translation by L. M.).

39 "[...] It was held that the servitude was not lost, because the intervening estate, through which the

From this text, therefore, we can draw the solution adopted by the jurist – or at least by Pomponius and his predecessor Minicius whose work the former comments upon – about relationships among *rivales*. Each *rivalis* constituted a separate easement on the farm where the perennial source of water was located (river, public channel, etc.): in fact, it was possible to constitute an easement of aqueduct only from a *caput aquae*.⁴⁰ Instead, the owner of the lower estate could let the water flow on the lands above through a common channel only after reaching an agreement with the owners of the land above, which probably had the form of a *pactio* or *stipulatio*.

(c) Finally, I consider if there was any special provision about private irrigation communities in the edict of the Roman Praetor.

I would like to point out that in the edict of the Roman Praetor, there was a title called *De aqua et aquae pluviae arcendae*. We learn about it through the commentaries of the Roman jurists on the praetor's edict reported in the Digest. This title was split into two parts, the first generically concerning *aqua*, the second regarding *actio aquae pluviae arcendae*. The content of this second part is well known and has been extensively studied: it deals with an action that can be brought by a landowner against a neighboring landowner when the first suffers or is afraid of suffering a damage to his farm caused by rain, due to a new construction or a new work carried out by the neighbor that changes the state of the area. However, it has never been very clear what the part of the title *De aqua* was specifically referring to. Otto Lenel, who reconstructed the content of the Perpetual Edict (last edition Leipzig, 1927), considered that this part of the title was referring to the servitude of water dealt with in this section, close to *actio aquae pluviae arcendae*, because of the common theme represented by water. However, some texts concerning *servitutes aquarum* are also found in the titles of the Edict expressly dedicated to servitudes.

Both the reading of the epigraphic texts on irrigation communities and the existence on the ground of the material remains of these communities, lead me to believe that in this part of the title the *praetor* (and the commentaries of the jurists) would not deal with water servitudes as such – a theme already dealt with in the proper title – but would address those situations in which water servitudes had been set up between various members of an irrigation community. The texts, as we shall see, seem to confirm this. They also allow us to believe that proper water servitudes were created between the members of the community, considering that those members used a *rivus* in common.

water was channelled, belonged to someone else, just as a servitude giving the right to channel water to the lowest estate could only be imposed on the highest estate if the water was also channelled over the intervening estate, so the same servitude, once attached to the lowest estate, could only be lost if,

at the same time, the water ceased to be channelled over the intervening estate as well or if all three of the estates became the property of the one owner" (translation by L. M.).

⁴⁰ See e.g. D.8.3.36 (Paul. II *resp.*); D.8.4.7 (Paul. V *ad Sab.*).

Essentially, the first part of the title would deal with the problem of water administration between several individuals; the second would concern itself with any damage caused by the water itself to one of the neighbors, in the case of a new work carried out by one of them.

The problems discussed by jurists in this context are various: for example, one wonders if it is possible to derive water from a public river to the advantage of more than one person. Ulpian, in D.39.3.10.2, citing Labeo, says that, if a river is navigable, the *praetor* must not let any water run from it that may make it less navigable, and the same goes if another navigable river arises from the water run.

From this, we can draw the conclusion that the establishment of a water servitude from a public river, also in favor of more people together in community, used to require a prior authorization of the *praetor*, who had to make sure that the change would not bring harm to the public.

Regarding the relationships between community members, it is frequently emphasized that, whenever an irrigation community wants to receive a new member, it is essential that all members agree because – as Ulpian writes in D.39.3.8 – when the right of the members is decreased, it is essential to investigate whether they agree to such a decrease.

I could say more about these and other rules, and this matter is certainly worthy of further investigation, which I hope to carry out in the future. For the moment, however, I hope I have succeeded in highlighting once again how inter-disciplinary research can be of great help to ancient world studies.

Bibliography

Bannon 2001

Cynthia Jordan Bannon. "Servitudes for Water Use in the Roman Suburbium". *Historia* 50 (2001), 34–52.

Bannon 2009

Cynthia Jordan Bannon. *Gardens and Neighbors. Private Water Rights in Roman Italy*. Ann Arbor, MI: University of Michigan Press, 2009.

Basile 2012

Raffaele Basile. *Usus servitutis e tutela interdittale*. Padova: CEDAM, 2012.

Bédoucha 2009

Geneviève Bédoucha. "Irrigazione". In *Dizionario di antropologia e etnologia*. Torino: Einaudi, 2009, 476–478.

Beltrán Lloris 2006

Francisco Beltrán Lloris. "An Irrigation Decree from Roman Spain: The Lex Rivi Hiberiensis". *Journal of Roman Studies* XCVI (2006), 147–197.

Beltrán Lloris 2010

Francisco Beltrán Lloris. "El agua y las relaciones intercomunitarias en la Tarraconense". In *Aquam perducendam curavit: captacion, uso y administracion del agua en las ciudades de la Betica y el Occidente romano*. Cádiz: Universitè de Cádiz, 2010, 21–40.

Beltrán Lloris 2011

Francisco Beltrán Lloris. "El regadío en la Hispania Romana, Estado de la cuestión". *Cuadernos de Pre-historia y aequología de la Universidad de Granada* 21 (2011), 9–56.

Bernigaud et al. 2014

Nicolas Bernigaud, Jean-François Berger, Laurent Bouby, Claire Delhon, and Catherine Latour-Argant. "Ancient Canals in the Valley of Bourgoin-La Verpillière (France, Isère): Morphological and Geoarchaeological Studies of Irrigation Systems from the Iron Age to the Early Middle Ages (8th Century BC–6th Century AD)". *Water History* 6 (2014), 73–93.

Bodini 2002

Gianni Bodini. *Antichi sistemi di irrigazione nell'arco alpino. Ru, Bisse, Suonen, Waale*. Quaderni di cultura alpina. Ivrea: Priuli & Verlucca, 2002.

Buzzacchi 2013

Chiara Buzzacchi. *Lex Rivi Hiberiensis. Per un'indagine sul processo civile nelle province*. Vol. 6. Minima Epigraphica et Papyrologica Separata. Rome: L'Erma di Bretschneider, 2013.

Buzzacchi 2015

Chiara Buzzacchi. "Pagi, governatori e giudici nell'Occidente di Roma in età classica: un esempio dall'epoca classica". In *Ravenna Capitale. Giudizi, giudici e norme processuali in Occidente nei secoli IV–VIII*. Santarcangelo di Romagna: Maggioli, 2015, 49–66.

Buzzacchi and Maganzani 2014

Chiara Buzzacchi and Lauretta Maganzani. "La lex rivi Hiberiensis: domande allo storico del processo romano". In *Lex rivi Hiberiensis. Diritto e tecnica in una comunità di irrigazione della Spagna romana*. Naples: Jovene, 2014, 93–119.

Capogrossi Colognesi 1966

Luigi Capogrossi Colognesi. *Ricerche sulla struttura delle servitù d'acqua in diritto romano*. Milan: Giuffrè, 1966.

Capogrossi Colognesi 2012

Luigi Capogrossi Colognesi. "D.8.4.2, e le deduzioni d'acque pubbliche e private". In *Hommes, cultures et paysages de l'Antiquité à la période moderne. Mélanges offerts à Jean Peyras*. Rennes: Presses Universitaires de Rennes, 2012, 151–160.

Capogrossi Colognesi 2014

Luigi Capogrossi Colognesi. "La lex rivi Hiberiensis e gli schemi delle servitù d'acqua in diritto romano". In *Lex rivi Hiberiensis. Diritto e tecnica in una comunità di irrigazione della Spagna romana*. Naples: Jovene, 2014, 75–91.

Castillo García 2008

Carmen Castillo García. “La tabula rivi Hiberien-sis: carácter del documento”. *Espacio, tiempo y forma. Historia Antigua XXI* (2008), 255–257.

Castillo García 2009

Carmen Castillo García. “Documentos de re-gadío en el valle del Ebro: ¿Figuraba la vascona Cascantum en el Bronce de Agón?” In *Los vas-cones de las fuentes antiguas. En torno a una etnia de la Antigüedad peninsular*. Ed. by J. A. Pintado. Barcelona: Publicacions i Edicions Universitat de Barcelona, 2009, 415–421.

Crawford and Beltrán Lloris 2013

Michael Hewson Crawford and Francisco Beltrán Lloris. “The Lex rivi Hiberiensis”. *The Journal of Roman Studies* 103 (2013), 233.

Cursi 1999

Maria Floriana Cursi. *Modus servitutis. Il ruolo dell'autonomia privata nella costituzione del sistema tipico delle servitù prediali*. Naples: Jovene, 1999.

Cursi 2014

Maria Floriana Cursi. “Modus servitutis: Aus-maß, Funktion und Typizität der Servituten”. In *In den Gefilden der römischen Feldmesser. Juristische, wissenschaftsgeschichtliche, historische und sprach-liche Aspekte*. Ed. by C. Möller and E. Knobloch. Berlin Studies of the Ancient World 13. Berlin: De Gruyter, 2014, 49–64.

Debidour 2009

Michel Debidour. “Le problème de l'eau dans une cité de Numidie: l'inscription hydraulique de ‘Lamasba’”. In *Urbanisme et urbanisation en Numidie militaire: actes du colloque des 7 et 8 mars 2008*. Ed. by A. Gros Lambert. Paris: De Boccard, 2009, 153–180.

Fiorentini 2003

Mario Fiorentini. *Fiumi e mari nell'esperienza giuridica romana. Profili di tutela processuale e di in-quadramento sistematico*. Milan: Giuffrè, 2003.

Gardini 2013

Marco Gardini. *Il regime giuridico delle servitù*. Parma: Campus, 2013.

Le Roux 2009

Patrick Le Roux. “Le pagus dans la Péninsule Ibérique”. *Chiron* 39 (2009), 19–44.

Leone 2012

Anna Leone. “Water Management in Late Antique North Africa: Agricultural Irrigation”. *Water History* 4 (2012), 119–133.

Maganzani 2012a

Lauretta Maganzani. “Le comunità di irrigazione nel mondo romano: appunti sulla documen-tazione epigrafica, giuridica, letteraria”. In *Revisione ed integrazione dei Fontes Iuris Romani Anteustiniani (FIRA), Studi preparatori I, Leges*. Ed. by G. Purpura. Torino: Giappichelli, 2012, 103–119.

Maganzani 2012b

Lauretta Maganzani. “Lex rivi Hiberiensis”. In *Revisione ed integrazione dei Fontes Iuris Romani Anteustiniani (FIRA), Studi preparatori I, Leges*. Ed. by G. Purpura. Torino: Giappichelli, 2012, 171–185.

Maganzani 2012c

Lauretta Maganzani. “Pianta del Priorato o dell'Aventino e Pianta di Tivoli”. In *Revisione ed integrazione dei Fontes Iuris Romani Anteustiniani (FIRA), Studi preparatori I, Leges*. Ed. by G. Purpura. Torino: Giappichelli, 2012, 153–157.

Maganzani 2012d

Lauretta Maganzani. “Tabula aquaria di Amiter-num”. In *Revisione ed integrazione dei Fontes Iuris Romani Anteustiniani (FIRA), Studi preparatori I, Leges*. Ed. by G. Purpura. Torino: Giappichelli, 2012, 121–124.

Maganzani 2012e

Lauretta Maganzani. “Tabula di Lamasba”. In *Revisione ed integrazione dei Fontes Iuris Romani Anteustiniani (FIRA), Studi preparatori I, Leges*. Ed. by G. Purpura. Torino: Giappichelli, 2012, 195–213.

Maganzani 2014a

Lauretta Maganzani. “La formula con intentio in-certa della lex rivi Hiberiensis (§ 15 III.39–43)”. In *Lex rivi hiberiensis. Diritto e tecnica in una comunità di irrigazione della Spagna romana*. Ed. by L. Magan-zani and C. Buzzacchi. Naples: Jovene, 2014, 181–222.

Maganzani 2014b

Lauretta Maganzani. "Le règlement des riparia dans les communautés d'irrigation de l'empire romain". In *Riparia, un patrimoine culturel. La gestion intégrée des bords de l'eau. Proceedings of the Sudbury Workshop, April 12–14, 2012. Actes de l'atelier Savoirs et pratiques de gestion intégrée des bords de l'eau – Riparia, Sudbury, 12–14 avril 2012*. Ed. by E. Hermon and A. Watelet. Oxford: British Archaeological Reports, 2014, 225–231.

Maganzani and Buzzacchi 2014

Lauretta Maganzani and Chiara Buzzacchi. *Lex rivi Hiberiensis. Diritto e tecnica in una comunità di irrigazione della Spagna romana*. Ed. by L. Maganzani and Ch. Buzzacchi. Naples: Jovene, 2014.

Masuelli 2009

Saverio Masuelli. *La refectio nelle servitù prediali*. Naples: Jovene, 2009.

Mentxaka Elepe 2009

Rosa María Mentxaka Elepe. "Lex rivi Hiberiensis, derecho de asociación y gobernador provincial". *Ridrom* (2009), 1–46.

Meuret 1996

Christophe Meuret. "Règlement de Lamasba: des tables de conversion appliquées à l'irrigation". *Antiquités Africaines* 32 (1996), 87–112.

Möller 2010

Cosima Möller. *Die Servituten. Entwicklungsgeschichte, Funktion und Struktur der grundstückvermittelten Privatrechtsverhältnisse im römischen Recht. Mit einem Ausblick auf die Rezeptionsgeschichte und das BGB*. Göttingen: Wallstein, 2010.

Nörr 2008

Dieter Nörr. "Prozessuales (und mehr) in der lex rivi Hiberiensis". *Zeitschrift der Savigny-Stiftung für Rechtsgeschichte* 125 (2008), 108–187.

Oleson 2000

John Peter Oleson. "Water-Lifting". In *Handbook of Ancient Water Technology*. Ed. by Ö. Wikander. Leiden: Brill, 2000, 217–302.

Pachtère 1908

Félix-Georges de Pachtère. "Le règlement d'irrigation de Lamasba". *Mélanges de l'École française de Rome* 28 (1908), 373–405.

Pavis d'Escurac 1980

Henriette Pavis d'Escurac. "Irrigation et vie paysanne dans l'Afrique du Nord Antique". *Ktema* 5 (1980), 181–191.

Platschek 2014

Johannes Platschek. "Iusiurandum und vadi-monium in der lex rivi Hiberiensis". In *Lex rivi hiberiensis. Diritto e tecnica in una comunità di irrigazione della Spagna romana*. Ed. by L. Maganzani and C. Buzzacchi. Naples: Jovene, 2014, 121–144.

Rodríguez-Almeida 2002

Emilio Rodríguez-Almeida. *Formae urbis antiquae. Le mappe marmoree di Roma tra la repubblica e Settimio Severo*. Rome: École Française de Rome, 2002.

Ronin 2012

Marguerite Ronin. "Partage de l'eau et pouvoir de décision dans l'Occident romain". In *Hommes, cultures et paysages de l'Antiquité à la période moderne. Mélanges offerts à Jean Peyras*. Rennes: Presses Universitaires de Rennes, 2012, 219–242.

Ronin 2015

Marguerite Ronin. *La gestion commune de l'eau dans le droit romain. L'exemple de l'Afrique romaine et de l'Hispanie (Ier siècle avant–V siècle après J.-Chr.)*. PhD thesis. École doctorale Sociétés, Cultures, Echanges (SCE) (Angers), Nantes, 2015.

Segenni 2005

Simonetta Segenni. "Frontino, gli archivi della cura aquarum e l'acquedotto tardo repubblicano di Amiternum (Corpus inscriptionum Latinarum, I2 1853 = ILLRP 487)". *Athenaeum* 93 (2005), 603–618.

Shaw 1982

Brent Shaw. "Lamasba: An Ancient Irrigation Community". *Antiquités Africaines* 18 (1982), 61–103.

Shaw 1984

Brent Shaw. "Water and Society in the Ancient Maghrib: Technology, Property and Development". *Antiquités Africaines* 20 (1984), 121–173.

Signorini 2014

Roberto Signorini. "Riflessioni sulla tutela inter-dittale dei flumina publica (D. 43,13 Ulp. 68 ad edictum)". *Jus LXI* (2014), 309–332.

Tarpin 2014

Michel Tarpin. “La ‘lex rivi Hiberiensis’: une restitution graphique de l’incipit”. *Zeitschrift für Papyrologie und Epigraphik* 192 (2014), 265–272.

Torrent Ruiz 2012

Armando José Torrent Ruiz. “Las acciones populares en la lex rivi Hiberiensis”. *Ridrom* IX (2012), 104–172.

Torrent Ruiz 2013a

Armando José Torrent Ruiz. “‘Lex rivi Hiberiensis’: desde el proceso formulario a la ‘cognitio extra ordinem’”. *Index. Quaderni camerti di studi romanistici* 41 (2013), 437–454.

Torrent Ruiz 2013b

Armando José Torrent Ruiz. “Los publicani en la lex rivi Hiberiensis”. *Rivista di Diritto romano* XIII (2013), 1–10.

Torrent Ruiz 2014

Armando José Torrent Ruiz. “¿Estaban previstas acciones populares en la ‘lex rivi Hiberiensis’?” In *Lex rivi Hiberiensis. Diritto e tecnica in una comunità di irrigazione della Spagna romana*. Ed. by L. Maganzani and C. Buzzacchi. Naples: Jovene, 2014, 145–180.

Trousset 1986

Pol Trousset. “Les oasis présahariennes dans l’antiquité: partage de l’eau et division du temps”. *Antiquités Africaines* 22 (1986), 163–193.

Tuccillo 2009

Fabiana Tuccillo. *Studi su costituzione ed estinzione delle servitù prediali nel diritto romano. Usus, scientia, patientia*. Naples: Satura, 2009.

Vallocchia 2012

Franco Vallocchia. *Studi sugli acquedotti pubblici romani I. La struttura giuridica*. Naples: Jovene, 2012.

Zuccotti 1994

Ferdinando Zuccotti. “La tutela interdittale degli ‘intervalla dierum et horarum’ previsti per l’esercizio dello ‘ius aquae ducendae’”. In *Diritto e processo nell’esperienza romana. Atti del seminario torinese in memoria di Giuseppe Provera, 4–5 dicembre 1991*. Naples: Jovene, 1994, 303–480.

Zuccotti 2004

Ferdinando Zuccotti. “Vivagni IV. Ancora sul ‘modus servitutis’: Tutti i colori di Gaio”. *Rivista di Diritto romano* IV (2004), 1–70.

Illustration credits

1 Bodini 2002, n. 9. 2 Bodini 2002, n. 10.
3 Beltrán Lloris 2006, n. 1. 4 Bodini 2002,

27.1–8. 5 Bodini 2002, 27.9–12.

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Sharing Water in the Roman Countryside: Environmental Issues, Economic Interests, and Legal Solutions

Summary

This paper seeks to provide lines of approach and hypotheses for a historical and geographic contextualisation of the jurisprudential texts of the Digest. It focuses upon the matter of water sharing in rural landscapes. After examining different landscapes, it argues that legal solutions proposed by Roman jurists originally applied to the situation of competition for natural resources observed in the periphery of Rome and were linked with the development of the city between the 3rd and 2nd centuries BC.

Keywords: Roman law; water management; land property; ancient countryside; urban periphery; food production

Dieser Beitrag versucht Herangehensweisen und Hypothesen zur historischen und geographischen Einordnung der rechtswissenschaftlichen Texte der Digesten vorzuschlagen. Der Fokus liegt dabei auf der Verteilung von Wasser in ländlichen Gebieten. Zunächst werden verschiedene Gebiete untersucht, um dann zu argumentieren, dass die rechtlichen Lösungen, die von den römischen Rechtsgelehrten vorgeschlagen wurden, sich ursprünglich auf die Konkurrenz um natürliche Ressourcen in der Umgebung von Rom bezogen und mit der Entwicklung der Stadt zwischen dem 3. und 2. Jh. v. Chr. in Verbindung standen.

Keywords: römisches Recht; Wasserverwaltung; Landbesitz; antike Landschaft; Stadtumgebung; Nahrungsmittelproduktion

I Introduction

The matter of water sharing is discussed in many different documents from the Roman world. Author Frontinus, in charge of the aqueducts of Rome at the turn of the 1st century AD, provides information about diversions from the public water network. The possibility of obtaining a concession is also confirmed for provincial cities.¹ Prominent texts (i.e. the *Table of Lamasba* and the *LRH*) deal with the specific subject of what has been called “communities of irrigation”² and for which easy parallels may be found in modern time Spanish rural communities,³ or African and Middle East oases.⁴ This paper focuses on the question of water sharing in the texts of the Roman jurisprudence compiled in the Digest. From these documents, we draw most of our knowledge of the rights that regulated a multiplicity of uses of water in the Roman countryside, especially the practice of sharing water between private landholders.

To begin with, I will present the main regulations and their evolution, and try to show that this topic is prevalent in legal texts. Their inclusion shows how concerned the jurists were with this matter and, therefore, also the people asking for their juridical advice. My aim will not be to explain how the water was shared due to the Roman jurisprudence: Roman legal texts have been thoroughly studied by jurists.⁵ Historical questions, however, necessarily lying at the base of the legal resolutions, need to be asked. I will, therefore, present some of the legal elements to try to answer the questions that underpin this need for legal solutions: where was it necessary to share water, and for which purposes? In response to these questions, I will propose some hypotheses and avenues of research, for which I will concentrate on the period of great changes that occurred in the Roman world between the 2nd century BC and the end of the 1st century AD, when most of the rules were actually enacted.

2 A real concern for water sharing in legal texts

One of the most noteworthy products of the Roman law is servitude or easement: by giving some rights to the holder of a dominant estate over a servient estate, the Roman jurists created an effective legal system to regulate the legal relationships between neighbors. In this case, it applies to the management of water. Typically, a water servitude will

1 See for instance in Thyssdrus (Africa Proconsularis) *Inscriptiones Latinae selectae* 5777 = *Corpus inscriptionum Latinarum* VIII 51.

2 Shaw 1982; Beltrán Lloris 2006.

3 Ribero 1989.

4 Troussel 1986; Bédoucha-Albergoni 1976.

5 Möller 2010; Franciosi 1967; Capogrossi Colognesi 1966; Capogrossi Colognesi 1976.

allow a landholder to access hydraulic resources he needs even if situated on the property of his neighbor. Upon this general pattern, various solutions were issued in order to answer the diversity of situations needing a settlement. The Digest mentions a right to conduct the water from one parcel of land to another, thanks to ditches or canals (*ius aquae ductus*) (a solution for which spring water was originally favored), a right to enter the property of a neighbor to draw water from his well or waterway (*ius aquae haustus*), and a right to cross someone else's estate with cattle in order to water the animals (*ius pecoris ad aquam appelandi*).⁶ Establishing such a right was not free. Although we do not know many details, it was sold and, therefore, had a price that was probably negotiated on the basis of the needs of the dominant estate and the capacity of the servient one. Once established, a water servitude clearly added to the price of the estate benefiting from it.

Our matter represents the actual subject of two titles (43.21 *De Rivis*; 43.22 *De fonte*) and a large part of two others (8.1 *De servitutibus*; 8.3 *De servitutibus praediorum rusticorum*), which is significant. It also emphasizes that there are many variations that may apply to one single right. If we take only the right to conduct water (*ius aquae ductus*), we learn from the texts that it can be split between different neighbors and that it can be scheduled according to the season (*de aqua cottidiana et aestiva*), to a night and day shift, or to hours. Some fragments also provide indications concerning the canal itself: where it may be dug, the material that must be employed, and the possibility for the holder of the dominant estate to mend or restore it. Finally, the conditions for acquiring or losing a servitude are described precisely.

The system originates as early as the time of the XII Tables (middle of the 5th century BC) with the *ius aquae ductus*, at the same time the *actio aquae pluviae arcendae* was probably introduced to minimize the damaging action of run-off water. The *ius aquae haustus* and the *ius adpulsus pecoris*, on the other hand, seem to have been elaborated later: around the 3rd and 2nd centuries BC.⁷ This development indicates that, although access to water constituted a very early concern in Roman central Italy, more solutions were progressively elaborated to adapt to new situations as the Empire grew, and in a context of increasing competition, new natural environments, different estate layouts, and modes of production had to be taken into account.

Without having to go as far as the African pre-desert or semi-arid regions of Spain, central Italy, for which we have numerous useful documents, presents a variety of agricultural exploitations, soils, and types of cultivations. My aim will now be to try to understand more precisely what plots of land and what type of estates the legal solutions produced by Roman jurists applied to. In other words, what kind of estates would need extra supplies of water from the neighboring plot?

6 Möller 2010, 78.

7 Möller 2010, 78; Möller 2016, 16.

3 Landed property and the necessity to share water

Most importantly, it is helpful to determine, even if only theoretically, some features of the localities and situations in which sharing water could become a necessity. It could happen in a natural environment somewhat deprived of plentiful supplies, but if the supplies are not that scarce, it mostly depends on the size of the plots. Columella (1st century AD) famously talked about an estate that he considered of a reasonable size, but must in fact have been as large as several thousand hectares, a *latifundium*, presumably provided with water sources, maybe small waterways or at least good run-off water catchments.⁸ Such an estate would need no extra supply of water. We must, therefore, think that solutions for water sharing chiefly relate to much smaller plots, likely to need water from the neighbors. The last criterion that has to be considered is the type of cultivation. Different sorts of cereals, fruit-trees, vegetables, and fodder do not all require the same quantity of water. Depending on what is cultivated on the parcel of land, water needs, and therefore competition, would vary.

The land property in Italy, during the period considered, does not present much homogeneity. Without making a detailed typology, I will just make some remarks concerning our issue. From the beginning of the Republic to around the end of the 3rd century BC, modest plots, cultivated by households for subsistence purposes, seem to have been the typical property in central Italy. Columella and Pliny mention a typical 7 *jugera* (~2 ha) property for that period. To make up for the very small properties, it was probably possible to use communal meadows.⁹ Aristocratic estates were of course, even at that period, much larger. Cato provides examples of 100 *jugera* (~25 ha) agricultural exploitation.¹⁰ This type of somewhat modest property still existed in the following period, the end of the Republic, even with the Roman expansion on the peninsula. Plots of 10 to 30 *jugerae* (2.5 to 7.5 ha) were distributed to *coloni* since the Gracchi (end of the 2nd century BC), and plots of 50 to 140 *jugerae* (12.5 to 35 ha) in Aquileia, Po Valley, were distributed in 181 BC, according to Livy.¹¹

The properties described, faced the emergence of very large estates belonging to wealthy aristocrats and called *latifundia* in the middle period of the Republic. Undoubtedly, this is what Columella refers to, even mentioning that some people owned even larger pieces of land. I already expressed doubts concerning the need to share water for such properties. However, it seems useful to underline some possible features. First, we

8 Columella. *Rust.* 1–3. The author gives the indication that the estate could be toured by a horse but fails to indicate how long this tour could have taken. It is, therefore, almost impossible to figure out the exact size of such a property, in spite of

many attempts; see Martin 1971.

9 Nicolet 2007, 103.

10 Cat. *Rur.* 1.7.

11 Liv. XXXIX.55.

know that the total property of a senator or of an *eques* could be split across various regions of the Mediterranean basin. Pliny reminds us that it is clever to take advantage of different soils and natural environments. Secondly, a solution much favored by wealthy landowners was to keep their estates in smaller and more manageable units.¹² One example of this was provided with the thirteen villas of the rich Sextius Roscius in the Tiber Valley in Umbria at the beginning of the 1st century BC provided by Cicero.¹³ At the end of the 1st century AD, Pliny also provides valuable information on the subject; acquiring an estate adjacent to one of his villas, he apparently did not join the two holdings.¹⁴ There is no reason why the case of Pliny should be isolated; a fragment of the Digest shows that the jurist Sabinus (1st century AD) thought about the consequences of this sort of transactions concerning water resources.¹⁵ Regardless of a change of ownership, a servitude remains attached to the original property, even if the servient and the dominant estates are at some point owned by the same person. It means that even a landlord like Pliny, head of a *latifundium*, but whose vast property was composed of a multitude of modest and separate units would, therefore, always need water servitudes in order to obtain the necessary water supplies.

The last aspect to be considered, is linked to the exceptional development of the urban markets, around the 2nd century BC. In the close vicinity of substantial cities and preferentially along the channels of distribution and communication (i.e. roads and rivers), small and valuable plots are cultivated. Although one cannot completely rule out the possibility that cereals were also cultivated in those areas, it is more likely that fresh goods, necessitating intensive cultivation were preferred, the profit expected from these being much bigger.¹⁶ Yet, for vegetables, flowers, and all the *pastio villatica* business, the need for irrigation in those parcels of land was very high all year round. Considering also the fact that plots are thought to have been small, we may doubt that each landlord had the opportunity to obtain a perennial and plentiful source of water. Irrigation water users, therefore, had to rely on servitudes over a neighbor's plot in order to satisfy their needs.

As we have seen, Italy was composed of many different types of properties. Water servitudes may be useful for all of them. From what I have described, however, I think that the suburban Roman area offers a pretty unique opportunity to take a closer and more accurate look at a pattern of landed property where hydraulic resource were the object of an intense competition and where sharing water, therefore, represented a crucial issue.

12 Carlsen 2001, 53.

13 Cic. *Rosc. Am.* 7.20.

14 Plin. *Am.* 3.19.2.

15 Pompon. 33 *ad Sab.* (*Dig.* 8.3.20.2).

16 About the lack of evidence for cereals cultivation in the suburban area, see Quilici Gigli 1994, 141.

4 An increasing need for water on small plots, from the 2nd century BC onwards

The field survey campaigns provide very valuable information about the distribution of agricultural exploitations, north-east of Rome.¹⁷ In particular, three sectors around the locality of Fidenae, Ficulea, and Crustumerium show a very high concentration of villas and farms. The estimated average size of the properties oscillates between 15 to 35 ha (400 x 400 m / 600 x 600 m).¹⁸ From Cato to Cassiodorus (6th century AD), not only the agricultural productivity of the Roman hinterland is well acknowledged by written sources, but also the type of cultivations, consisting of fresh and quality products, and market gardening activity, all requiring a fair amount of water.¹⁹ Archeological evidence of intensive irrigation is also available and has been carefully observed in the three aforementioned areas.²⁰ Some of them correspond very well to legal dispositions. Private aqueducts supplying villas may, for instance, be related to the relationship between a dominant and a servient estate. The presence of a nymphaeum near the Aniene reminds us that people living on the sides of a river could freely use the water.²¹ It has been proposed that some of the large cisterns situated on the eastern side of the Tiber were maybe destined to be filled up at night, the water then being used during the day.²² This system would be compatible with the possibility to apply a schedule to a right of drawing water.²³

It is then striking to observe that these areas with an exceptional density of villas – Fidenae, Ficulea, and Crustumerium – are mostly deprived of plentiful supplies of subterranean water, as the hydrogeological map of the Lazio Region illustrates.²⁴ Therefore, the reason for the high concentration of villas is probably not related to an abundance of groundwater resources, but in the proximity to Rome and the accessibility to the distribution channels (two requirements Cato advises to be met for the settlement of his ideal estate). The Fidenae/Ficulea zone is, in this concern, the most interesting. We know from surveys that the concentration of villas increases significantly around the Via Nomentana and where the Tiber is accessible. The profitability of fresh and quality goods relied on the capacity to transport the products to the markets as quickly and cheaply

17 Quilici and Quilici Gigli 1980; Quilici and Quilici Gigli 1986.

18 Quilici Gigli 1994, 140.

19 For a survey of literary evidence from Cato the Elder to Cassiodorus, see Thomas and Wilson 1994, 156–159. For other written sources about irrigation around Rome, see for instance Corpus inscriptionum Latinarum VI, 1261; XIV, 3676; Frontin. *Ag.* 9. 4–5; Cic., *Leg. agr.* 2.

20 Wilson 2008, 731–768, mostly based on the *Latium*

Vetus survey.

21 Wilson 2008.

22 Wilson 2008, 739.

23 Nera. 4 *Regularum* (*Dig.* 8.3.2.1) ; Iul. 43 *Dig.* (*Dig.* 43.20.4).

24 The map is too large to be reproduced here, but can be downloaded at the following address: http://www.regione.lazio.it/prl_ambiente/?vw=documentazioneDettaglio&cid=8671 (visited on 25/05/2018).

as possible. The same cultivations on well-watered lands, but distant from the market, were very unlikely to bring much profit.

Due to the limited size of these plots that required year-round irrigation, we may assume that the water supply was mostly dependant on the intricate system of rights and duties mentioned earlier, designed to share access to underground water. Of course, other solutions were applied, although the limits of this paper did not allow them to be studied. It is clear that the proximity of the Tiber was a valuable advantage that required an irrigation/drainage system, often the result of a pooling of resources and work. Rain water must also have become an increasingly valuable resource, also noticeable in the legal texts, since the *actio aquae pluviae arcendae*, was probably increasingly used to protect supplies, as well as to secure the drainage devices. In a context of competition for natural resources, all these uses clearly required the legal settlements that jurists provided.

5 Conclusion

A fair consideration of the exploitation of hydraulic resources requires the examination of many different elements, from a broad range of subjects. My original question consisted in asking, in what environment and for what purposes was the sharing of water necessary, or more accurately, what real problems did the jurists face that led them to give the answers in the jurisprudential texts?

Generally speaking, we observe a growing need for irrigation and for irrigation infrastructure starting in the 2nd century BC.²⁵ Developing around Rome, the market gardening activity led to increasing competition for water resources, due to environmental and economic reasons. Facing this situation, the jurists had to provide legal solutions, considering both general and private interests at the same time, which is a notable feature of the Roman law. The situation of competition for natural resources around the urban market of Rome in the Middle Republic, generated by the expectation of high profits, is one of the main social and economic problems that jurists faced, and for which they had to seek legal solutions.

Trying to provide a historical, geographic, and social context for the Roman jurisprudence is a challenging task, but considering the availability of such detailed and informative documentation, it ought to be attempted and could lead to a much better understanding of the Roman countryside, provided that we are able to integrate it with archaeological and historical data.

25 Marguerite Ronin. "Funding Irrigation. Between Individual and Collective Investments". In *Capital, Investment and Innovation in the Roman World*. Ed.

by P. Erdkamp, K. Verboven, and A. Zuiderhoek. Oxford Studies on the Roman Economy. Oxford: Oxford University Press (forthcoming).

Bibliography

Bédoucha-Albergoni 1976

Geneviève Bédoucha-Albergoni. "Système hydraulique et société dans une oasis tunisienne". *Études rurales* 62 (1976), 39–72. URL: <https://etudesrurales.revues.org/620> (visited on 25/05/2018).

Beltrán Lloris 2006

Francisco Beltrán Lloris. "An Irrigation Decree from Roman Spain: the *Lex Rivi Hiberiensis*". *JRS* 96 (2006), 147–197.

Capogrossi Colognesi 1966

Luigi Capogrossi Colognesi. *Ricerche sulla struttura delle servitù d'acqua in diritto romano*. Milan: Giuffrè, 1966.

Capogrossi Colognesi 1976

Luigi Capogrossi Colognesi. *La Struttura della proprietà e la formazione dei "lura praediorum" nell'età repubblicana*. Milan: Giuffrè, 1976.

Carlsen 2001

Jesper Carlsen. "Landowners, Tenants and Estate". In *Landwirtschaft im Imperium Romanum. Vorträge der Tagung ins BMW-Werk Regensburg-Harting*, 2000. Ed. by P. Herz and G. Waldherr. *Pharos – Studien zur griechisch-römischen Antike*. St. Katharinen: Scripta Mercaturae, 2001, 41–55.

Franciosi 1967

Gennaro Franciosi. *Studi sulle servitù prediali*. Naples: Jovene, 1967.

Martin 1971

René Martin. *Recherches sur les agronomes latins et leurs conceptions économiques et sociales*. Paris: Les Belles Lettres, 1971.

Möller 2010

Cosima Möller. *Die Servituten: Entwicklungsgeschichte, Funktion und Struktur der grundstückvermittelten Privatrechtsverhältnisse im römischen Recht*. Quellen und Forschungen zum Recht und seiner Geschichte 16. Göttingen: Wallstein Verlag, 2010.

Möller 2016

Cosima Möller. "Elemente des Römischen Wasserrechts – lex und natura, servitus und vetustas". In *Wasser – Wege – Wissen auf der iberischen Halbinsel vom Römischen Imperium bis zur muslimischen Herrschaft. Tagungsband zur gleichnamigen Tagung in Elche 2014*. Ed. by I. Czeguhn, Y. Quesada Morillas, and J. A. Pérez Juan. Baden-Baden: Nomos Verlag, 2016, 9–28.

Nicolet 2007

Claude Nicolet. *Rome et la conquête du monde méditerranéen: 264–27 avant J.-C. Tome 1: les structures de l'Italie romaine*. 10th ed. Nouvelle Clío, Paris: PUF, 2007.

Quilici Gigli 1994

Stefania Quilici Gigli. "The Changing Landscape in the Roman Campagna". In *Landuse in the Roman Empire. Analecta Romana*. Ed. by J. Carlsen, P. Ørsted, and J. E. Skydsgaard. Vol. Suppl. 22. Rome: L'Erma di Bretschneider, 1994, 134–144.

Quilici and Quilici Gigli 1980

Lorenzo Quilici and Stefania Quilici Gigli. *Latium Vetus III: Crustumerium*. Rome: Consiglio Nazionale delle Ricerche, 1980.

Quilici and Quilici Gigli 1986

Lorenzo Quilici and Stefania Quilici Gigli. *Latium Vetus V: Fidenae*. Rome: Consiglio Nazionale delle Ricerche, 1986.

Ribero 1989

Anne-Marie Ribero. *Le tribunal des eaux de Valenciar*. Perpignan: Université de Perpignan, 1989.

Shaw 1982

Brent D. Shaw. "Lamasba: An Ancient Irrigation Community". *Antiquités Africaines* 18 (1982), 61–103.

Thomas and Wilson 1994

Robert Thomas and Andrew Wilson. "Water Supply for Roman Farms in Latium and South Etruria". *Papers of the British School at Rome* 62 (1994), 139–196.

Trousset 1986

Pol Trousset. “Les oasis présahariens dans l’Antiquité: partage de l’eau et division du temps”. *Antiquités Africaines* 22 (1986), 163–193.

Wilson 2008

Andrew Wilson. “Villas, horticulture and irrigation infrastructure in the Tiber Valley”. In *Mercator Placidissimus. The Tiber Valley in Antiquity: New Research in the Upper and Middle River Valley*. Ed. by F. Coarelli and H. Patterson. Rome: Edizioni Quasar, 2008, 731–768.

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Irrigation in 3rd Millennium Southern Mesopotamia: Cuneiform Evidence from the Early Dynastic IIIb City-State of Lagash (2475–2315 BC)

Summary

Southern Mesopotamia was essentially agrarian and depended on artificial irrigation. The earliest cuneiform evidence for fully-developed irrigation networks stems from royal inscriptions and archival records from a temple archive from the city-state of Lagaš, ca. 2475–2315 BC. These sources testify to a four-level irrigation network, probably established upon the unification of the state by Urnanše and Eanatum. From the river, water flowed to primary canals with regulators, and from there branched off to secondary canals. Distributors regulated the water flow to the fields. The construction of primary canals and regulators was conducted by the ruler who drew on the *corvée* troops of the temples. The temples maintained the lower-level irrigation structures, such as the distributors and dikes in their fields.

Keywords: Sumerian city-state of Lagaš; ruler; temple; royal inscriptions; administrative texts; hydraulic installations; *corvée* work

Wirtschaft und Gesellschaft Südmesopotamiens basierten auf Bewässerungsfeldbau. Erste keilschriftliche Nachweise für vollentwickelte Bewässerungssysteme stammen aus dem sumerischen Staatsaat Lagaš (ca. 2475–2315 v. Chr.). Herrscherinschriften und Urkunden aus Tempelarchiven dokumentierten ein vierstufiges Bewässerungssystem, das Wasser aus den Flüssen über primäre Kanäle mit Regulatoren und sekundäre Kanäle mit Verteilern auf die Felder leitete und wahrscheinlich nach der Einigung des Staates durch Urnanše und Eanatum etabliert wurde. Die Anlage von primären Kanälen und Regulatoren oblag dem Herrscher, der auf die Arbeitskräfte der Tempel des Staates zugriff. Die Tempel hatten für die Instandhaltung der an ihren Feldern gelegenen Verteilern, Deichen usw. Sorge zu tragen.

Keywords: sumerischer Stadtstaat Lagaš; Herrscher; Tempel; Königsinschriften; Verwaltungsurkunden; Bewässerungsanlagen; Arbeitsdienst

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[1]

Beginning with the invention of cuneiform writing around 3300 BC,¹ the society and economy of Southern Mesopotamia – the alluvium between the Zagros Mountains in the east and the desert of Iraq in the west, south of modern Baghdad and stretching down to the gulf – are abundantly documented by thousands of cuneiform texts. The vast majority consist of administrative records from the archives of large, state-run economic households. These households held the property of almost all resources, such as arable land, orchards, reed-thickets, and livestock including cattle, swine, sheep and goats, and employed and provided for large parts of the population. Thousands of archival records testify to their activities in agriculture, horticulture, breeding, fishery, and crafts.² As early Mesopotamian societies were essentially agrarian, it is no surprise that administrative texts pertaining to agricultural production, such as records of field measurements, sowing, harvest, storage and distribution of crops, constitute a large part of all economic records.

[2]

Due to the climate, water regime and hydrological landscape of Southern Mesopotamia, agriculture was only possible by means of artificial irrigation.³ Firstly, the Southern Mesopotamian alluvium was below the 200 mm isohyet, and characterized by a desert climate with a hot, dry summer and a humid, cold winter. Thus, annual precipitation was insufficient for dry-farming.⁴ Secondly, the main rivers, the Euphrates and Tigris

- 1 The chronology used in the present paper follows Sallaberger and Schrakamp 2015a; Sallaberger and Schrakamp 2015b.
- 2 For general surveys of late 4th to mid-3rd millennium cuneiform sources, see Bauer 1998; Englund 1998; Krebernik 1998.
- 3 The following outline of the hydrological landscape

- and climate is based on the more recent descriptions by Charles 1988, 1–9; Hunt 1988, 190–192; Hruška 1995, 25–32, 43–52; Rost and Abdulamir 2011, 206–208; Wilkinson 2003, 71–99; Bagg 2012, 261–270; Wilkinson 2012, 35–46; Rost 2015, 25–35.
- 4 Charles 1988, 1–2; Bagg 2012, 261–262.

followed a flood pattern that did not match the needs of agriculture and were characterized by unpredictable fluctuations. Cereals were sown in October to November, grew during the winter months and were harvested in April or May when the rivers reached their highest level. As a result of the spring rains and the snowmelt from the highlands, water levels increased over the winter months and reached their maximum in April or May. This especially applies to the Euphrates, which is joined only by the Khabor River. The Tigris in contrast, is fed by four main tributaries from the Zagros Mountains, which have steep slopes, carry lots of erosion material and are subject to heavy rainfalls, and is therefore more violent and more unpredictable than the Euphrates.⁵ Moreover, the alluvial rivercourses of Southern Mesopotamia show a gentle gradient which can be as low as 5–10 cm per km, diminishing to as low as 3 cm per km in the delta region; therefore, both rivers tend to change their courses especially during the spring months.

In addition, the constant deposition of silts creates natural levees up to a height of a few meters which raise the riverbed and cause the river to flow above the level of the plain. These levees are the key element of the alluvial hydraulic landscape. They have a triangular cross-section, an average width of 2–5 km, elevate up to 3 m above the plain level, are well drained; and provide the agricultural ground of the Southern Mesopotamian alluvium. As their backslopes contribute a gradient normal to the riverbed that is significantly steeper than that of the plain, they provide ideal conditions for irrigation based on gravity flow, improving the drainage of agricultural land and helping avoid the risks of salinization through standing water.⁶ These levees promoted the development of shorter irrigation canals normal to the riverbed running down the backslopes. This led to development of so-called “herringbone patterns” of canals and fields,⁷ which are confirmed for the Ur III period (21st century) by field plans and have been reconstructed to a degree for the ED IIIb/Presargonic period as well.⁸

[3]

As Southern Mesopotamia was located beyond the dry-farming belt, Sumerian agriculture is often associated with water shortage. Though as water levels were low during the sowing in September to November, peaked immediately prior to harvest in April or May, and often brought unpredictable floods; control and protection were crucial for cultivating winter crops. Thus, the problem was rather to provide the required amount of water at a given time. These needs were met by means of water management, which

5 Charles 1988, 6–7; Bagg 2012, 262–263, 267; Wilkinson 2012, 38–39.

6 Instructive discussions of the levee system are found in Charles 1988, 8. 23–25; Hunt 1988, 193–195;

Postgate 1992, 174–176; Bagg 2012, 263; Wilkinson 2012, 35–36, 42–43; Rost 2015, 25–26.

7 Wilkinson, Rayne, and Jotheri 2015.

8 Liverani 1990, 171.

fulfilled four central functions, namely (1) supply, (2) storage, (3) protection, and (4) drainage, i.e. leaching.⁹

[4]

Before discussing the cuneiform evidence pertaining to irrigation systems in Southern Mesopotamian, a general description of irrigation systems is provided.¹⁰ First of all, open-surface irrigation systems include a facility like a head-gate that directs water from the rivercourse to the subsequent water management facility. Beyond the head-gate, water is distributed through a number of primary, secondary, tertiary, and field canals of different rank and length. The water flow within these canals is controlled by different hydraulic devices, the most important of which are inlets, outlets, distributors and regulators. Inlets are located at the heads of canals, sometimes provided with flexible gates, and control the amount of water directed into the subsequent section of the irrigation system. Outlets regulate the amount of water directed from field canals into the irrigated areas and can likewise be equipped with gates. Distributors regulate the water flow from one canal into two or more canals of a lower rank. While some distributors have a layout that allows for a proportional distribution of water, others are equipped with gates and allow for systematic distribution of water. Regulators control the water flow within an irrigation system, maintain the water level within specific canals, and can temporarily increase or dam up the water flow. Usually, regulators are constructed across a particular canal, are located slightly downstream from canal inlets, and their number in an irrigation system corresponds to the number of canals. It is exactly these elements that can be identified in the cuneiform texts.

[5]

Though administrative texts related to agriculture feature prominently in the earliest cuneiform records, evidence for water management in the earliest texts is virtually absent. The ca. 5000 so-called archaic texts from Uruk and Jemdet Nasr, datable to ca. 3300–2900 BC, refer to huge tracts of arable land and mention enormous amounts of grain, but direct mention of hydraulic installations is apparently absent. Surprisingly, irrigation is also only referred to once in Englund's survey of the archaic texts. He assumes that the archaic pictograph GANA₂, which denotes areas of arable land, represents an "irrigated field defined on a long axis by two parallel canals, with feeder canals running between them", and suggests a hypothetical reconstruction of an account of fields

⁹ Postgate 1992, 176–183; Bagg 2012, 269.

204–206.

¹⁰ This outline is based on Rost and Abdulmir 2011,

situated along a waterway.¹¹ The shape of the sign itself, notably, seems to indicate furrow irrigation. In addition, the archaic sign E_a, which is thought to correspond to later Sumerian eg₂ “dike, ditch”, has recently been interpreted by Monaco as “a pictographic representation of a dyke with two attached branches, as streams of water flowing out of it, to form ditches or channels for irrigation purposes”.¹² However, Pemberton, Postgate, and Smyth assumed that “the archaic sign for eg represents a canal with banks each side”,¹³ Steinkeller prefers an interpretation as a pictograph of the cross-section of “a broad earthen wall which accommodated a ditch or a small canal running along its top.” This will be translated as “dike” for convenience and discussed in more detail below (see below [18]).¹⁴ References to hydraulic installations are almost completely lacking in the ca. 450 archaic texts from Ur, tentatively dated to ca. 2700 BC. Only a fragmentary field list possibly mentions a field situated along a “dike” (eg₂, E, see below [18]) and perhaps a “dam” (durun_x, KU (?), see below [21]) (UET 2, 98 rev. ii 4 IN₁₄ IN₂₃ 3N₁ KU E ĠAL₂).¹⁵ The ca. 1000 administrative texts from Fara/Šuruppag, mostly datable towards the end of the Early Dynastic IIIa/Fara period ca. 2575–2475 BC,¹⁶ include a reference to “men who work at the dike” (lu₂ eg₂ a₃, WF 13 = WVDOG 143, 29 rev. ii 7, iv 8).¹⁷ An Early Dynastic IIIa/Fara period incantation from Fara/Šuruppag seemingly refers to the “water of the dike/ditch which fills the dike/ditch” (SF 54 = BFE 6 rev. iii 1–3 a-sur₃ sur₃ e-se₃-gen₇ a-eg₂ <eg₂> e-se₃-gen₇).¹⁸

To sum up, administrative texts from the late 4th to mid-3rd millennium hardly provide evidence for hydraulic installations. This agrees with late 4th to early 3rd millennium settlement patterns that are based on survey data and said to indicate that larger irrigation networks did not exist prior to ca. 2700, as recently pointed out by Nissen.¹⁹

[6]

However, it is probable that earlier cuneiform references to irrigation networks are masked behind the ambiguity of early cuneiform writing. It is known that the basic Sumerian term for both “river” and “major canal” (see below [13]) appears in its standard-orthographic writing i₇/id₂, a combination of the signs A plus ENGUR, as late as the Early Dynastic IIIb period in royal inscriptions of Eanatum of Lagaš around 2450 BC.

11 Englund and Grégoire 1991, 1–2; Englund 1998, 204 n. 457, 206–208 fig. 83.

12 Monaco 2014, 280.

13 Pemberton, Postgate, and Smyth 1988, 213.

14 Steinkeller 1988, 73.

15 Burrows 1935, 12. Whether KU or DUR₂ is an early defective writing for durun_x(KU.KU) remains unclear.

16 On the date of the texts from Fara/Šuruppag, see Sallaberger and Schrakamp 2015b.

17 Sjöberg 1998, 81; Steible and Yıldız 2015, 4, 49.

18 Krebernik 1984, 36–47, 382–383 (copy); Keetman 2015, 90.

19 Adams and Nissen 1972, 38; Nissen 2015.

Earlier sources simply write A, which basically means “water”. This interchange is observed most clearly in two royal inscriptions of Eanatum of Lagaš, which refer to the digging of a “new canal” (FAOS 5/1 Ean. 2 = RIM E1.9.3.5 v 16–17 $i_x/id_5(A)$ gibil mu-na-dun // FAOS 5/1 Ean. 3–4 = RIM E1.9.3.6 vi 8–9 $i_7/id_2(A.ENGUR)$ gibil mu-na-dun, see below [13]). Most scholars regard this interchange as a purely graphic phenomenon and consequently adopt the reading i_x/id_5 for the simplex A.²⁰ The same interchange is attested in the writing of the “inlet” of the “canal of the steppe” (ka i_x/i_7 eden) in Early Dynastic IIIb/Presargonic administrative texts from Umma/Zabala, which is often written with the older simplex i_x/id_5 (CUSAS 14, 123 obv. i 2; CUSAS 14, 237 obv. ii 3; CUSAS 33, 24 obv. i 2; CUSAS 33, 60 obv. i 2; CUSAS 33, 266 obv. i 1, etc.), but occasionally also with the later compound sign i_7 (CUSAS 14, 56 obv. i 2, cf. CUSAS 33, 284 rev. ii 3).²¹ An ED IIIa/Fara period list of waterways from Fara/Šuruppak, on the contrary, still employs the simplex A or i_x/id_5 instead of A.ENGUR or i_7/id_2 and seems to corroborate the above interpretation (SF 72). The simplex A is already attested in the earliest copy of this list of waterways from the late 4th or early 3rd millennium (ATU 3 pl. 91 W 20266,81, cf. ATU 3 pl. 79 W 20266,80).²²

In this connection, a late 4th or early 3rd millennium lexical list cited as *Tribute* or *Word List C*, a list of words arranged according to their meaning that was copied for educational purposes and is also known from the ED IIIa/Fara period (ca. 2575–2475 BC), merits discussion.²³ Unlike other archaic lists that cover only a single semantic field, *Word List C* is divided into seven subsections that cover various semantic fields, which correspond to the most important branches of archaic economy and their administrative bureaus, respectively.²⁴ The last subsection deals with agriculture and mentions terms for agricultural work and ploughing teams, refers to the spring flood and includes elements of the irrigation network.²⁵ While the late 4th or early 3rd millennium copies simply write A, the corresponding entries of ED IIIa/Fara period copies instead have pa_5 , which denotes “secondary canals”; and eg_2 , which denotes a “dike” and is considered also to designate a “ditch” by some scholars (see below [17], [18]). The significance of this important observation remains yet to be discussed. But it is probable that the several hundred attestations of A in late 4th and early 3rd millennium texts also include references to watercourses. It is also obvious that the more differentiated and less ambiguous

20 Behrens and Steible 1983, 3, 166–167 (with references); Bauer 1985, 2–3; Bauer 1998, 431; Krebernik 1998, 283 n. 525; Krebernik 2007, 41; Civil 2013, 45 n. 84; Nissen 2015, 93. – Occasionally, the interchange of A.ENGUR and A is observed in personal names mentioned in administrative texts from Lagaš from the reign of Urukagina, see Foxvog 2011, 95, though these may be scribal errors.

21 The correct reading of the CUSAS 14 references was

established by Marchesi 2015, 150 n. 119.

22 Krebernik 1998, 280 n. 490; 283 n. 525; 316 n. 761; Krebernik 2007, 41 n. 10.

23 Veldhuis 2006; Civil 2010, 215–228; Civil 2013; Veldhuis 2014, 79–81.

24 Veldhuis 2006, 190–195; Civil 2013, 19–22.

25 Veldhuis 2006, 192–193; Civil 2013, 42–46; Veldhuis 2014, 81.

irrigation terminology of *Word List C* – A or i_x/id_5 “river” or “major canal”, pa_5 “secondary canal”, and eg_2 “dike” or “ditch” (see below [13], [17]–[18]) – was a recent development of the ED IIIa/Fara period (ca. 2575–2475 BC).

[7]

Based on the interchange of A or i_x/id_5 and A.ENGUR or i_7/id_2 in ED IIIb/Presargonic texts from Lagaš referred to above, a similar conclusion has been put forward most recently by Nissen.²⁶ Instead of a purely orthographic phenomenon, Nissen assumed that “technical terms only become necessary when the object described becomes important enough to be addressed unambiguously”, and concluded that “only from late Early Dynastic times on [...] had canals and irrigation systems reached a level of complexity which needed an administration and professional terminology of its own”. In addition, he pointed out that the office of the gu_2 -gal, which is thought to have been related to the administration of irrigation systems and translated in German as “Deichgraf”, makes its appearance as late as the ED IIIa/Fara period (ca. 2575–2475 BC) in a lexical list of professions known as ED Lu₂ D from Fara/Šuruppak (SF 48 obv. iv 4). It should be added that the title gu_2 -gal appears for the first time as an element of personal names from Šuruppak, such as $lugal-gu_2$ -gal “the king is a gu_2 -gal”, $ereš-gu_2$ -gal “the queen is a gu_2 -gal”. These clearly refer to the king’s role as a provider of the irrigation network (e.g. TŠŠ 115 = WVDOG 143, 25 obv. i 8; WF 5 = WVDOG 143, 13 rev. ii 8; WF 35 obv. v 5).²⁷ Finally, Nissen emphasizes that both official inscriptions of ancient Near Eastern rulers that refer to the construction of canals and larger groups of administrative texts dealing with irrigation are attested as late as the the ED IIIb/Presargonic period, i.e. ca. 2475–2300 BC, though this might well be due to archival contexts and accidents of discovery.

[8]

The aforementioned ED IIIb/Presargonic texts provide the earliest cuneiform evidence for fully-developed irrigation networks and stem from the Sumerian city-state of Lagaš, which was situated in modern Southeast Iraq. Lagaš covered an area of approximately 3000 km² and was one of the most powerful ED IIIb/Presargonic city- or petty-states of Sumer.²⁸ It included the four major cities of Ġirsu, Lagaš, Niġen, and Guabba at the ancient coast of the Gulf, which were situated along a branch of the Tigris.²⁹

26 Nissen 2015, 93–94.

27 Cf. Andersson 2012, 178 n. 1063.

28 On the history of ED IIIb/Presargonic Lagaš, see Cooper 1983; Bauer 1998; Sallaberger and Schrakamp 2015b; Schrakamp 2015b.

29 This waterway was previously considered to be an eastern branch of the Euphrates, but identified as the Tigris, see most recently Heimpel 1990, 204–213; Steinkeller 2001.

[9]

The ED IIIb/Presargonic cuneiform sources from Lagaš are twofold. First, they include a corpus of ca. 190 so-called royal inscriptions dating from the reigns of Urnanše to Urukagina (i.e., eri-enim-ge-na),³⁰ i.e. ca. 2475–2315 BC. These sources report the accomplishments of the rulers of Lagaš, such as military campaigns, temple buildings, and the construction and enlargement of the irrigation network, and thus provide the historical, political, ideological, and geographical background.³¹ They are complemented by ca. 1800 administrative texts.³² These are dated, with a few exceptions, to the reigns of the last three rulers of Lagaš (Enentarzi, Lugalanda and Urukagina), i.e. ca. 2337–2315 BC, and derive from the household of the wife of the ruler, which was called the “woman’s quarter” (e₂-mi₂) under Enentarzi and Lugalanda and referred to as the “temple of (the goddess) Babu” (e₂ ^dba-bu₁₁) during the reign of Urukagina.³³ This institution was supervised by the queen, was surpassed in size only by the temple of Ningîrsu, Lagaš’s tutelary deity, and is currently regarded as a paradigm for ED IIIb/Presargonic Sumerian temple households. It possessed at least 9000 hectares of arable land, orchards, forests, cane-brakes, cattle, and livestock, and employed ca. 1200 people in agriculture, animal husbandry, fishery, and crafts. It provided for them through allotments of subsistence fields and allocations of barley, emmer, flour, oil and vegetables, as well as textiles and wool. The institution was largely self-sustaining, and its resources were regarded as the property of the gods. Above all, the temples were subservient to the palace, which interfered in the temple economies, was the center of royal power, and administered by the ruler (ensi₂), who acted as the earthly steward of the gods. This characterization likewise applies to other temple archives, such as the contemporary temple of Inanna of Zabala – a cultic center in the area of Lagaš’s northwestern neighbour Umma, from the time of Lugalzagesi – and slightly older administrative records from other households within the state of Umma.³⁴ The 3rd-millennium temples can therefore be described as redistributive households that managed subsistence agriculture and provided for a large part of the population.

30 On the reading eri-enim-ge-na, see Schrakamp 2015b, 304–310.

31 See the editions in Steible 1982; Cooper 1986; Frayne 2008 and the glossary in Behrens and Steible 1983.

32 For a list and a general description of these sources, see Selz 1995, 9–11; Beld 2002, 5–35; Foxvog 2011,

59 n. 2; Schrakamp 2013, 447; Schrakamp 2015b, 303–304 n. 1.

33 Schrakamp 2013; Schrakamp 2015b, 337–342. On the reading e₂-mi₂, see Schrakamp 2015b, 334–335 n. 248, on the reading ^dba-bu₁₁, see Rubio 2010, 35–39 and Keetman 2014, 458.

34 Schrakamp 2013, 452–454.

[10]

About 20 royal inscriptions dating from the reigns of Urnanše to Urukagina (ca. 2475–2315 BC) refer to royal irrigation projects, i.e. the digging, maintenance, and adjustment of canals and the construction and restoration of regulators.³⁵ The inclusion of these waterworks among the outstanding royal accomplishments underlines the importance of the irrigation network and demonstrates that its maintenance was both a royal obligation and prerogative, which contributed to the ruler's prestige. In addition, these inscriptions refer to the earliest-documented "interstate water war", a long-lasting border conflict between the state of Lagaš and its northwestern neighbor Umma, which was fought for the possession of the Guedena, a very fertile, irrigated area of land in the border region of both states.³⁶ In this context, the ED IIIb/Presargonic royal inscriptions include the earliest attestations to "hydraulic warfare", i.e. the strategic destruction of hydraulic installations and diversion of water, which was practiced in the Southern Mesopotamian alluvium in times of political fragmentation. Since Southern Mesopotamian society and economy depended on artificial irrigation, this form of warfare often had fatal results.³⁷

Fifty-seven administrative texts from the temple of Babu, corresponding to 3% of the whole archive, deal with the administration, organisation and maintenance of the irrigation network and, thus, constitute a sizable dossier.³⁸ These texts testify to the organisation of irrigation works by the chief administrator (nu-banda₃) of the temple household and document inspections of the irrigation network (gid₂, literally "to measure") or parts thereof, such as canals, dikes, and distributors, assignments (du₃) of work quotas to temple dependents, their acceptance (dab₃) and their completion (AK).³⁹ Thus, the administrative texts do not only convey data on the technical aspects of water management, such as the construction of different types of waterworks. As they stem from the archive of a well-documented institutional household, they also offer detailed data on social aspects of Southern Mesopotamian water management, such as the organisation of irrigation works, the social status of workers employed, the system of irrigation work obligations, and the like.

35 Laurito and Pers 2002.

36 Cooper 1983; Steiner 1986; Sallaberger and Schrakamp 2015b; Schrakamp 2015b.

37 The fatal results of hydraulic warfare are well documented for the Early Old Babylonian period. In 1889–1877 BC, Abisare and Sumuel of Larsa successfully diverted a branch of the Euphrates, which previously had supplied the rivalling city of Isin and won the long-standing conflict between both cities. Later, Sinmuballit of Babylon (1812–1793 BC) successfully applied methods of hydraulic warfare

against the city of Larsa. On hydraulic warfare during the Old Babylonian period, see Renger 1970, 75–76; Renger 1990, 36; Frayne 1989; Charpin 2002.

38 For a list of texts, see Maeda 1984; Steinkeller 1999, 540–541; Beld 2002, 25–26 n. 86. To these, DP 568 and MVN 3, 11 = AWAS 60 should be added. Some contemporary work assignments from the temple of Inanna at Zabala might likewise refer to irrigation work, see Schrakamp 2013, 452 with n. 41.

39 Maeda 1984, 33–39.

[11]

In 1984, Maeda published a basic study of ED IIIb/Presargonic irrigation practices which based on 34 administrative texts. He established their typology, demonstrating that they refer to surveys of canals, the assignment of work quotas to temple dependents, and the execution of irrigation work, and thus focused on the administrative aspects of water management. Aside from this, he devoted some space to a short discussion of the basic terminology of irrigation networks and some of the ruler's irrigation projects referred to in royal inscriptions.⁴⁰ These were basically studied in 1988 by Hruška, who focused on the technical terminology of water management in a broader sense.⁴¹ In the same year, Steinkeller discussed some key terms of mid- to late-3rd millennium irrigation terminology.⁴² Several aspects of mid- to late-3rd millennium irrigation practices were discussed, moreover, in 1994 by Civil in his edition of an early-2nd millennium educational poem – usually referred to as *Georgica Sumerica* or *The Farmer's Instructions* – that includes valuable data on irrigation.⁴³ These publications are complemented by several other contributions that focus, however, on late 3rd millennium irrigation terminology and practice,⁴⁴ and deal with the system of corvée obligations,⁴⁵ the hydrology of the Southern Mesopotamian alluvium,⁴⁶ and even hydraulic warfare.⁴⁷ Though it has been emphasized that these texts are “of prime importance for the reconstruction of irrigation techniques in southern Babylonia in Early Dynastic times;”⁴⁸ they have not yet been fully edited nor come under systematic study. The ongoing *Topoi* research project will, therefore, fill in this research gap. The present paper summarizes the most important results available. An edition of the administrative texts is in preparation.⁴⁹

[12]

Though the ED IIIb/Presargonic texts from Lagaš provide the earliest written evidence for full-fledged irrigation networks and the corresponding terminology, the meaning of the Sumerian terms designating the different elements of the irrigation network is often controversial, especially when their interpretation is based on 2nd and 1st-millennium

40 Maeda 1984.

41 Hruška 1988.

42 Steinkeller 1988.

43 Civil 1994, 109–140.

44 Sauren 1966; Salonen 1968; Bauer 1971; Bauer 1973; Kang 1973; Maekawa 1987; Lafont 1980; Hunt 1988; Pemberton, Postgate, and Smyth 1988; Waetzoldt 1990; Sallaberger 1991; Bauer 1992; Steinkeller 1999; Dight 1998; Dight 2002; Laurito and Pers 2002; Rost 2011; Rost and Abdulmir

2011; Lecompte 2012; Rost 2015; Steinkeller 2015.

45 Maekawa 1987.

46 Carroué 1986; Steinkeller 2001; Rost 2011; Studevent-Hickman 2011.

47 Ceccarelli 2015; Keetman 2015.

48 Steinkeller 1999, 540–541; cf. Steinkeller 1988, 73.

49 Note that the administrative texts published in Marzahn 1991 and Marzahn 1996 are transliterated in the unpublished works of Marzahn 1989 and Selz 1996.

bilingual lexical sources or etymology.⁵⁰ However, the way these terms are distributed in royal inscriptions, on the one hand, and administrative texts from the temple of the goddess Babu, on the other, perfectly reflects the position of the different elements of an irrigation network and, thus, assures their proper identification: While the construction of primary canals and regulators is almost exclusively attested in royal inscriptions (see below [13]–[16]), the administrative texts mostly refer to the construction and maintenance of distributors, canals, and dikes that were situated along the fields of the temple of Babu (see below [17]–[22]).⁵¹ This, in turn, indicates that royal inscriptions and administrative texts from the temple of Babu refer to different levels of responsibility and accountability in the construction and maintenance of the irrigation network, as illustrated in the following discussion (see below [23]–[26]). In order to avoid terminological ambiguity, the different components of the irrigation network will be addressed using the technical terminology outlined above (see above [4]).

[13]

The Sumerian term for “(primary) canal” is *i*₇, which basically means “river”,⁵² and refers to the largest category of canals. This terminological ambiguity is considered to result from the low gradient of the alluvium, due to which both rivers and primary canals run from the north to the south, with a tendency toward straightness.⁵³ Such a direction is attested, for example, for the LUMmagendu canal, whose direction of flow is indicated on a cuneiform map from the Sargonic period (2300–2181 BC) (RTC 159),⁵⁴ and the “canal which goes to Niĝen” (*i*₇ niĝen₆^(ki)(-še₃)-du), which was the most important waterway of the state of Lagaš, connected the main cities of the state of Lagaš on an axis from the northwest to southeast and had a length of almost 50 km, thus demonstrating that primary canals reached considerable lengths (see below [14]). Unlike other categories of waterways, almost all canals designated as *i*₇ bore proper names, with the single exception of the “canal of the Urindua field” (*i*₇ aša₃ urin-du₃-a), whose name derives from a field.⁵⁵ However, there are indications that *i*₇ is sporadically used as a generic term for all kinds of waterways, such as an administrative text summarizing *i*₇ waterways under the rubric pa₃ “secondary canal” (DP 648, see below [19]), and a scribal exercise probably dating from Eanatum or Enanatum I that combines the names of canals, deities, fishes, and snakes associated with specific cities (BiMes. 3, 26).⁵⁶

50 This approach was followed e.g. by Salonen 1968.

51 Cf. the methodological remarks in Sallaberger 1996, 39–41.

52 Sauren 1966, 35–40; Stol 1976–1980, 356; Maeda 1984, 39, 42–44; Hruška 1988, 61; Steinkeller 1988, 84–85; Hruška 1995, 54, 56; Laurito and Pers 2002,

311; Nissen 2015, 93–94.

53 Wilkinson 2012, 36.

54 Edzard, Farber, and Sollberger 1977, 220; Röllig 1980–1983, 464.

55 Maeda 1984, 42.

56 See the edition in Biggs 1973 and Bauer 1978.

Primary canals are mentioned both in royal inscriptions and administrative texts, but their construction is, notably, almost only referred to in royal inscriptions. The most numerous attestations are found in inscriptions of Urnanše, who united the cities of Ġirsu, Lagaš, Niġen, and Guabba into a single state.⁵⁷ Six inscriptions mention royal irrigation projects and report the “digging” (dun) of seven or eight distinct waterways (FAOS 5/1 Urn. 24 = RIM E1.9.1.17 ii 3–7; Urn. 26 = E.1.9.1.9 iii 7–v 4; Urn. 27 = E1.9.1.12 iii 2–4; Urn. 34 = E1.9.1.20 v 3–5; Urn. 51 = E1.9.1.6b v 10–vi 2).⁵⁸ Though only two of them, the i_x a-suġur and the i_x LAK175,⁵⁹ are explicitly referred to as “primary canals” (i_x), this classification most likely also applies to the remaining waterways: The nin-LAK175-ba-DU is thought to be the same as the i_x LAK175 and perhaps in some ways identical to the “canal which goes to Niġen” (see below [14]).⁶⁰ The sumur-du₇-gen₇-du canal appears as a “primary canal” (i_7 sumur-du₇-gen₇, i_7 sumur-du₇-du) in later administrative texts (DP 480 obv. ii 1; DP 637 rev. iv 1, see below),⁶¹ and ^den-lil_x(E₂)-pa₃-da-uš-gal is considered to be an earlier spelling for ^den-lil_x(E₂)-le-pa₃-da (VS 14, 72 = AWL 5 obv. ii 4) and i_7 ^den-lil_x(E₂)-le-pa₃ (VS 27, 23 obv. iii 4) in later archival sources.⁶² The pa₃-saman₃ is, to judge from its name, which includes the element pa₃, a “secondary canal” (see below [7]), but as it is certainly the same as the pa₃-^dsaman₃-kaš₄.DU, which is referred to as “primary canal” (i_7) in a scribal exercise (BiMes. 3, 26 obv. ii 6) and inscriptions of Urukagina, it is most probably a primary canal as well.⁶³ The ^dnin-ġir₂-su-pa₃-da(-)IL.MA.NI (?) and the eg₂-ter-sig are otherwise unattested.⁶⁴ As these waterways were likewise “dug” (dun), at least the former might be a primary canal as well. The latter, in contrast, is nominally referred to as “dike”, “embankment”, or possibly “ditch” (eg₂, see below [18]) and would, therefore, designate a smaller waterway. The fact that this waterway bore a proper name points to it being a larger canal. After Urnanše, the digging (dun) of primary canals is only attested in inscriptions of Urnanše’s grandson Eanatum, who dug (dun) a “new primary canal” (i_x/i_7 gibil) by the name of “LUMmagendu canal” (i_7 LUM-ma-gen₇-du₁₀) (FAOS 5/1 Ean. 2 = RIM E1.9.3.5 v 15–19, vii 3–6; Ean. 3 = E1.9.3.6 vi 6–9; Ean. 67 = E1.9.3.14 ii 2’–3’).⁶⁵ Later royal inscriptions, on the contrary, do not refer unambiguously to the “digging” (dun) of new primary canals. As all hydraulic installations created by Eanatum had names including the element LUMma, such as the LUMmagendu canal and its respective “regulator” (ġeš-keše₂-ra₂ i_7 LUM-ma-gen₇-du₁₀, see

57 Selz 1995, 295, 298; Schrakamp 2015b, 345–346.

58 Behrens and Steible 1983, 423–424; Laurito and Pers 2002, 276.

59 On the reading ^dnin-šaga_x, see Cavigneaux and Krebernik 1998–2001; Frayne 2008, 90.

60 Edzard, Farber, and Sollberger 1977, 223, 227; Selz 1995, 184–187, 209, 269.

61 Edzard, Farber, and Sollberger 1977, 228.

62 Edzard, Farber, and Sollberger 1977, 212; Selz 1995, 130.

63 Edzard, Farber, and Sollberger 1977, 229; Selz 1995, 234; Bauer 1998, 478.

64 Edzard, Farber, and Sollberger 1977, 223, 230; Selz 1995, 221, 257.

65 Behrens and Steible 1983, 423–424; Bauer 1998, 464; Laurito and Pers 2002, 276.

below [15]), and LUMma is conventionally considered to be Eanatum's second name,⁶⁶ it is assumed that the LUMmaġir_{nun}ta (i₇ LUM-ma-ġir₂-nun-ta) and the ŠedaLUMma canal (i₇ še-da-LUM-ma) were dug by this ruler as well.⁶⁷ Except for the constructions of regulators (ġeš-keše₂-ra₂), which are reported by Eanatum, Enanatum I, Enmetena, and Urukagina, which will be discussed later in this paper (see below [15]), only six inscriptions of Urukagina refer to royal irrigation projects executed on the three primary canals (FAOS 5/1 Ukg. 1 = RIM E1.9.9.2 iii 4'-7', 12'-15'; Ukg. 4/5 = E1.9.9.1 ii 7-13/ii 9-15, xii 29-45/xii 5-21; Ukg. 6 = E1.9.9.3 v 5-7; Ukg. 8 = E1.9.9.10 iii 3'-6'; Ukg. 14 = E1.9.9.4 i 1-2).⁶⁸ Urukagina does not report the "digging" (dun), but rather the "hoeing" (al - du₃) of the Pasamankas₄.DU canal (i₇ pa₅-^dsaman₃-kas₄.DU), the "little canal" (i₇ tur) that Urukagina renamed to Ningġirsunibrutanirġal (i₇ ^dnin-ġir₂-su-nibru^{ki}-ta-nir-ġal₂), and the "canal which goes to Niġen" (i₇ niġen^{ki}-du). As all of these canals are already mentioned prior to Urukagina's reign,⁶⁹ the "hoeing" (al - du₃) is interpreted as a designation for maintenance work, probably due to erosion and deposition of silt, in contrast to the "digging" (dun) of new waterways.⁷⁰

Seventeen of fifty-seven administrative texts dealing with irrigation, corresponding to 30% of the whole dossier, mention "primary canals" (i₇), providing 26 attestations in total (DP 628 obv. i 1, rev. i 2; DP 637 rev. iv 1; DP 640 obv. i 2; DP 641 rev. iv 1; DP 642 rev. i 2; DP 644 rev. iii 1; DP 646 rev. i 2, 3, ii 4; DP 647 obv. i 2; DP 648 obv. i 1, 2; DP 658 rev. ii 1; DP 659 rev. i 3, ii 1; Nik. 1, 8 = AWEL 8 rev. ii 3; TSA 23 rev. v 2; VS 14, 130 = AWL 2 obv. i 1; VS 25, 97 obv. i 5, ii 3, iv 3; VS 27, 23 obv. i 3, iii 4; VS 27, 36 obv. i 1, <i₇>^den-lil_x(E₂)-le-pa₃ (?); VS 27, 36 rev. iv 1). These refer to nine different primary canals, including the "canal which goes to Niġen" (i₇ niġen^{ki}-du), the Imah canal (i₇ maḥ), the LUMmagendu canal (i₇ LUM-ma-gen₇-du₁₀), the Ningġirsunibrutanirġal canal (i₇ ^dnin-ġir₂-su-nibru^{ki}-tanir-ġal₂), and the Sumurdu(gen) canal (i₇ sumur-du₇, i₇ sumur-du₇-gen), all of which are mentioned in royal inscriptions. The "canal of the Urindua field" (i₇ aša₅ urin-du₃-a), the Enlilepa canal (i₇ ^den-lil_x(E₂)-le-pa₃), the Enlilešumugi canal (i₇ ^den-lil_x(E₂)-šu-mu-ġi₄), the Nemur(gen) canal (i₇ nemur(-gen₇)), and the ŠedaLUMma canal (i₇ še-da-LUM-ma) only appear in archival records. However, seven texts mention primary canals merely as a point of reference for the location of dike work, in notations such as "this is the dike which runs from the Imah (canal) to the erected emblem of the goddess Nanše" (eg₂ i₇-maḥ-ta uri₃-du₃-a ^dnaše-še₃ ġal₂-la-am₆, VS 25, 97 obv. i 5-ii 1), or "from the durun_x of the Imah canal 120 m, it is (a stretch of) dike not to be done" (durun_x i₇-maḥ-ta 20

66 Marchesi 2006, 20-26.

67 Maeda 1984, 44.

68 Behrens and Steible 1983, 423-424; Laurito and Pers 2002, 277.

69 Carroué 1986, 14; Selz 1995, 47 n. 214; Schrakamp 2015b, 335-336 n. 258. Maeda 1984, 43, and Bauer

1998, 439, assume that this canal was constructed by Urukagina, but overlook the earliest reference in the scribal exercise BiMes. 3, 26 obv. i 1, tentatively dated to Eanatum or Enanatum I.

70 Hruška 1988, 65; Selz 1995, 47 n. 214; Attinger 2005, 269.

NIĜ₂.DU eg₂ nu-ke₃-dam, VS 14, 130 = AWL 2 obv. i 1; cf. DP 641 rev. iv 1–2; VS 25, 97 obv. iv 2–3; VS 27, 23 obv. i 3–ii 2; VS 27, 23 obv. iii 4–rev. i 2; VS 27, 23 rev. i 5–6).⁷¹ Others do not refer to the primary canals proper, but to their U₃, a term which is considered to denote their ancient course, spoilbanks, or the like (see below [22]), as is attested for the Imaḥ canal (U₃ i₇¹-maḥ, DP 568 obv. ii 1; U₃ i₇-maḥ-ta ša₃ aša₅-ga-še₃, DP 646 rev. ii 4–5; U₃ i₇¹(ENGUR)-maḥ-kam, DP 658 rev. ii 1). As the U₃ of the Imaḥ canal is variably also referred to as the U₃ of Daterabbar by one and the same work assignment, it is even uncertain whether the Imaḥ canal proper is meant here at all (cf. DP 647 obv. i 1–2 3 lu₂ o.2.o kiĝ₂-be₂ ½ eše₂ 5 ge kiĝ₂ du₃-a U₃ i₇-maḥ *versus* DP 647 rev. v 1 šu-niĝen₂ 3,10 NIĜ₂.DU 1c ge kuš₃ 3c kiĝ₃ du₃-a U₃ ter-abbar^{ki}-ka; VS 27, 36 rev. iv 1–2 U₃ i₇-maḥ da-ter-abbar^{ki} kiĝ₂ du₃-a ^dba-bu₁₁).⁷²

However, only nine texts, corresponding to 11.5%, testify to work on primary canals. Notably, the digging (dun) of new canals is never mentioned. Instead, the administrative texts testify to maintenance and repair and refer to the “hoeing” (al – du₃, see above) and “cleaning” of primary canals (šū-luḥ – ak),⁷³ or their respective beds (ša₃ i₇).⁷⁴ Some of them are related to a royal irrigation project of Urukagina. An assignment of work to temple dependents from Urukagina’s 2nd year records the hoeing of the “Ninĝirsuni-brutanirgal canal” on a stretch of 540 m, more precisely at its “outlet” (kuĝ₂) at the Ubur field ([gu₂-an]-še₃ [1,30] NIĜ₂.DU [šū-du₃]-a 2c šū-si 5c [ki]ĝ₂ du₃-a i₇¹ al du₃ [dⁿ]in-ĝir₂-su-[ni]bru^{ki}-[ta-nir]-ĝal₂, TSA 23 rev. v 1–2).⁷⁵ Notably, this assignment was not made by the “captain” of the temple, as usual, but by the king himself ([eri]-enim-ge-na [lu]gal lagas_x(NU₁₁.BUR)^{la.ki}-ke₄ kuĝ₂ aša₅ ubur₂-ra-ka en-ig-gal nu-banda₃ mu-na-du₃ 1., TSA 23 rev. v 3–vi 1, see below [23]–[26]). The historical background is known from Urukagina’s royal inscriptions. These report the hoeing of the “canal which goes to Niĝen,” the construction of its respective regulator (ĝeš-keše₂-ra₂), its renaming to “Canal ‘Ninĝirsu has authority from (the city of) Nippur’” (i₇^dnin-ĝir₂-su-nibru^{ki}-ta-nir-ĝal₂), and its subsequent junction with the “little canal which Ĝirsu had” (i₇ tur ĝir₂-su^{ki} i₃-tuku-a), on the occasion of Urukagina’s coronation as king in his 2nd regnal year (see below [14]).⁷⁶

71 Cf. Hruška 1991, 209.

72 Maeda 1984, 47.

73 Salonen 1968, 427; Steinkeller 1988, 75; Civil 1994, 115, 179; Hruška 1995, 57; Attinger 2005, 254.

74 Veldhuis 2006, 193; Civil 2013, 44–45.

75 Englund 1988, 177–178 n. 38, assumes that the length measurements do not refer to the horizontal extent of stretches of dike, but to the volume of earthwork moved and, thus, represent an earlier precursor of the Ur III period system of volume notations. However, this seems excluded: the survey texts DP 654 and VS 25, 97, describe stretches of

dike not only in terms of their length, but also of their width (daĝal-be₂) and height (sukud-be₂). In addition, VS 25, 100, records several work quotas in dike work in terms of their length and records some work quotas that were executed on the two banks (gu₂ 2c-be₂ ke₃-dam) of the dike. The fact that the individual work quotas are congruent with the summary in the subscript of the texts demonstrates that not volumes, but length measurements are recorded (see below [18]).

76 Schrakamp 2015b, 335–336.

Another text, datable to Urukagina's 1st or 2nd regnal year, records an assignment in canal work, undertaken on a 80.5 m stretch of the ŠedalUMma canal, which is otherwise unattested (š_u-niĝ_{en} 1,20 ½ lu₂ kiĝ₂-be₂ 1 eše₂ 7c ge kuš₃ 1c kiĝ₂ i₇ du₃-a še-da-LUM-ma, Nik. 1, 8 = AWEL 8 rev. ii 1-3). As this work assignment provides the only other reference to the Ubur field (aša₅ ubur₂-ra ĝal₂-la-am₆, Nik. 1, 8 = AWEL 8 rev. ii 3),⁷⁷ and mentions the same gangs of corvée workers (cf. the names in TSA 23 obv. i 1-v 4 and Nik. 1, 8 = AWEL 8 obv. i 1-rev. i 1),⁷⁸ it is obviously related to Urukagina's irrigation project as well. Thus ŠedalUMma has been considered to be the former name of the "little canal which the city of Ĝirsu had", before it was renamed and connected to the "canal which goes to Niĝen".⁷⁹ The type of work undertaken at the ŠedalUMma canal is not specified, but the corresponding gangs of corvée troops and their comparably low work loads lead to the assumption that hoeing is referred to (compare, e.g., TSA 23 obv. i 1-4 13 lu₂ lu₂ 1-še₃ kiĝ₂ kuš₃ 4c šu-du₃-a 2c šu-si 4c-ta i₃-ši-ti, kiĝ₂-be₂ [½] eše₂ kuš₃ 2c šu-du₃-a 2c [u]r^{d.še3}šer₇-da; Nik. 1, 8 = AWEL 8 obv. i 1-4 13 ½ lu₂ lu₂ 1-še₃ kiĝ₂ kuš₃ 2c-ta kiĝ₂-be₂ 4c ge kuš₃ 1c ur^{d.še3}šer₇-da). Two texts from Urukagina's 4th year confirm this assumption. While the first records the acceptance of an assignment in canal work at the Enlilešumugi canal with work quotas as low as 1 m per capita, adding up to 27 m in total (kiĝ₂ du₃-a i₇ ^den-lil_x(E₂)-le-šu¹-mu-gi₄-kam en-ig-gal NU-banda₃ lu₂ iĝi-niĝ_{en} deli-deli-e-ne e-dab₅ 3., DP 644 rev. iii 1-5), the other records an expenditure of "hoe blades" (gag al) at the otherwise unattested Enlilešumugi canal (š_u-niĝ_{en} 1,02 gag al i₇ ^den-lil_x(E₂)-le-šu¹-mu-gi₄-a en-ig-gal NU-banda₃ e-ne-ba 3., DP 572 rev. i 1-ii 2).⁸⁰ Moreover, a survey denoting "work" (kiĝ₂) on a 880 m stretch of the "canal which goes to Niĝen" could likewise be related to Urukagina's irrigation project (2,20 ½ eše₂ 4c ge kiĝ₂ i₇ niĝ_{en}^{ki}-du ĝal₂-la-am₆ aša₅ kuš₃ du₆-sir₂-ra-ka-kam en-ig-gal NU-banda₃ mu-gid₂ 2., DP 640 obv. i 2-ii 2). However, as its date formula only refers to the 2nd regnal year, but omits the ruler's name, this remains uncertain.⁸¹ Finally, an administrative text from Urukagina's early reign records the "acceptance" (dab₅) of work quotas in hoeing the LUMmagendu canal that add up to 30 m and were assigned to the "corvée troops" (sur_x) of the temple of Babu by its chief administrator (NU-banda₃) (š_u-niĝ_{en} ½ eše₂ kuš₃ 2c kiĝ₂ bala-am₆ sur_x-re₂ e-dab₅ i₇ al-du₃ kiĝ₂ u₂-rum ^dba-bu₁₁ i₇ LUM-ma-gen₇-du₁₀, DP 659 rev. i 1-ii 1).⁸² The same irrigation project is probably referred to in an assignment of work on the LUMmagendu canal from the year of Urukagina's accession (š_u-niĝ_{en} 5c ge kiĝ₂ du₃-a i₇ LUM-ma-gen₇-du₁₀ eri-enim-ge-na ensi₂ lagas_x(NU₁₁.BUR)^{la.ki}-ke₄ mu-du₃ 1.,

77 LaPlaca and Powell 1990, 92.

78 Cf. Maeda 1984, 43-44, 50-51; Maekawa 1987, 53-59.

79 Maeda 1984, 43-44; Carroué 1986, 19, with reservations.

80 Maeda 1984, 43; Selz 1995, 131.

81 Maeda 1984, 37.

82 Maeda 1984, 50 n. 5, presents prosopographical arguments for the dating to the early reign of Urukagina.

DP 628 rev. i 1-ii 1). As the per capita work load can be estimated at ca. 0.5 m, clearly the canal hoeing is referred to (e.g. DP 628 obv. i 1-4 kuš₃ 1c kiġ₂ du₃-a i₇ LUM-ma-gen₇-du₁₀ ge-num, kuš₃ 1c lu₂ a kum₂).⁸³ The hoeing is most probably also attested for “canals” (i₇) at the Urindua field (DP 648 obv. i 1-3), but these are subsumed as “secondary canals” (DP 648 obv. i 3, ii 2) and will be discussed later (see below [17]).

As the “hoeing” of primary canals was important enough to deserve mention in royal inscriptions, it comes as no surprise that administrative texts likewise refer to the hoeing of canals as a means of dating. Two administrative texts from the first year of an unnamed ruler bear an unusual date formula that refers to “the month (of the) issue of the inlet of the primary canal” (iti niġ₂ ka i₇-ka-kam, DP 165 rev. ii 4; iti niġ₂ ka i₇-ka-ka, STH 1, 45 = AWAS 44 obv. ii 4). As one of them mentions the “hoeing” of a primary canal by the ruler (ensi₂ i₇ al¹ du₃ ¹-da mu-til₃-la-a, DP 165 obv. ii 2-4), it is tempting to correlate these texts with the construction of the “inlet” (ka) reported in Urukagina’s inscriptions (FAOS 5/1 Ukg. 4/5 = RIM Et.9.9.1 ii 7-13/ii 9-15, xii 29-45/xii 5-21), but a dating to Urukagina is not assured (see below [14]).⁸⁴ In addition, a delivery of timber includes the notion that the chief administrator of the temple “cleared it out when he blew the Sumurdu canal with the hoe” (en-ig-gal nu-banda₃ i₇ sumur-du₇-ra₂ al i₃-mi-du₃-a-a na i₃-mi-de₅, DP 480 obv. i 3-ii 3),⁸⁵ thus, reflecting his role in organizing the irrigation work performed by the dependents of the temple (see below [24]–[25]). As it dates from the 1st year of an unnamed ruler, it is tempting to correlate it with an assignment of work on the Sumurdu canal that is likewise dated to the 1st year of an unknown ruler, but this text refers to the cleaning of the bed of the Sumurdu canal, performed on a length of 120 m by the “men of the goddess Babu”, i.e. the dependents of the sanctuary (šu-niġen₂ 20 niġ₂.DU kiġ₂ du₃-a ša₃ i₇ sumur-du₇-ka šu-luḥ ak lu₂ ^dba-bu₁₁-ke-ne, DP 637 rev. iv 1-v 1). The last work assignment (kiġ₂ du₃-a) specifies that the bed of the canal of the Urindua field had to be cleaned at a length of 366 m (šu-niġen₂ 1,00 niġ₂.DU 2c ge kiġ₂ du₃-a i₇ aša₅ urin-du₃-a ša₃ i₇-da šu-luḥ ke₃-dam, DP 646 rev. i 1-4), “from the u₃ of the Imaḥ canal to the midst of the Urindua field”, thus informing that the Urindua canal crossed the field itself (u₃ i₇-maḥ-ta ša₃ aša₃-ga-še₃, DP 646 rev. ii 4-5).⁸⁶ To sum up, administrative texts almost exclusively attest to the maintenance of primary canals, with the exception of documents directly related to Urukagina’s irrigation projects, undertaken on the “canal which goes to Niġen” during his early reign. The fact that these irrigation projects were not only reported in royal inscriptions, but were also occasionally referred to in date formula, underlines their importance.

83 Cf. Hruška 1988, 63, with a different interpretation.

84 Carroué 1986, 20; Selz 1993b, 401; Schrakamp 2015b, 348 n. 354, with a discussion of earlier interpretations. The fact that the household of the wife

of the rulers is referred to as e₂-mi₂, “women’s quarter”, argues for a dating to Urukagina’s predecessor.

85 On na – de₅ “to clear out” see Sallaberger 2005.

86 Maeda 1984, 43, 47.

As mentioned above, 16 administrative texts mention primary canals as points of reference in surveys or in assignments of work on nearby installation, and, thus, are informative about the location of waterways in relation to other elements of the irrigation network, important buildings, fields, and orchards. First, these texts demonstrate that primary canals bordered on fields.

An already mentioned acceptance of work assignments states that the “canal of the Urindua field” (i_7 aša₅ urin-du₃-a) had to be cleaned “to the middle of the field” (ša₃ aša₅-ga-še₃, DP 646 rev. ii 5) and, thus, demonstrates that this canal crossed the eponymous Urindua field, as is also indicated by the name of the canal itself (cf. above [13]). A survey done by the chief administrator (nu-banda₃) of the temple of Babu records 140 rods $\frac{1}{2}$ rope 4 reeds or 882 m of “work which is on the canal which goes to Niĝen” (2,20 $\frac{1}{2}$ eše₂ 4c ge kiĝ₂ i₇ niĝen^{ki}-du ĝal₂-la-am₆, DP 640 obv. i 2–ii 1) and indicates that this waterway ran along the “field of the Dusira outlet” (aša₅ kuĝ₂ du₆-sir₂-ra, DP 640 obv. ii 2). References to “outlets” (kuĝ₂) in relation to fields are also found in two of the administrative texts concerning Urukagina’s irrigation project on the “canal which goes to Niĝen” cited above (Nik. 1, 8 = AWEL 8; TSA 23).⁸⁷ Two surveys refer to “dikes which lie along the Nemur canal” (eg₂ i₇ nemur-da nu₂-a(-am₆), DP 642 rev. i 2; VS 25, 97 obv. ii 3). This notation most likely denotes the “dikes” or “embankments” that accommodated the primary canal on both sides. A survey mentions a “durun_x of the Imah canal” (durun_x i₇-maĥ, VS 14, 130 = AWL 2 obv. i 1, see below [21]) as a point of reference, thus, indicating that primary canals included durun_x as well. Another survey mentions “the kab₂-tar distributor of the Enlilepa canal” (kab₂-tar^den-lil_x(E₂)-le-pa₃, VS 27, 36 obv. i 1) as a point of reference. This could indicate that the water flow from primary canals to waterways of lower rank was controlled by means of kab₂-tar distributors and could be confirmed by another survey of “dikes” or “embankments” at the Daterabbar field. It states that the Enlilepa canal included at least two kab₂-tar distributors that were eroded by the water (4c ge kab₂-tar 1c-am₆ 3c kab₂-tar 2c-kam-ma-am₆ <i₇>^den-lil_x(E₂)-le-pa₃-ta a e-de₆, VS 27, 23 rev. i 3–6), but additional indications, however, are lacking (see below [20]).

To sum up, “primary canals” are designated as i_7 . These are mentioned both in royal inscriptions and administrative texts, but the construction of new primary canals is only referred to in inscriptions of the rulers of Lagaš, whereas administrative texts merely testify to maintenance work, with the notable exception of a group of records related to Urukagina’s irrigation project conducted on the “canal which goes to Niĝen”. In addition, the construction of new primary canals is almost exclusively reported in inscriptions of Urnanše and his grandson Eanatum. This probably reflects Urnanše’s attempt

87 Maeda 1984, 43; Carroué 1986, 50; LaPlaca and

Powell 1990, 98.

to establish a far-flung irrigation network upon the unification of the four main cities of Lagaš into a single state. This agrees with the evidence from the Ur III period, during which the excavation of (new) primary canals is almost never reported in the tens of thousands of administrative texts, but is referred to by Urnamma, after the unification of Babylonia proper.⁸⁸

[14]

A well-known primary canal, attested through ED IIIb/Presargonic to Ur III cuneiform texts, is the “canal which goes to Niĝen” ((i₇) niĝen^(ki)-(še₃-)du). As mentioned above, it might in part be the same waterway as the i_x LAKI75 and nin-LAKI75-ba-DU canals dug by Urnanše, but the basic data can be found in inscriptions of Urukagina, which are complemented by a handful of administrative texts.⁸⁹ Urukagina boasts that he built the Eninnu, the temple of the god Ningirsu in the city of Ĝirsu, at its “mouth” (ka), and the Esirara, the temple of the goddess Nanše in the city of Niĝen, at its “tail” (kuĝ₂), and extended it to the south as far as the sea. Moreover, Urukagina joined the “canal which goes to Niĝen” with the “little canal which Ĝirsu had”. According to his royal inscriptions, the project was accomplished when Urukagina received the kingship of Lagaš from the god Ningirsu. On this occasion, the “little canal” was given its new name, “canal ‘the god Ningirsu has authority from the city of Nippur’”; by the king (^dnašše i₇ niĝen^(ki)-du i₇ ki-aĝ₂(-ĝa₂)-ne₂ al mu-na-du₃ (...) ša₃ mu-ba-ka i₇ tur ĝir₂-su^{ki} i₃-tuku-a ^dnin-ĝir₂-su-ra al mu-na-du₃ mu u₄-be₂-ta-be₂ e-še₃-ĝar (i₇) ^dnin-ĝir₂-su nibru^{ki}-ta eri-enim-ge-na-ke₄ mu mu-na-se₂₁ i₇ niĝen^(ki)-du-a mu-na-ni-la₂, FAOS 5/1 Ukg. 4/5 = E1.9.9.1 ii 7-13/ii 9-15, xii 29-40/xii 5-16, cf. Ukg. 1 = RIM E1.9.9.2 iii 4'-11', see above [13]).⁹⁰ Two or three administrative texts of a corresponding date, discussed above, refer to irrigation work at this waterway (DP 640; Nik. 1, 8 = AWEL 8; TSA 23, see above [13]). Obviously, the “mouth” (ka) and “tail” (kuĝ₂) designate the “inlet” and the “outlet” of this

88 Civil 1994, 135; Wilkinson 2012, 38, 42; Rost 2015, 134-137, with references; cf. Jacobsen 1960.

89 Carroué 1986. For the reading ((i₇) niĝen^(ki)-(še₃-)du and its variants see Bauer 1971, 148-151; Carroué 1986, 18; Keetman 2016, 9, for Ur III administrative texts, which are beyond the scope of the present paper, see also Rost 2011; Studevent-Hickman 2011. On the dating of Urukag-

ina's irrigation projects to the first two years of his reign see Schrakamp 2015b, 335-336, 347-350, for a list of administrative texts pertaining to his irrigation works see Maeda 1984, 51 and Beld 2002, 25-26 n. 86.

90 Carroué 1986, 18, 49 n. 40-43; Schrakamp 2015b, 347-350.

primary canal,⁹¹ with the “mouth” being its head gate.⁹² Thus, running on an axis from the northwest to the southeast, the “canal which goes to Niĝen” connected the cities of Ĝirsu, Lagaš, Niĝen and Guabba at the ancient coast and, with an estimated length of almost 50 km, was the longest canal of the state.⁹³ Carroué assumed that the “mouth” (ka) of the “canal which goes to Niĝen” referred to its head gate, which he consequently located within the city of Ĝirsu. In support of this conclusion, Carroué referred to later inscriptions of Gudea of Lagaš that locate various buildings and sanctuaries within the city of Ĝirsu, such as the “lapis lazuli quay of the Kasura” (kar za-gin₃ ka₂-sur-ra) and the Emaḥ (e₂-maḥ) “at the river/canal” (i₇-da). Thus, Carroué supposed the head gate of the “canal which goes to Niĝen” in the area of the thalweg dividing the northern part between the *Tells centraux* and the *Tells de l’Est*. Moreover, Carroué referred to a brick inscription which commemorates the construction of the ĝeš-keše₂-ra₂ of the “canal which goes to Niĝen” by Urukagina, which he translated as “digue”. As this was constructed of durable materials and its respective inscriptions stemmed from Ĝirsu, Carroué provisionally identified this ĝeš-keše₂-ra₂ as the inlet or head gate of the “canal which goes to Niĝen”, which he supposed was located in the thalweg referred to above (see below [15]).⁹⁴ Two administrative texts from the first year of an unnamed ruler bear an unusual date formula, that refers to “the month (of the) issue of the inlet of the primary canal” (iti niĝ₂ ka i₇-ka-kam, DP 165 rev. ii 4; iti niĝ₂ ka i₇-ka-ka, STH 1, 45 = AWAS 44 obv. ii 4). As one of them mentions the “hoeing” of a primary canal by the ruler (ensi₂ i₇ al ‘du₃’-da mu-til₃-la-a, DP 165 obv. ii 2–4), it is tempting to correlate these texts with the construction of the “inlet” (ka) reported in Urukagina’s inscriptions, but their dating to the reign of Urukagina is by no means assured.⁹⁵

While ancient levees discernible on modern satellite imagery are thought to represent the “canal which goes to Niĝen” and the abovementioned reconstruction of its course is generally accepted, the location of its head gate is not.⁹⁶ Rost considered the possibility that the canal drew its water directly from the ancient Tigris, which is located in the immediate vicinity (literally, “the banks”) of the city of Ĝirsu by an inscription of

91 On ka and kuĝ₂, see Sauren 1966, 49–50; Stol 1976–1980, 358; Maeda 1984, 39 n. 13, 44; Carroué 1986, 16, 18; Hruška 1988, 65; Laurito and Pers 2002, 279; Rost 2011, 227, 242; Nissen 2015, 93–94. Sauren, Stol and Nissen regard kuĝ₂ as an earlier spelling for kuĝ₂ zi-da, which is amply attested in Ur III administrative texts, but this interpretation does not agree with the context of Urukagina’s inscription, nor with the more recent interpretation of kuĝ₂ zi-da as “weir” or “barrage” by Steinkeller 1988, 74; Steinkeller 2001, 35 n. 46; cf. Waetzoldt 1990, 8–9.

92 Carroué 1986, 17–18.

93 Carroué 1986, 15 fig. 1; 23 fig. 2.

94 Carroué 1986, 16–18.

95 Carroué 1986, 20; Selz 1993b, 401; Schrakamp 2015b, 348 n. 354. The fact that the household of the wife of the rulers is referred to in one of these documents as e₂-mi₂, “women’s quarter”, instead of e₂ ‘ba-bu₁₁, “temple of Babu”, argues for a dating to Urukagina’s predecessor.

96 Rost 2011, 226 n. 14, refers to the unpublished dissertation of Pournelle 2003, 90–96, which is not available to the present author.

Enmetena (im-dub-ba ^dnin-ĝir₂-su-ka gu₂ i₇ idigna-še₃ ĝal₂-la gu₂-gu₂ ĝir₂-su^{ki}-ka, FAOS 5/1 Ent. 28 = RIM E1.9.5.1 iv 4–7) and is represented by an ancient levee system discernible on modern satellite imagery.⁹⁷ This, however, would contradict the inscriptions of Urukagina, which locate the head gate of the canal within the city of Ĝirsu. A possible solution that harmonizes epigraphic and archaeological evidence has been proposed by De Maaijer and Rost. They assumed that the “canal which goes to Niĝen” extended all the way to the ancient course of the Tigris, but presuppose that its northern part was referred to as “Ĝirsu canal”.⁹⁸ In this context, it needs to be recalled that Urukagina connected the “little canal which Ĝirsu had” with the “canal which goes to Niĝen” (see above [14]). Based on remote-sensing data, Rey identified the “canal which goes to Niĝen” with a major northeast-southeast waterway that flowed east of Ĝirsu. Unlike Carroué and Rost, he suggested that the “little canal (which Ĝirsu had)” was a “second-tier water-supply feature [which] flowed through part of the city” and proposed an identification with a large-scale wadi-like gully in the western part of the tell that was flanked by a linear levee.⁹⁹ This problem yet remains to be solved.

[15]

As mentioned above, the water level within a primary canal is normally controlled by means of a regulator at the head gate (see above [4]). In the cuneiform sources from ED IIIb/Presargonic Lagaš, such a regulator would be expected to be mentioned in royal inscriptions as a part of a “primary canal” (i₇). Therefore, the Sumerian term for regulator is most likely ĝeš-keše₂-ra₂, which only appears in royal inscriptions of Eanatum, Enanatum I, Enmetena, and Urukagina (FAOS 5/1 Ean. 2 = RIM E1.9.3.5 vii 10; En. I 33 = E1.9.4.9 v 8; Ent. 35 = E1.9.5.26 iv 2, vi 2, viii 4; Ukg. 7 = E1.9.9.8 iii 1’).

However, the interpretation of ĝeš-keše₂-ra₂ is subject to a long-standing debate. Jacobsen regarded the so-called ‘construction énigmatique’, a huge structure of baked bricks and bitumen excavated at Tello/Ĝirsu discussed later (see below [16]), as a “weir” and assumed that the ED IIIb/Presargonic ĝeš-keše₂-ra₂ mentioned by Eanatum and Enmetena denote comparable hydraulic installations.¹⁰⁰ Based mainly on 2nd- to 1st-millennium lexical texts which mention *irritum*, *irritum ša* i₇, *mihir* i₇, and *riksum* as its Akkadian equivalents, Sauren and Salonen interpreted ĝeš-keše₂-ra₂ as a barrage (“Kanalsperre”) that regulated the water flow at the inlets or outlets of canals.¹⁰¹ Kupper and Sollberger accepted Jacobsen’s proposal, pointing out that the area of the ‘construction énigmatique’ yielded an inscription of Piriĝme of Lagaš (late 22nd century

97 Rost 2011, 226–227 n. 14.

98 De Maaijer 1996, 62–64 fig. 1; Rost 2011, 226–227 n. 14.

99 Rey 2016, 31–35.

100 Jacobsen 1960, 182.

101 Sauren 1966, 51–52; Salonen 1968, 218–219.

BC) that commemorates the construction of a $\dot{g}\acute{e}s\text{-}k\acute{e}\acute{s}_2\text{-}r_2$, and proposed an identification with the ‘construction énigmatique’.¹⁰² Bauer reviewed the ED IIIb/Presargonic attestations from Lagaš. He suggested that these inscriptions describe the $\dot{g}\acute{e}s\text{-}k\acute{e}\acute{s}_2\text{-}r_2$ as “great mountains of baked bricks” ($kur\text{-}gal\ \acute{s}eg_{12}\ alur_x$) with a varying “storage capacity” ($ni\dot{g}in_2$, ENGUR) of more than 1050 hl, and suggested an interpretation as storage reservoir (“Staubecken”).¹⁰³ This was accepted by Maeda, Steinkeller, Civil (“dam”) and Hruška (“Stauwehr”).¹⁰⁴ Cooper, likewise, translated $\dot{g}\acute{e}s\text{-}k\acute{e}\acute{s}_2\text{-}r_2$ as “reservoir”, but argued that the ED IIIb/Presargonic inscriptions from Lagaš did not refer to the $\dot{g}\acute{e}s\text{-}k\acute{e}\acute{s}_2\text{-}r_2$ as “great mountains of baked bricks”, but to the number of baked bricks used for their construction, which added up to 432 000 (2 $\acute{s}ar_2\text{-}gal\ \acute{s}eg_{12}\ alur_x\text{-}ra$) and 648 000 bricks (3 $\acute{s}ar_2\text{-}gal\ \acute{s}eg_{12}\ alur_x\text{-}ra$), respectively. In addition, he argued that the subsequent capacity measures did not refer to the “storage capacity” ($ni\dot{g}en_2$, LAGAB) of the $\dot{g}\acute{e}s\text{-}k\acute{e}\acute{s}_2\text{-}r_2$, but to an amount of “bitumen” ($esir_2$, LAGAB \times HAL) used to caulk the brickwork, differently computed at 2592 hl, 2528 hl, and 2649.9 hl.¹⁰⁵ Carroué independently proposed the same interpretation for Urukagina’s inscription that commemorated the construction of the $\dot{g}\acute{e}s\text{-}k\acute{e}\acute{s}_2\text{-}r_2$ at the “canal which goes to Niġen”. As this $\dot{g}\acute{e}s\text{-}k\acute{e}\acute{s}_2\text{-}r_2$ was constructed of durable materials and its respective inscriptions stemmed from Ġirsu, Carroué provisionally identified this $\dot{g}\acute{e}s\text{-}k\acute{e}\acute{s}_2\text{-}r_2$ as the inlet or head gate of this waterway (see above [14]) and interpreted $\dot{g}\acute{e}s\text{-}k\acute{e}\acute{s}_2\text{-}r_2$ as dam (“digue”).¹⁰⁶ Hruška considered Carroué’s proposal possible, but assumed that the bitumen would be used as mortar instead of caulking.¹⁰⁷ Postgate and Pemberton, Postgate, and Smyth fully agreed with Jacobsen’s proposal and pointed out that the use of baked bricks and bitumen documented by the inscriptions of Eanatum, Enmetena, and Urukagina perfectly agrees with the ‘construction énigmatique’. Based on a comparison with more recent and modern regulators from Nahrawan and modern Yemen, they assumed that ancient Near Eastern specimens operated flexible flood gates of wood, as indicated by the element $\dot{g}\acute{e}s$ “wood” in the term itself.¹⁰⁸ This interpretation was essentially adopted by Dight, who discussed further possible textual attestations of regulators, as well as their mode of operation, and emphasized the difference between a regulator and a weir or dam, but, to complicate matters, interpreted $kab_2\text{-}tar$ (see below [20]) as a designation for regulators, as well.¹⁰⁹ Rey, however, assumed that $\dot{g}\acute{e}s\text{-}k\acute{e}\acute{s}_2\text{-}r_2$ may also denote a “bridge”. He based this proposal on a recent reinterpretation of the ‘construction énigmatique’ that is discussed in the subsequent section (see below [16]).¹¹⁰

102 Kupper and Sollberger 1971, 119.

103 Bauer 1973, 9–11.

104 Maeda 1984, 43; Hruška 1988, 65; Steinkeller 1988, 74; Civil 1994, 130.

105 Cooper 1986, 42 n. 2; 81 n. 2.

106 Carroué 1986, 17–18.

107 Hruška 1988, 69 n. 29.

108 Postgate 1988, xi–xiii; Pemberton, Postgate, and Smyth 1988, 218–221; Postgate 1992, 177–178.

109 Dight 2002, 116–118.

110 Rey 2016, 32, 34.

A review of the evidence clearly demonstrates that $\hat{g}\acute{e}š-keše_2-ra_2$ denotes regulators that controlled the flow of water of “primary canals” (i_7). First of all, the distribution of textual references to $\hat{g}\acute{e}š-keše_2-ra_2$ is striking. While administrative texts never mention $\hat{g}\acute{e}š-keše_2-ra_2$, four royal inscriptions of Eanatum, Enanatum I, Enmetena, and Urukagina include seven attestations that refer to three, perhaps four, distinct $\hat{g}\acute{e}š-keše_2-ra_2$. These are, notably, only attested as part of “primary canals” (i_7) and constructed of durable materials, i.e. baked bricks and bitumen. The usage of these materials is also known from traditional Iraqi head regulators, indicates that $\hat{g}\acute{e}š-keše_2-ra_2$ were exposed to immense hydraulic stress and likewise argues for the abovementioned interpretation.¹¹¹ Eanatum “erected the $\hat{g}\acute{e}š-keše_2-ra_2$ of the LUMmagendu (canal) with 2.592 hl of bitumen” (d nin- $\hat{g}\acute{e}r_2$ -su-ra LUM-ma-gen $_7$ -du $_{10}$ mu-na-uš sa \hat{g} -eš $_2$ mu-ni-rig $_8$ e $_2$ -an-na-tum a $_x$ (DA) šum $_2$ -ma d nin- $\hat{g}\acute{e}r_2$ -su-ka-ke $_4$ $\hat{g}\acute{e}š-keše_2-ra_2$ LUM-ma-gen $_7$ -du $_{10}$ r esir $_2$!(LAGAB)¹ 60,00 gur 2-UL mu-ni-du $_3$, FAOS 5/1 Ean. 2 = RIM EI.9.3.5 vii 3–13). Though the sign denoting “bitumen” is, judging from the copy, slightly damaged, Bauer’s reading ni $\hat{g}\acute{e}n_2$ and its interpretation as “storage capacity”, is rather a guess based on the context, are virtually excluded. On the one hand, the corresponding description of the $\hat{g}\acute{e}š-keše_2-ra_2$ erected by Urukagina shows a clear instance of the sign esir $_2$ (LAGAB×HAL) “bitumen” instead of the very similar sign ni $\hat{g}\acute{e}n_2$ (LAGAB), as pointed out by Cooper and Carroué.¹¹² On the other hand, the element -ni- in the verb mu-na-ni-du $_3$ “he erected” can only refer to the material that the $\hat{g}\acute{e}š-keše_2-ra_2$ were made of and, thus, excludes the reading ni $\hat{g}\acute{e}n_2$ “storage capacity”.¹¹³ Enmetena, likewise, reports that “he erected the $\hat{g}\acute{e}š-keše_2-ra_2$ of the LUMmagendu (canal) with 648 000 baked bricks and 2649.6 hl (of bitumen)” ($\hat{g}\acute{e}š-keše_2-ra_2$ LUM-ma-gen $_7$ -du $_{10}$ 3 šar $_2$ -gal šeg $_{12}$ alur $_x$ -ra 30,40 gur-sa \hat{g} - $\hat{g}\acute{e}l_2$ en-me-te-na-ke $_4$ d nin- $\hat{g}\acute{e}r_2$ -su-ra mu-na-ni-du $_3$, FAOS 5/1 Ent. 35 = RIM EI.9.5.26 iv 2–8). As the amount of bitumen almost matches the figure given by Eanatum, Enmetena obviously restored the $\hat{g}\acute{e}š-keše_2-ra_2$ that was built by his predecessor. Unlike Eanatum, Enmetena used baked bricks (šeg $_{12}$ alur $_x$ -ra).¹¹⁴ Bauer translated “great mountain of baked bricks” (kur-gal šeg $_{12}$ BAHAR $_2$), but as Urukagina’s corresponding description of his $\hat{g}\acute{e}š-keše_2-ra_2$ unambiguously refers to a number of bricks instead of a “mountain” (2 šar $_2$ -gal šeg $_{12}$ alur $_x$ -ra), Cooper promoted the respective reading “648 000 baked bricks” (3 šar $_2$ -gal šeg $_{12}$ alur $_x$ -ra).¹¹⁵ In a later passage of this inscription, Enmetena boasts that he “erected the $\hat{g}\acute{e}š-keše_2-ra_2$ of the LUMma(gendu canal)(?) in the Guedena”, a fertile area in the border region between Lagaš and Umma (< $\hat{g}\acute{e}š$ >-keše $_2-ra_2$ LUM-ma<gen $_7$ -du $_{10}$ >(?)) gu $_2$ -eden-na-ka mu-na-ni-du $_3$, FAOS 5/1 Ent. 35 = RIM EI.9.5.26 vi 2–5). This could testify to the

111 Rost and Abdulmir 2011, 213–214.

112 Carroué 1986, 17–18; Cooper 1986, 80–81; cf. Stol 2012, 50.

113 On this usage of the prefix {ni} see Balke 2006, 47–48; Jagersma 2010, 176.

114 On šeg $_{12}$ alur $_x$ -ra “baked bricks” see Bauer 1973, 10 n. 8; Steinkeller 1978, 74 n. 6; Steinkeller 1987, 59; Heimpel 2009, 193.

115 Cooper 1986, 66–67.

construction of a second $\hat{g}\acute{e}s\text{-}k\acute{e}s\acute{e}_2\text{-}r\acute{a}_2$ at an otherwise unattested waterway in the Guedena area. That the $\hat{g}\acute{e}s\text{-}k\acute{e}s\acute{e}_2\text{-}r\acute{a}_2$ of the Lummagendu canal is again mentioned at the end of the inscription, and Enmetena refers to himself as “the one who erected (a) regulator(s)” ($\hat{g}\acute{e}s\text{-}k\acute{e}s\acute{e}_2\text{-}r\acute{a}_2$ du₃-a), might argue for the latter proposal.¹¹⁶ As the passage in question is badly preserved and seems to contain scribal mistakes, it might likewise refer to the $\hat{g}\acute{e}s\text{-}k\acute{e}s\acute{e}_2\text{-}r\acute{a}_2$ at the Lummagendu canal and indicate its location.¹¹⁷ The second well-attested $\hat{g}\acute{e}s\text{-}k\acute{e}s\acute{e}_2\text{-}r\acute{a}_2$ was constructed by Urukagina, who provided the “canal which goes to Niĝen” with a $\hat{g}\acute{e}s\text{-}k\acute{e}s\acute{e}_2\text{-}r\acute{a}_2$ of 216 000 baked bricks and 2620.8 hl of bitumen ([$\hat{g}\acute{e}s\text{-}k\acute{e}s\acute{e}_2\text{-}r\acute{a}_2$] i₇ niĝen^{ki}-du mu-na-du₃ 2 šar₂-ĝal šeg₁₂ alur_x-ra 30,20 gur-saĝ-ĝal esir₂ mu-na-ni-du₃, FAOS 5/1 Ukg. 7 = RIM E1.9.9.8 iii 1'-iv 5').¹¹⁸ This, most probably, took place when Urukagina connected the “little canal” with the “canal which goes to Niĝen” (see above [14]). Another reference to the construction of a $\hat{g}\acute{e}s\text{-}k\acute{e}s\acute{e}_2\text{-}r\acute{a}_2$ of baked bricks is found in an inscription of Enanatum I, Enatum’s successor, which is unfortunately badly preserved (en-an-na-tum₂-me ^dlugal-urub^{ki}-ra $\hat{g}\acute{e}s\text{-}k\acute{e}s\acute{e}_2\text{-}r\acute{a}_2$ [(x) ^dn]in-ĥur-saĝ-ĝa₂¹ [...] šeg₁₂ alur_x-ra mu-na-ni-du₃, FAOS 5/1 En. I 33 = RIM E1.9.4.9 v 6–11). Despite its bad preservation, it is clear that this $\hat{g}\acute{e}s\text{-}k\acute{e}s\acute{e}_2\text{-}r\acute{a}_2$ was dedicated to the god Lugalurub, whereas the aforementioned regulators were dedicated to Niĝirsu. Consequently, Enanatum’s inscription testifies to the existence of a third $\hat{g}\acute{e}s\text{-}k\acute{e}s\acute{e}_2\text{-}r\acute{a}_2$. As the $\hat{g}\acute{e}s\text{-}k\acute{e}s\acute{e}_2\text{-}r\acute{a}_2$ constructed by Enatum, Enmetena, and Urukagina were located at “primary canals” (i₇), this is likely for Enanatum’s $\hat{g}\acute{e}s\text{-}k\acute{e}s\acute{e}_2\text{-}r\acute{a}_2$ as well.

To sum up, ED IIIb/Presargonic royal inscriptions testify to the existence of at least three $\hat{g}\acute{e}s\text{-}k\acute{e}s\acute{e}_2\text{-}r\acute{a}_2$. As these were part of as many primary canals, consisted of baked bricks and bitumen, and their construction deserved mention in royal inscriptions, $\hat{g}\acute{e}s\text{-}k\acute{e}s\acute{e}_2\text{-}r\acute{a}_2$ most likely denotes a regulator. Their construction with baked bricks and bitumen, moreover, parallels that of modern Iraqi dams.¹¹⁹ This also agrees with the etymology of $\hat{g}\acute{e}s\text{-}k\acute{e}s\acute{e}_2\text{-}r\acute{a}_2$, which literally means “wood which binds”.¹²⁰ The element $\hat{g}\acute{e}s$ “wood” certainly refers to a flexible wooden gate.¹²¹ This might likewise agree with an early 2nd-millennium lexical list which mentions the “mouth”, i.e. the inlet, of a $\hat{g}\acute{e}s\text{-}k\acute{e}s\acute{e}_2\text{-}r\acute{a}_2$ (ka $\hat{g}\acute{e}s\text{-}k\acute{e}s\acute{e}_2\text{-}r\acute{a}_2$ = *pi i-ri-ri-ti*, Saĝ A iii [MSL SS 1: 22] 45). Another list associates the “reed of the $\hat{g}\acute{e}s\text{-}k\acute{e}s\acute{e}_2\text{-}r\acute{a}_2$ ” (*ge* $\hat{g}\acute{e}s\text{-}k\acute{e}s\acute{e}_2\text{-}r\acute{a}_2$) with the “reed of the kuĝ₂-zi-da” (*ge* kuĝ₂-zi-da, OB Forerunner Hĥ VIII–IX [MSL 7: 195] 171–173), amply attested as a designation of barrages of reed and mudbrick in administrative texts from the Ur III period (21st century BC).¹²² The fact that among the ca. 8000 administrative texts from the Ur III period, only three refer to a “ $\hat{g}\acute{e}s\text{-}k\acute{e}s\acute{e}_2\text{-}r\acute{a}_2$ of the god Enlil” ($\hat{g}\acute{e}s\text{-}k\acute{e}s\acute{e}_2\text{-}r\acute{a}_2$)

116 Cf. the remarks of Bauer 1973, 11 n. 10; Selz 1995, 172.

117 Maeda 1984, 43.

118 For collations and restorations, see Cooper 1986, 80–81, and Frayne 2008, 282.

119 Rost and Abdulmir 2011, 209–211.

120 Cf. Bauer 1973, 9.

121 Pemberton, Postgate, and Smyth 1988, 220.

122 On kuĝ₂ zi-da, see above [14] n. 91.

^den-lil₂(-la₂) in the province of Lagaš, perfectly corresponds to the lack of attestations in the ED IIIb/Presargonic administrative texts,¹²³ though Ur III royal inscriptions, likewise, provide a single reference (cf. above [13] on “primary canals”).¹²⁴ Finally, it needs to be pointed out again that the inscription of Piriġme of Lagaš, mentioned above, likewise, associates a ġeš-keše₂-ra₂ with a primary canal (i₇). More importantly, it was found in the same area as the ‘construction énigmatique.’ Notably, this corresponds to the assumed location of the “inlet” (ka) or the head gate of the “canal which goes to Niġen”, which was provided with a ġeš-keše₂-ra₂ by Urukagina. The question whether such ġeš-keše₂-ra₂ could be represented by the ‘construction énigmatique’ will be discussed in the following section.

[16]

In 1929–1932, excavations at Ġirsu/Tello unearthed the remains of a huge structure of baked bricks and bitumen with a length of ca. 40 m, a width of ca. 20 m, and a preserved height of ca. 4 m between the *Tells centraux* and the *Tell de l’Est*.¹²⁵ As the excavators interpreted this structure as either a sanctuary of the ancestry cult, a place of jurisdiction, or a regulator, and its function is still the matter of a long-standing debate, it is often referred to as ‘construction énigmatique.’¹²⁶ As already mentioned, Jacobsen compared the structure with a Sasanian weir at the Naharwan canal near Sharhurwan-al-asfal, interpreted it as a regulator and considered it to be an archaeological instance of the ġeš-keše₂-ra₂ mentioned by Eanatum, Enmetena, and Urukagina (see above [15]).¹²⁷ Barrelet doubted that the ‘construction énigmatique’ could be compared with the Sasanian regulator because of its dimensions. Most importantly, she objected that ‘construction énigmatique’ was constructed on an altitude that excludes an interpretation as a regulator.¹²⁸ Kupper/Sollberger pointed out that the areal of the ‘construction énigmatique’ yielded the inscription of Piriġme of Lagaš which commemorates the building of a ġeš-keše₂-ra₂ (see above [15]) and regarded the ‘construction énigmatique’ as the regulator built by this ruler.¹²⁹ Pemberton, Postgate, and Smyth adopted Jacobsen’s interpretation

123 Maekawa 1992, 212–214, 223 n. 55; 243 no. 92 rev. ii 16; Sallaberger 1993/1994, 58 no. 5 rev. 1–2; 58–59 n. 10. Sauren 1966, 51–52 takes keše₂-ra₂ in Ur III administrative texts as an orthographic variant of ġeš-keše₂-ra₂, but in fact this term almost always occurs as ma₂-la₂ keše₂-ra₂, which refers to the plaiting of reeds into a raft, see Civil 1994, 139 n. 50 and Steinkeller 2001, 33 n. 21.

124 Laurito and Pers 2002, 280, 288.

125 See the archaeological documentation in Parrot 1948, 211–219; Barrelet 1965, 112–115; Margueron

2005, 67–81; Huh 2008, 206–214, and the photographs in Parrot 1948, 213; Planche XXIVb; Postgate 1992, 177 fig. 9. 2; Margueron 2005, 71–73, 89; Rey 2016, 32.

126 See the summary of earlier interpretations in Barrelet 1965; Margueron 2005, 65–67; Huh 2008, 214.

127 Jacobsen 1960, 182.

128 Barrelet 1965.

129 Kupper and Sollberger 1971, 119. On the find-spot of this inscription see Parrot 1948, 108 n. 39; Barrelet 1965, 108, 114; Huh 2008, 210, 213.

as a regulator, but added that the use of bitumen and baked bricks corresponds with the description of *ĝeš-keše₂-ra₂* in ED IIIb/Presargonic inscriptions (see above [15]), though they estimated the amount of bricks used for the ‘construction énigmatique’ at approximately 68 500 and, thus, considered it to be a smaller cousin of the ED IIIb/Presargonic *ĝeš-keše₂-ra₂*. Referring to modern regulators from Yemen, they assumed that the regulator operated by means of a movable barrier of wood, pointing out that according to the excavators a “cavité profonde était visible, ou l’on reconnaît volontiers un point précis d’attache pour une poutre du toit.”¹³⁰ Dight subscribed to this interpretation.¹³¹ Recently, Margueron published a thorough review of the archaeological data and earlier proposals. Most importantly, he demonstrated that the ‘construction énigmatique’ was erected at a much lower altitude than Barrelet had assumed. Moreover, he interpreted the thalweg between the central and eastern tells as the course of an ancient canal and regarded the use of bitumen in the ‘construction énigmatique’ as a clear indication of a waterway. However, Margueron argued that the remains of the ‘construction énigmatique’ show no traces of a beam slot used to fix a movable gate or barrage. As he, in addition, doubted that a regulator would be located within the city, he proposed a reconstruction of the ‘construction énigmatique’ as a bridge gapping a canal.¹³² This was subsequently accepted by Rey.¹³³

The interpretation of the ‘construction énigmatique’ is, thus, still a matter of debate. Though, a regulator is by no means excluded. On the one hand, Margueron demonstrated that the altitude of the structure did not exclude a regulator, and, on the other hand recent survey and geodata identified the thalweg between the *Tell de l’Est* and the *Tells centraux* as the course of an ancient canal, possibly to be identified with a section of the “canal which goes to Niĝen.” Moreover, the cuneiform evidence outlined above (see above [14]) demonstrates that the inlet or even the head gate of the “canal which goes to Niĝen” is expected in the same area as the ‘construction énigmatique’. In addition to this, the fact that both ED IIIb/Presargonic *ĝeš-keše₂-ra₂* and modern regulators from Iraq were built of baked bricks and bitumen could likewise indicate that the ‘construction énigmatique’ was a regulator. The fact that these are also used as bridges gapping canals could harmonize these data with Margueron’s proposal to interpret the structure as a bridge.¹³⁴

130 Pemberton, Postgate, and Smyth 1988, 218–221, with a reference to Parrot 1948, 216.

131 Dight 2002.

132 Margueron 2005.

133 Rey 2016, 32–33.

134 Rost and Abdulamir 2011, 211, 216.

[17]

It is generally agreed that the Sumerian designation for secondary canals and canals of lower rank is pa_5 , corresponding to Akkadian *atappu*, *palgu*, and *pattu*.¹³⁵ A notable exception to this interpretation was made by Jacobsen; he assumed that “ pa_5 often run along the top of artificial dykes (e[g_2]) to preserve desirable elevation?”¹³⁶

The pa_5 canals are attested first in the ED IIIa/Fara period (2575–2475 BC) copies of *Word List C*, where the sign pa_5 interchanges with the more archaic writing A (see above [6]). The sign pa_5 in its typical shape is a compound consisting of the sign E or eg_2 in which the sign PAP or pa_4 is inscribed (E × PAP). Two explanations have been suggested. Assuming that the denomination of a canal as pa_5 is not determined by its size, but “on the condition that canals of the same rank run parallel and cross or join each other”, Maeda analyzes pa_5 as a compound of E and PAP, i.e. “canal + cross”.¹³⁷ Steinkeller, in contrast, considered pa_5 to be a compound of eg_2 , which he interpreted as a pictograph of “the cross-section of two parallel ridges or levees, separated by a raised water channel” or “a broad earthen wall which accommodated a ditch or small canal running along its top”, and pa_4 , which he considered to represent “a profile of a ditch”.¹³⁸ This implies the existence of a more developed irrigation network. The pictographic value of these signs, however, is a matter of debate (see below [18]). ED IIIa/Fara period copies of *Word List C*, however, more often testify to the disjunct graphic variant PAP.E, instead of a compound E × PAP (see above [6]),¹³⁹ which is still used in an inscription of Urnašē.

The pa_5 are attested in ED IIIb/Presargonic royal inscriptions and administrative texts from Lagaš. Their distribution supports the interpretation of ‘secondary canal’. In the royal inscriptions, only four references to pa_5 are found, mostly in hydronyms.¹⁴⁰ Two are included in the name of the Pasaman or Pasamankas₄.DU canal, which is discussed above and denotes a primary canal, despite its name (see above [13]). The Paku canal (pa_5 -ku₃), a waterway mentioned by Enmetena, is said to be adjoined by fields (aša₅ abbar niĝen^{ki}-ka pa_5 -ku₃-ge us₂-sa, FAOS 5/1 Ent. 1 = RIM E1.9.5.17 v 3–4). In a historical inscription that reports the “water war” between Lagaš and Umma, Eanatum of Lagaš obliges the enemy ruler on oath not to invade Lagašite territory and not to alter “its dikes and ditches” (eg_2 pa_5 -be₂, FAOS 5/1 Ean. 1 = RIM E1.9.3.1 xvi 30 *et passim*). This provides the earliest attestation for the binominal expression eg_2 pa_5 “dike (and) canal”. It is also found in the ED IIIb/Presargonic personal name lugal- eg_2 - pa_5 -mah₃ (DP

135 Stol 1976–1980, 356; Maeda 1984, 39, 46; Hruška 1988, 61, 63, 65; Steinkeller 1988, 73; Civil 1994, 109–112. Hruška 1988, 65, assumes that pa_5 canals were also used for shipping traffic, but the sources he quotes do not support this assumption.

136 Jacobsen 1982, 62.

137 Maeda 1984, 46.

138 Steinkeller 1988, 73.

139 Civil 2013, 42.

140 Behrens and Steible 1983, 274, 423–424; Laurito and Pers 2002, 276–277, 282.

612 obv. iii 1), which clearly refers to the king's function as provider of the irrigation network,¹⁴¹ but is more amply attested in later sources and thought to refer to the whole of the irrigation network.¹⁴²

Surprisingly, only two, maybe three of fifty-seven administrative texts pertaining to irrigation mention pa₅ canals, providing four or five references in total (DP 648 obv. i 3, obv. ii 2; VS 27, 23 obv. iii 2–3; VS 27, 36 obv. ii 1). Attestations are also found in place names and hydronyms, such as pa₅ absu “pa₅ canal of Absu”, mentioned in a survey of waterworks at the u₃ of the Imaḥ canal at the Daterabbar field (VS 27, 36 obv. ii 1), and the toponyms pa₅-enku, pa₅-sir₂^(ki)-ra, and pa₅-še-muš which derive from waterways.¹⁴³ The most instructive references are found in an administrative text that mentions three waterways with lengths of 60 m, 360 m, and 870 m, respectively, states that “these are pa₅ canals of the Urindua field” (pa₅ aša₅ urin-du₃-a-kam, DP 648 obv. ii 2), and records their “hoeing” by the chief administrator of the Babu temple (en-ig-gal nu-banda₃ al bi₂-du₃ 4., DP 648 rev. i 1–3). This indicates that pa₅ canals were situated alongside fields. Notably, the shorter waterways with lengths of 60 m and 360 m are referred to as “straight i₇ canal” and “i₇ canal at its side”, respectively, but subsumed under the rubric “large pa₅ canals” (1,00 NIĜ₂.DU i₇ si-sa₂ 10 NIĜ₂.DU i₇ da-ba pa₅ gu-la-am₆, DP 648 obv. i 1–3). The longest waterway, on the contrary, is referred to as “pa₅ canal at the side of the wall” with a length of 870 m (2,20 NIĜ₂.DU ½ eše₂ pa₅ da bad₃-ka ġal₂-la-am₆, DP 648 obv. ii 1). Normally, i₇ denotes “primary canals”, but this apparent terminological deviation could easily be explained by the assumption that i₇ is used here in its generic meaning “canal (*par excellence*)” (see above [13] for a different proposal). The fact that an administrative text refers to an “i₇ canal of the Urindua field” (i₇ aša₅ urin-du₃-a, DP 646 rev. i 1–3), which is possibly the same as the “pa₅ canal of the Urindua field” (pa₅ aša₅ urin-du₃-a-kam, DP 648 obv. ii 2) could support this assumption.

In connection to this, a survey of “dikes at the Urindua field” (eg₂ aša₅ urin-du₃-a, DP 641 rev. v 5) deserves mentioning. It refers to a stretch of dike “from the wall of the temple of the goddess Babu to the temple of the goddess Našše, the tamarisk garden is its border” with a length of 840 m (bad₃ e₂-mi₂-ta e₂ d^{našše}-[še₃] 2,20 NIĜ₂.DU [eg₂ nu]-ke₃-dam ġeš^{še}šeneg sar-ra za₃-be₂, DP 641 obv. i 1–4) and goes on with the measurement of a stretch of dike extending “from the tamarisk garden to the temple of the goddess Nanše” of 390 m (ġeš^{še}šeneg sar-ra-ta e₂ d^{našše}-še₃ 1,00 NIĜ₂.DU ½ eše₂ eg₂ ke₃-dam, DP 641 obv. i 5–ii 2). Their combined length of 840 m + 390 m matches the total length of the aforementioned “straight i₇ canal” and “pa₅ canal at the side of the wall” with 870 m + 360 m, respectively. In consequence, the “pa₅ canal at the side of the wall” and the

141 On this name, see Foxvog 2011, 83; Andersson 2012, 132, 322.

143 See the references in Edzard, Farber, and Sollberger 1977, 135–137.

142 Foxvog 1986, 65; Civil 1994, 112.

“straight i_7 canal” hoed by the chief administrator of the temple of the goddess Babu (DP 648) correspond to the dikes extending “from the wall of the temple of the goddess Babu to the temple of the goddess Nanše” and those “from the tamarisk garden to the temple of the goddess Nanše” in the survey of dikes at the Urindua field (DP 641).¹⁴⁴ This means that the former text mentions the pa_5 canals themselves, whereas the latter refers to their “dikes” or “embankments” (eg_2) instead. As these are the most frequently-attested elements of the irrigation network in ED IIIb/Presargonic administrative texts from Lagaš, on the one hand, and are most often associated with fields, on the other (see below [18]), it is highly probable that many attestations of such “dikes” (eg_2) in fact refer to those of the pa_5 canals that irrigated fields. This assumption is confirmed by a survey of “dikes of the Daterabbar field” (eg_2 $a\check{s}a_5$ $da-ter-abbar^{ki}$ - $ka-kam$, VS 27, 23 rev. ii 4). It refers to two “(stretches of) dikes which will not be made” (eg_2 $nu-ke_3$ - dam , VS 27, 23 rev. i 2) that extend on a length of 600 and 540 m, respectively, and are said to lie alongside the $MURGU_2$ - pa_5 . Though its meaning is unclear, $MURGU_2$ - pa_5 apparently refers to a sort or a part of a pa_5 canal (1,40 $ni\hat{g}_2$.DU eg_2 $MURGU_2$ pa_5 - da nu_2 - a za_3 - be_2 1,30 $ni\hat{g}_2$.DU $MURGU_2$ pa_5 - $danu_2$ - $a-ta$ i_7 d $en-lil_x(E_2)$ - pa_3 za_3 - be_2 , VS 27, 23 obv. iii 1–rev. i 1). This assumption, likewise, agrees with the suggestion that pa_5 often run along the top of dikes (eg_2), is probably also supported by the close association of pa_5 and eg_2 in the binominal expression eg_2 pa_5 - $(-be_2)$ “dikes (and) ditches”, and is finally matched by the fact that fields are often associated with eg_2 (see below [18]). The last reference to pa_5 canals in the irrigation texts is found in a survey. It mentions a “ pa_5 canal of Abzu” (pa_5 $abzu$) and a “distributor of (the) Abzu (canal)” (kab_2 - tar $abzu$) (VS 27, 36 obv. i 3–ii 1). This indicates that pa_5 canals irrigated fields and most likely means that “distributors” (kab_2 - tar) regulated the water flow from the pa_5 canal to the furrows (see below [20]).¹⁴⁵ Administrative texts dealing with fields and orchards corroborate this conclusion. An allocation of subsistence fields ($a\check{s}a_5$ $\check{s}uku$) to temple dependents demonstrates that pa_5 canals were situated “at their side” ($a\check{s}a_5$ $ni\hat{g}_2$ - e_{11} - $\check{s}e_3$ $\hat{g}al_2$ - la pa_5 za_3 - be_2 , DP 607 obv. ii 3–4). Though further references in the ED IIIb/Presargonic texts from Lagaš are lacking, an ED IIIb/Presargonic legal document from the city Isin documenting sales of land mentions several fields that were located at pa_5 canals.¹⁴⁶ An account of timber from the “orchard of the goddess Babu” ($kiri_6$ d $ba-bu_{11}$) demonstrates that the woodlands of the temple, likewise, were irrigated by pa_5 canals and mentions, for example, that “the 3rd pa_5 canal” of an orchard “is located along the side of the bank of the (primary) canal” (pa_5 $3c$ - kam - ma - am_6 a_2 gu_2 i_7 - ka - $\check{s}e_3$ e - $\hat{g}al_2$, DP 419 obv. ii 1–2, see also DP 419 obv. i 3, 7,

144 Maeda 1984, 40–41, 46.

145 Maeda 1984, 45.

146 Wilcke 1996, 47–73 obv. 1–4, iii 3–5, etc.

ii 5, iii 2, 5, iv 2, rev. i 1, 5; DP 424 obv. i 3, ii 3, 5, rev. i 1, ii 4, ii 6, iii 2).¹⁴⁷ Another timber account refers to “tamarisks at the dikes of the Dakišeg field, which were counted where they grew” (^ḡēš^ššeneg eg₂ aša₅ da-kišeg₂-ka ki mu₂-a ba-šid-da, VS 27, 79 rev. i 1–2), and even mentions a near-by “distributor” (kab₂-tar) (kab₂-tar ur-^dnašše-na-silim-ma-ta eg₂ aša₅ ^dinnana-ka za₃-be₂, VS 27, 79 obv. iv 1–2).¹⁴⁸ The pa₅ canals irrigating orchards on top of the riverine levees would be expected to flow normal to the primary canal from which they drew their water,¹⁴⁹ as indicated by a Classic Sargonic or Post Sargonic/Late Akkadian map from Ġirsu (RTC 258). This is also true for orchards with vegetables (DP 387 obv. i 3, rev. i 2). Occasionally, “dikes” in gardens (eg₂ du₃-a kiri₆, eg₂ kiri₆ du₃-a) are mentioned (DP 655 obv. i 1–2, rev. ii 1; VS 14, 100 = AWL 1 obv. i 1–2, ii 5–6, see below [18]). Most likely, these refer to the embankments that accompanied the respective pa₅ canals. A section of such a pa₅ canal is possibly described in a document that records the survey and acceptance of “work at the Daterabbar field” (kiġ₂ aša₅ da-ter-abbar^{ki}-ka-kam, DP 654 rev. iii 1), which is discussed later (see below [20]).

To sum up, the term pa₅ is attested almost exclusively in administrative texts from the temple of Babu and designates “secondary canals.” These were fed by “primary canals” (i₇) and irrigated the fields and orchards of the temple that were situated along these waterways. The fact that the administrative texts include only very few references to pa₅ is conditioned by the fact that eg₂ often refer to the “dikes” or “embankments” that accompanied the secondary canals, in perfect agreement with the interpretation of eg₂ as “dike”, “embankment” proposed in the next section.

[18]

The most frequent term in the ED IIIb/Presargonic texts from Lagaš is e or eg₂, which corresponds to Akkadian *ikum*.¹⁵⁰ The earliest attestations are found in an Early Dynastic I/II administrative text from Ur that mentions a field located at an eg₂ and a list of “men who work at the eg₂” from Fara/Šuruppag dating from the subsequent Early Dynastic IIIa/Fara period (see above [5]). Copies of *Word List C*, datable to the same period, mention eg₂ along with other terms pertaining to the irrigation network (see above [6]). However, the meaning of eg₂ is debated. Thureau-Dangin referred to lexical lists which equate eg₂ si-ga with Akkadian *i-ku iš-pu-uk* and descriptions in terms of height and concluded that eg₂ means “levée de terre”.¹⁵¹ Edzard noted that Old Babylonian date formula

147 Civil 1994, 113. Note that RTC 151, a Sargonic period map depicting various canals, mentions a “(primary) canal” (i₇) by the name of ter-sikil “pure forest”, which might derive from a near-by forest, see Selz 2011, 214 n. 6.

148 Selz 2011, 222–224.

149 Wilkinson 2003, 92.

150 For the reading eg₂ instead of e see Civil 1994, 136 n. 2. Bauer 2009, 256, points to an interchange of eg₂ and a in eg₂ zi-^{du} and a zi-^{du}, respectively.

151 Thureau-Dangin 1932, 23–25.

refer to the construction of the Anepada canal, observed that eg_2 – $si.g$ correlates with i_7 – $ba-al$ “to dig a canal”; concluded that $si.g$ means “dredge” and that both date formula refer to successive stages in the construction.¹⁵² This interpretation was accepted by Sauren, who reviewed Ur III administrative texts and suggested that eg_2 has three meanings. Based on Edzard, he assumed that eg_2 meant a canal in an earlier stage than i_7 . In addition, he proposed that eg_2 denotes both a small canal, as well as a dike that accommodates a canal.¹⁵³ The latter interpretations were subsequently adopted by Salonen.¹⁵⁴ Most scholars accepted that eg_2 denotes a “ditch”, and Stol, resuming Edzard’s proposal $si.g$ = “dredge”, even stated “prinzipiell hieß jeder Kanal, der ein Feld umgab, ob klein oder groß, $e[g_2]$ (*ikum*).”¹⁵⁵ Jacobsen proposed a different solution. Interpreting pa_3 as a designation for “branch canals and feeders”, he assumed that these “run along the top of artificial dykes ($e[g_2]$) to preserve desirable elevation” and thus associated eg_2 with dikes, levées or bunds.¹⁵⁶ Foxvog independently pointed out that $saḥar$ – $si.g$ “to fill earth (upon/into) apparently refers to the raising up of an earthen levee, whether a dam or dike, or the walls of an irrigation ditch” and regarded pa_3 “as the proper ditch and eg_2 as its retaining wall.”¹⁵⁷ Based on Jacobsen and Foxvog, Steinkeller elaborated this proposal. He interpreted the sign ϵ or eg_2 as a depiction of “the cross-section of two parallel ridges or levees, separated by a raised water channel” or “a broad earthen wall which accommodated a ditch or small canal running along its top”. In addition to this, he pointed out that eg_2 are never attested with verbs for “digging” or “dredging” (dun , $ba-al$), but with terms for “erecting, raising” (du_3), “piling up” ($si.g$), and “making” (AK) and described in terms of height ($sukud$), while id_2 have a “depth” (bur_3). Thus, he concluded that “what the eg amounted to, therefore, was two parallel ridges or levées, separated by a raised water channel” and referred to modern Iraqi *fāriq* and *umud* for comparison, argued that eg_2 never refers to a water channel and translated it as “dike” for convenience.¹⁵⁸ Pemberton, Postgate, and Smyth, in contrast, suggested the more neutral translation “bund”. First, they pointed out that later lexical lists mention “canal bunds”, “field bunds”, and “boundary bunds” (eg_2 i_7 - da = (*iku*) *na-a-ru*, eg_2 a - $\dot{s}a_3$ - ga = (*iku*) *eq-li*, eg_2 us_2 - sa - du = (*iku*) *i-te-e*). Thus, they saw no reason to associate the eg_2 mentioned in cuneiform texts with canals, and so interpreted eg_2 “as walls to contain and direct the flow of water”. Though they agreed with Jacobsen and Steinkeller in interpreting ϵ or eg_2 as a depiction of a canal with banks each side, they considered the meanings “canal”, “canal-between-bunds”, and “bund” likewise possible. But as an Old Babylonian inscription of Rimsin of Larsa refers to a canal with “its two banks like mountain” (eg_2 2 - a - be_2

152 Edzard 1957, 112 n. 567.

153 Sauren 1966, 40–42.

154 Salonen 1968, 216.

155 Nissen 1976, 25; Stol 1976–1980, 356; Maeda 1984,

39–42; Hruška 1988, 61, 65; Renger 1990, 32–33.

156 Jacobsen 1982, 62.

157 Foxvog 1986, 65.

158 Steinkeller 1988, 73–74.

hur-saĝ-gen₇), they concluded that each of the two ridges of a canal was a single eg₂ and referred to the binominal expression eg₂ pa₅ “bunds and canals” as a support. Finally, Pemberton, Postgate, and Smyth emphasized that this reinterpretation has significant implications. On the one hand, the long-running border dispute between Lagaš and Umma would have been fought for a border bund (eg₂) instead of a canal. On the other hand, the assumption that fields were usually surrounded by bunds would imply that basin irrigation was normal.¹⁵⁹ Similarly, Waetzoldt translated eg₂ as “Damm; Deich; Graben mit Dämmen” and “breiterer Wassergraben”, pointing out that only contextual data allows for a differentiation between dikes that accompanied waterways or canals on both sides, flood dikes and dikes which accommodated a canal, or the waterway itself.¹⁶⁰ Based on lexical, literary, and administrative texts mostly from the Ur III period, Civil provided a thorough review of prevalent interpretations. He pointed out that si.g does not mean “to dredge”, but “to pile up” and concluded that the abovementioned interpretations as “ditch”, “small canal”, and the like have no basis. As eg₂ and pa₅ are associated with si.g = *šapākum* “to pile up” and ba-al = *herûm* “to dig”, he argued that eg₂ refers to “embankments”. In support of this conclusion, he interpreted the binominal expression eg₂ pa₅ “levees and irrigation ditches” as a designation for the whole hydraulic system, which stands for the whole range of terms designating artificial watercourses, though admitting that textual sources referring to the “two sides” of a canal (a₂ 2-a-be₂) indicate that only one of the two embankments of a ditch is referred to. As corroboration, Civil discussed different types of work undertaken at eg₂ structures, such as “erecting” (du₃), “piling up” (si.g), or reinforcing of levees or banks with vegetable matter, such as reeds, rushes, and sand (u₂-saĝ₁₁).¹⁶¹ Based on a unique ED IIIb/Presargonic document that describes eg₂ in terms of “its two banks” (gu₂ 2c-be₂), Steinkeller translated eg₂ as “a small canal” and considered his previous interpretation as ascertained.¹⁶² Most recently, Monaco commented on the shape of the archaic correspondents of eg₂. He assumed that “[t]he sign, in its basic shape (E_a), most probably is a pictographic representation of a dyke with two branches attached, as streams of water flowing out of it, to form ditches or channels for irrigation purposes”, emphasizing that “the sign developed from the original four branches shape (Uruk IV) [ca. 3300–3000 BC] to the two branches shape (Uruk III/ED I and later periods) [ca. 3000–2700 BC], with an intermediate three branches shape.”¹⁶³

Whether the sign E or eg₂ depicts the profil of a dike with a channel on its top or a canal with ditches, thus, remains unclear, especially when taking into account that the earliest attestations for eg₂ “dike”, “embankment” are attested in an ED I/II administrative

159 Pemberton, Postgate, and Smyth 1988, 212–217.

160 Waetzoldt 1990, 1–3, 16–17.

161 Civil 1994, 109–140.

162 Steinkeller 1999, 543.

163 Monaco 2014, 280.

text from Ur (ca. 2700 BC) and ED IIIa/Fara period (2575–2475 BC) copies of *Word List C* (see above [5]–[6]). A review of ED IIIb/Presargonic textual references, however, demonstrates that *eg*₂ almost always refers to a “dike” or “embankment”.

Royal inscriptions, in contrast, include only two or three attestations that relate *eg*₂’s with major canals and their branch-offs, such as the inscriptions of Enmetena that report the extension of the *eg*₂ of the Imah₃ canal (FAOS 5/1 Ent. 41 = E1.9.5.2); these rather refer to earthen embankments piled up to serve as border demarcations (*e*₂-an-na-tum₂ ensi₂ lagas_x(NU₁₁.BUR)^{la.ki} pa-bil₃-ga en-mete-na ensi₂ lagas_x(NU₁₁.BUR)^{la.ki}-ke₄ en-a₂-kal-le ensi₂ umma^{ki}-da ki e-da-sur *eg*₂-be₂ i₇ nun-ta gu₂-eden-na-še₃ eb₂-ta-ni-e₃ (...) *eg*₂-ba na-ru₂-a e-me-sar-sar na-ru₂-a me-silim-ma ki-be₂ bi₂-gi₄ eden umma^{ki}-še₃ nu-dib, FAOS 5/1 Ent. 28/29 = RIM E1.9.5.1 i 32–ii 10/ii 1–27).¹⁶⁴ Urnāšē reports the “digging” (*dun*) of several primary canals (*i*_x) as well as a waterway by the name of *eg*₂-ter-sig, which is clearly identified as a canal by the verb *dun* “to dig” (*eg*₂-ter-sig *mu*-dun, FAOS 5/1 Urn. 26 = RIM E1.9.1.9 iv 1–2, see above [13]). The fact that it bears a proper name suggests a primary canal, but this is a notable exception. Instead, royal inscriptions mention *eg*₂ that were “erected” (*du*₃), such as the *eg*₂ da-šal₂ (*eg*₂ da-šal₂ mar-du₂ *mu*-du₃, FAOS 5/1 Urn. 40 = RIM E1.9.1.31 ii 1–3), which is known as the “dike of the Dasal field” from later archival records (*ki*₂ aka *eg*₂ da-šal₂-ka-kam, DP 636 rev. ii 1; on the field cf. Nik. 1, 80 = AWEL 80 obv. i 3; VS 14, 85 = AWL 12 rev. i 2; VS 14, 167 = AWL 15 obv. ii 3), or “made” (*ak*), such as the “exalted border dike/embankment of Ninġirsu” (*eg*₂ maḥ^d nin-ġir₂-su-ka, FAOS 5/1 Ent. 41 = RIM E1.9.5.2 v 1–4). Others rather seem to refer to embankments piled up to demarcate the border between Lagaš and its northwestern neighbor Umma, such as “the border embankments of Ninġirsu and the border embankments of Našše” (*eg*₂ ki-sur-ra^d nin-ġir₂-su-ka *eg*₂ ki-sur-ra^d našše). This is obviously indicated by an inscription of Eanatum obligating the ruler of Umma not to transgress “its *eg*₂ and *pa*₅ canals” (*eg*₂ pa₅-be₂, FAOS 5/1 Ean. 1 = RIM E1.9.3.1 obv. xvi 25–31 *et passim*), which supports the assumption that *eg*₂ almost exclusively denotes dikes or embankments (cf. FAOS 5/1 Ean. 1 = RIM E1.9.3.1 rev. v 12–13, 37–38; En. I 29 = RIM E1.9.4.2 viii 2–4; Ent. 28/29 = RIM E1.9.5.1 iii 2–4/iii 28–30, vi 9–20/vi 21–32). However, Enmetena reports that the rulers of Umma “had the water go out” (*a*-e i₃-mi-e₃) the border embankments of Ninġirsu and the border embankments of Našše (*ur*-lum-ma ensi₂ umma^{ki}-ke₄ *eg*₂ ki-sur-ra^d nin-ġir₂-su-ka *eg*₂ ki-sur-ra^d našše *a*-e i₃-mi-e₃, FAOS 5/1 Ent. 28/29 = RIM E1.9.5.1 ii 28–35/iii 12–19; cf. iii 34/iv 24–iv 10/iv 38).¹⁶⁵ This supports the assumption that *eg*₂ occasionally also denotes “a small canal” referred

164 Behrens and Steible 1983, 95; Steiner 1986, 220, 222–223; Pemberton, Postgate, and Smyth 1988, 212, 214, 216; Laurito and Pers 2002, 276–285.

165 On this much-debated passage, cf. Ceccarelli 2015; Keetman 2015.

to above, as indicated by a ED IIIa/Fara period incantation (SF 54 = BFE 6, see above [5]).

While royal inscriptions hardly contain a handful of references, thirty-nine of fifty-seven administrative texts, corresponding to 68.5% of the total, refer to *eg₂*, providing 100 attestations in total (DP 614 rev. i 1; DP 615 rev. ii 1; DP 616 obv. i 1, rev. ii 1; DP 617 obv. i 1, rev. iii 1; DP 622 obv. v 8, rev. iii 2, iv 2, iv 3; DP 623 obv. iii 7, 9, v 4, rev. i 2, v 2; DP 624 rev. i 1; DP 625 rev. ii 2; DP 626 obv. i 1, rev. i 1; DP 627 obv. i 1, rev. i 1; DP 630 obv. i 1, iv 4, rev. i 6, ii 1, 2; DP 634 rev. iii 3; DP 636 rev. ii 1; DP 638 rev. ii 2; DP 639 obv. i 1; DP 641 obv. i 3, ii 1, 4, 6, rev. iii 1, 5, 9, iv 1, 2, v 2, 3, 5; DP 642 obv. i 1, 2, ii 1, 3, rev. i 2, 3, ii 4; DP 645 obv. ii 7; DP 652 rev. i 2; DP 653 rev. ii 1; DP 654 rev. i 2; DP 655 obv. i 1, rev. i 1; DP 656 obv. i 1; DP 657 obv. i 1, rev. ii 1; TSA 24 rev. i 3; VS 14, 100 = AWL 1 rev. i 1; VS 14, 130 = AWL 2 obv. i 1, 2, ii 2, 3, iii 1, rev. i 1, ii 1, iii 1; VS 25, 74 rev. v 2; VS 25, 77 obv. i 2, rev. i 2; VS 25, 83 obv. i 1, rev. ii 1; VS 25, 84 rev. iii 1; VS 25, 86 rev. iii 2; VS 25, 97 obv. i 5, ii 3, iv 1, rev. i 1, 3, ii 2, 4, iii 2, 4, iv 2; VS 25, 100 rev. iii 1, 3, iv 2; VS 25, 103 obv. i 2, rev. ii 1; VS 25, 105 rev. ii 2; VS 27, 23 obv. i 1, 2, ii 3, iii 2, rev. i 2, ii 2, 3, 4, iii 3; VS 27, 96 rev. iii 2). Thus, *eg₂* is the most frequently-mentioned irrigational term. The observation that most Ur III text pertaining to irrigation testify to the construction and maintenance of dikes or embankments likewise applies to the ED IIIb/Presargonic texts from Lagaš.¹⁶⁶

As the precise meaning of *eg₂* is controversial, the most important physical characteristics will be addressed first. Most references to *eg₂* are found in survey texts and work assignments that describe *eg₂* in terms of their length, such as “from the *durun_x* of the *Imaḥ* (canal): 20 rods. This is (a section of) dike not to be done (*durun_x i₇-maḥ-ta 20 niĝ₂.DU eg₂ nu-ke₃-dam*, VS 14, 130 = AWL 2 obv. i 1–2), “total: 70 rods (is the section of) dike of the *ušgal* field” (*šū-niĝen₂ 1,10 niĝ₂.DU eg₂ aša₅ uš-gal-kam*, DP 622 obv. v 7–8), and the like. A handful of references, however, include more detailed data and support the meaning of “dike” or “embankment”. Occasionally, dikes are summarized as “dikes, among them small and large ones” (*eg₂ tur maḥ-ba*, VS 14, 100 = AWL 1 rev. i 1) or referred to as “small dikes” (*eg₂ tur-tur*, DP 641 rev. iii 5). Such general qualification may perhaps be compared to the “exalted border dikes/embankments” mentioned in an inscription of Enanatum I (*eg₂ maḥ ki sur-ra*, FAOS 5/1 Ent. 41 = RIM E1.9.5.1 ii 4, v 2). The most instructive text is a survey of dikes at fields of the wife of the ruler (*eg₂ aša₅ u₂-rum para₁₀-nam-tar-ra dam lugal-AN-da ensi₂ lagaš_x(NU₁₁.BUR)^{la,ki}-ka*, VS 25, 97 rev. iv 2–6). The first section denotes the lengths of dikes at the *Urindua* field, adding up to 1140 rods ½ rope 1 reed or 6.840 m (*šū-niĝen₂ 20,00 la₂ 1,00 ½ eše '1c' ge niĝ₂.DU eg₂ 'aša₅ urin-du₃-a-kam*, VS 25, 97 obv. iv 4-rev. i 1). Notably, this text also denotes their “height” (*sukud*), and includes notations such as “40 rods [= 240 m] 3 reeds [= 9 m] (is

166 Hunt 1988, 193; Civil 1994, 110, 134.

their length), 2 cubits [= 1 m] is their height, these are (the dikes) at the side of the wall” (VS 25, 97 obv. i 1–2 40 NIĜ₂.DU 3c ge sukud-be₂ kuš₃ 2c da bad₃-kam), “80 rods [= 480 m] (is their length), 2 cubits [= 1 m] is their height, 20 rods [= 120 m] (is their length), 3 cubits [= 1.5 m] is their height, these are the dikes that run from the Imaḥ canal to the erected emblem of the goddess Nanše” (1,20 NIĜ₂.DU sukud-be₂ kuš₃ 2c 20 NIĜ₂.DU sukud-be₂ kuš₃ 3c eg₂ i₇ maḥ-ta urin-du₃-a^d našše-še₃ ḡal₂-la-am₆, VS 25, 97 obv. i 3–ii 1). This indicates that eg₂ denotes “dikes” with a height varying of 1 m, 1.5 m (see above), 2 m (3,40 NIĜ₂.DU 8c ge sukud-be₂ kuš₃ 4c, VS 25, 97 obv. ii 2), and 2.5 m (4,00 NIĜ₂.DU sukud-be₂ kuš₃ 5c, VS 25, 97 obv. ii 4). Another administrative text that records a survey and acceptance of a work quota, likewise, describes kab₂-tar distributors in terms of height and includes notations such as “(its length is) ½ rope, its width is 2 reeds, its height is 3 cubits. (Its length) is 4 reeds, its width is 2 reeds, its height is 1 reed, it is that of the kab₂-tar distributor of Damu” (½ eše₂ 2c ge daḡal-be₂ 2c ge-am₆ sukud-be₂ kuš₃ 3c 4c ge daḡal-be₂ 2c ge sukud-be₂ 1c ge kab₂-tar da-mu-ka-kam, DP 654 obv. i 1–ii 1, cf. also DP 654 obv. ii 3–5, iii 3–5).¹⁶⁷ That these figures denote the length, width and height of “dikes” that constituted kab₂-tar distributors is clear from a work assignment that lists work several quotas on “dikes of the Ašatur (field)” (eg₂ aša₅ tur, DP 639 obv. i 1–ii 5), but subsumes these as “dikes at/of the kab₂-tar distributor of the Ašatur (field) of the Guedena” (kab₂-tar aša₅ tur gu₂-eden-na-ka-kam, DP 639 rev. i 1–2). Similar notations specifying the length (gid₂), width (daḡal), and height (sukud) of eg₂ are also found in Ur III texts that record the construction of dikes and calculate the volume of earthwork moved.¹⁶⁸ Waetzoldt argued that sukud “height” merely denotes vertical extent and could likewise refer to the depth of a “ditch” (eg₂), otherwise referred to as bur₃ “depth”,¹⁶⁹ but indications that this also applies to the ED IIIb/Presargonic texts from Lagaš are lacking. On the contrary, the fact that precisely the same waterways at the Urindua field are referred to as pa₅ in one survey text (DP 648 obv. i 1, ii 1–2), while another reference to the same waterway mentions their eg₂ instead (DP 641 obv. i 1–ii 1), demonstrates that eg₂, here, denotes the “dikes” of the same waterway that was referred to as pa₅ before (see above [17]). This agrees with the assumption that the binominal expression eg₂ pa₅(-be₂) refers to the whole of the irrigation network (see above [17]). Analogous to this, it is likewise possible that eg₂ aša₅ urin-du₃-a refers to the dikes or embankments of i₇ aša₅ urin-du₃-a. In connection with this, it should be noted that Maeda argued for an identification of the i₇ aša₅ urin-du₃-a (DP 646 rev. i 2, see above [13]) with eg₂ aša₅ urin-du₃-a, which he however, likewise, interpreted as a “canal”.¹⁷⁰ This could explain the remarkable lengths of the eg₂ associated with the Urindua field,

167 See the edition in Steinkeller 1988, 79–81.

168 Waetzoldt 1990, 1–4; Civil 1994, 116, 124.

169 Waetzoldt 1990, 1–2, 16–17.

170 Maeda 1984, 43.

which amount to 6.870 m in a single survey text (š_u-niĝ_{en}₂ 20,00 la₂ 1 ½ eše₂ NIĜ₂.DU eg₂ ʾaša₅ urin-du₃-a-kam¹, VS 25, 97 obv. iv 4–rev. i 1, see above [18]).

An assignment of work on “dikes at/of the Ašatur (field) of the Guedena” (eg₂ aša₅ tur gu₂-eden-na-ka) provides additional data on the physical characteristics of eg₂ (VS 25, 100 rev. iv 1). This text records assignments of work to 77 corvée troops, organized in six gangs under as many overseers, with a work quota of 9 m per capita (lu₂ 1-še₃ kiĝ₂ 3c ge-ta, VS 25, 100 obv. i 2–3). Four of six assignments record that “their work ... will be done on its two banks” (kiĝ₂-be₂ ... gu₂ 2c-be₂ ke₃-dam, VS 25, 100 obv. ii 1, 6, iii 3, rev. ii 1). The fact that an eg₂ thus had “two banks” (gu₂ 2c-be₂) corroborates that eg₂ denotes “two parallel ridges or levées, separated by a raised water channel” as suggested by Steinkeller and Pemberton, Postgate, and Smyth,¹⁷¹ or even “a small canal.”¹⁷² In addition, some gangs of corvée troops are assigned a work quota on stretches of dike which are qualified as u₂ a-egir₄-ra nu-tuku, literally “(stretch of dike which) has no brushwood on its *water-back*” (VS 25, 100 rev. i 5–ii 4 6 lu₂ kiĝ₂-be₂ 7c ge 2c-be₂ ke₃-dam 4c ge u₂ a-egir₄-ra nu-tuku lu₂-kur-re₂-bi₂-gi₄, see also obv. i 1–5, iii 2–4, rev. ii 2–4, iii 3–4). The meaning of a-egir₄, “water-back”, and its obvious antonym a-igi, “water-front”, are controversial.

Based on an acceptance by corvée troops (sur_x) of a work quota of 27 and 24 m on the a-egir₄ and a-igi of a durun_x, Maeda translated the above as “water behind” and “water in front”, though without explanation.¹⁷³ Steinkeller translated them as “water at the back (of the reservoir)” and “water at the front (of the reservoir)” and suggested an interpretation of “back (upper) and front (lower) weirs closing the dam (durun_x)” (DP 654 rev. ii 3–5 ½ eše₂ la₂ 1c ge a igi 8c ge a egir₄ durun_x ki-mah).¹⁷⁴ Steinkeller’s interpretation was widely accepted.¹⁷⁵ But as a survey of dikes at the Daterabbar field mentions a-igi and a-egir₄, with a length of 2100 and 180 m, respectively (ʾ6,00¹ la₂ 10 NIĜ₂.DU a-igi 30 NIĜ₂.DU a-egir₄, VS 25, 77 obv. ii 3–4), Steinkeller revised his former proposal in favor of “(water) downstream” and “(water) upstream.”¹⁷⁶ However, since neither proposal appears likely in the context of the description of dikes as a-egir₄-ra nu-tuku, a-igi and a-egir₄ most likely denote the water-side or interior slope and the air-side or exterior slope of the embankment, respectively, with (eg₂) u₂ a-egir₄-ra nu-tuku referring to a “(stretch of dike) which has no brushwood on its air-side/exterior slope.” The planting of slopes with brushwood, as a means of reinforcing embankments against erosion, is well-documented in Ur III administrative texts, though usually written

171 Pemberton, Postgate, and Smyth 1988, 216; Steinkeller 1988, 73; Steinkeller 1999, 543.

172 On this important reference, see Steinkeller 1999, 543.

173 Maeda 1984, 47.

174 Steinkeller 1988, 79–81.

175 Maekawa 1992, 214, 223 n. 52; Dight 2002, 118–119; Bagg 2011–2013, 122; cf. Maeda 1984, 46–47; Bauer 1995, 294.

176 Steinkeller 1999, 543.

differently, as u_2 -saga₁₁.¹⁷⁷ Additional attestations are possibly found in another tablet, that refers to “dikes of the Urindua field” (eg_2 aša₅ urin-du₃-a, DP 641 rev. v 5). This probably reads “60 rods ½ rope [= 390 m] is (the length of a stretch of) dike which is not reinforced with brushwood” (6,00 ½ eše₂ niĜ₂.DU eg_2 u_2 nu-ta₃-ga-am₆, DP 641 rev. v 3). u_2 SA.SA-dam, said of “small dikes” (eg_2 tur-tur) in connection with the acceptance of a work quota, probably also denotes a type of work for which “brushwood” (u_2) was used, but for the lack of parallels this is a guess based on the context (2,00 niĜ₂.DU la₂ 4c ge eg_2 tur-tur-am₆ u_2 SA-SA-dam ru-lugal-ke₄-ne e-dab₃, DP 641 rev. iii 5–8).

A handful of administrative texts demonstrate that eg_2 were susceptible to erosion and, thus, likewise support the interpretation as a “dike” or “embankment”. One text summarizes stretches of dike with a combined length of 100 rods or 600 m, ½ rope 1 reed or 33 m of which were “eaten by the water” (a-e gu₇-a) (1,40 4c ge eg_2 tur-maḥ-ba ½ 1c ge a-e gu₇-a, VS 14, 100 = AWL 1 rev. i 1–2).¹⁷⁸ Clearly, this refers to the erosion of embankments.¹⁷⁹ Though only rarely attested in ED IIIb/Presargonic texts from Lagaš (cf. also VS 27, 23 obv. ii 1 5,00 niĜ₂.DU aša₅ še-da-šU.NIĜEN₂-ta a ¹e₃-a¹ i₃-¹gu₇-gu₇¹ (?)),¹⁸⁰ erosion of embankments is frequently referred to in Ur III administrative texts. The fact that eg_2 “eaten by the water” (a-e gu₇-a) were maintained by heaping up earth again supports the assumption that eg_2 means “dike” or “embankment”.¹⁸¹ Two stretches of dike with a length of 12 m and 9 m, which were part of two “distributors” (kab₂-tar, see below [20]) at the Daterabbar field, were “carried away by the water” (a e-de₆) (4c ge kab₂-tar 1c-am₆ 3c ge kab₂-tar 2c-kam-ma-am₆ <i₇>^den-lil_x(E₂)-le-pa₃-ta, ¹a e¹-de₆, VS 27, 23 rev. i 3–6). This might refer to more severe damage and could denote that stretches of dike were flushed away.¹⁸²

The abovementioned references clearly demonstrate that eg_2 mostly denotes dikes or embankments. In fact, most texts associate eg_2 with fields. Almost all of these references are found in notations such as eg_2 aša₅ da-ter-abbar^{ki}-ka “dikes of the Daterabbar field” (VS 25, 77 rev. i 2), eg_2 aša₅ gibil-tur “dikes of the Gibiltur field” (DP 614 rev. i 1), and the like (DP 614 rev. i 1; DP 615 rev. ii 1; DP 616 rev. ii 1; DP 617 obv. i 1, rev. iii 1–2; DP 622 obv. v 8, rev. iii 2, iv 2–3; DP 623 obv. iii 7, 9, v 4; DP 625 rev. ii 2; DP 626 obv. i 1, rev. i 1; DP 627 obv. i 1, rev. i 1; DP 630 obv. i 1, iv 1, rev. i 6, ii 1, 2; DP 634 rev. iii 3; DP 636 rev. ii 1; DP 638 rev. ii 2; DP 639 obv. i 1; DP 641 rev. v 5; DP 642 obv. ii 1, 3, rev. i 3, ii 4; DP 645 obv. ii 7 (?); DP 652 rev. i 2; DP 657 obv. i 1, rev. ii 1; TSA 24 rev. i 3; VS 14, 130 = AWL 2 rev. iii 1; VS 25, 74 rev. v 2; VS 25, 77 obv. i 2, rev. i 2; VS 25, 83

177 Waetzoldt 1990, 3; Civil 1994, 70, 121–124; cf. Selz 1996.

178 Lecompte 2012.

179 Bauer 1972, 56; Stol 1976–1980, 358; Civil 1994, 126, 139 n. 39; Wilcke 1999a, 316.

180 Selz 1996, with collation.

181 Wilcke 1999a, 306–320; Wilcke 1999b.

182 Cf. the discussion of references in Ur III administrative text in Salonen 1968, 334, 401; Waetzoldt 1990, 10; Civil 1994, 126, 139 n. 39; Wilcke 1999a, 306–308.

obv. i 1, rev. ii 1; VS 25, 84 rev. iii 1–2; VS 25, 86 rev. iii 2; VS 25, 97 rev. i 1, ii 2, 4, iii 2, 4, iv 2; VS 25, 100 rev. iv 2; VS 25, 103 obv. i 2, rev. ii 1; VS 25, 105 rev. ii 2; VS 27, 23 rev. ii 4, iii 3; VS 27, 96 rev. iii 2). Their lengths are as low as 15 m (VS 25, 84 rev. iii 1–2) or 36 m (DP 639), but lengths of ca. 100 m (DP 616; DP 626), up to 200–300 m or even 600 m (DP 634; DP 638; VS 25, 77; VS 25, 101) are by no means exceptional. While some dikes are only attested once, others are repeatedly referred to and always have almost the same length, such as the “dike of the Garamud field” (eg₂ aša₅ gara₂-mud), which is calculated at 185.5 m or 186 m (š_u-niĝ₂ 30 NIĜ₂.DU 1C ge kuš₃ 3C eg₂ aša₅ gara₂-mud, DP 623 obv. iii 7; š_u-niĝ₂ 30 NIĜ₂.DU 2 ge eg₂ aša₅ gara₂-mud, DP 652 rev. i 1–2; š_u-niĝ₂ 30 NIĜ₂.DU 1C ge kuš₃ 3C eg₂ aša₅ gara₂-mud, VS 25, 86 rev. iii 1–2) or the “dike of the Abbar field (eg₂ aša₅ abbar) with a length of 90–126 m (DP 616; DP 626; DP 627; DP 645; DP 657). It has been suggested that these figures refer to the total length of their respective irrigation ditches,¹⁸³ but definite proof is still lacking. The longest stretch of dike is attested in the above-mentioned survey recording “(stretches of) dike at/of the Urindua field”, with a height varying between 1 m and 2.5 m, and a total length of 1140 rods ½ rope, corresponding to 6870 m (š_u-niĝ₂ 20,00 la₂ 1 ½ eše₂ NIĜ₂.DU eg₂ 1 aša₅ urin-du₃-a-kam¹, VS 25, 97 obv. iv 4-rev. i 1, see above [18]). According to the reconstruction of Marzahn, this figure refers to the total length of dikes that enclosed the Urindua field on three sides, while the fourth side was adjacent to the Imah primary canal.¹⁸⁴ Though mostly denoting “dikes” or “embankments”, eg₂ could, thus, reach enormous lengths. The longest eg₂ is attested for the “dike of the Daterabbar field” (eg₂ aša₅ da-ter-abbar^{ki}); based on several administrative texts recording the maintenance of “dikes” or “embankments” (eg₂), their combined length has been calculated at more than 10 600 m (VS 14, 130 = AWL 2; VS 27, 23; VS 27, 36).¹⁸⁵

In this context, it is also important to recall the abovementioned proposal of Pemberton, Postgate, and Smyth, who assumed that eg₂ denotes “bunds” that enclosed the fields. If fields were regularly placed between bunds, they assume that basin irrigation was the norm in the southern alluvium.¹⁸⁶ It is also important to remember that fields were located on the slopes of riverine levees that extended 2–3 km on both sides of the river or primary canal (see above [2]). Thus, the length of eg₂ recorded in the aforementioned texts would conform with this proposal, which would imply that notations such as eg₂ aša₅ da-ter-abbar^{ki}-ka “dikes of the Daterabbar field” (VS 25, 77 rev. i 2) would denote “bunds”. However, some observations contradict rather than support this proposal. First, it has already been mentioned (see above [17], [18]) that there is one clear example where eg₂ denotes the “dikes” or “embankments” that enclosed a pa₅ waterway instead

183 Maeda 1984, 41–42.

184 Marzahn 1989, (2) 47; see also Hruška 1991, 209; Selz 1996, 667.

185 Maeda 1984, 41; see also Hruška 1991, 209 and Selz 1996, 678.

186 Pemberton, Postgate, and Smyth 1988, 216.

of bunds. This interpretation corresponds to the binominal expression $eg_2 pa_5(-be_2)$, “dikes (and) canals”. Secondly, two surveys mention “dikes which lie alongside the Nemurgen canal” ($eg_2 i_7 nemur-gen_7-da nu_2-a$, DP 642 rev. i 2; $eg_2 i_7 nemur-da nu_2-a-am_6$, VS 25, 97 obv. ii 3). Thirdly, one of these texts mentions “dikes which are adjacent to the field of Ningirsu” ($eg_2 a_5a_5 dnin-gir_2-su-ka-ke_4 us_2-sa-am_6$, VS 25, 97 rev. ii 2) as well as “dikes which lie alongside the side of the ušgal field” ($eg_2 a_2 a_5a_3 uš-gal-še_3 ḡal_2-la-am_6$, VS 25, 97 rev. ii 4, see also rev. iii 2). In addition, the other survey refers to “dikes which lie alongside the Aḡeštin field” (7,10 niĜ₂.DU $eg_2 a_5a_3 a-ḡeštin-ka-da nu_2-a$, DP 642 obv. ii 2–3). The precise significance of these locations remains to be elucidated, but it seems improbable that notations such as $eg_2 a_5a_3 da-ter-abbar^{ki}-ka$ “dikes of the Daterabbar field” (VS 25, 77 rev. i 2) denote “bunds” enclosing fields for basin irrigation.

Two largely parallel administrative texts provide another argument against a general interpretation as “bund”. These mention stretches of “(assigned/erected) (stretches of) dike of the orchards of the Galamaḥ” (1 ½ e_2e_2 6c ge kiri₆ gala maḥ, VS 14, 100 = AWL 1 obv. i 1–2; 2 e_2e_2 8c ge kuš₃ 4c šu-du₃-a 2c $eg_2 du_3-a$ kiri₆ gala-maḥ, DP 655 obv. i 1–2) and other stretches of dike, summarizing them as “dikes, among the large and small ones” (1,40 4c ge tur maḥ-ba, VS 14, 100 = AWL 1 rev. i 1) or “assigned/erected dikes of orchards” (šu-niġen₂ 1,40 ½c e_2e_2 5c ge eg_2 kiri₆ du₃-a-kam, DP 655 rev. ii 1; cf. DP 656), in context with damages caused by erosion (20c ½c ge a-e gu₇-a, see above [18]). It is most likely that these refer to the eg_2 of pa_5 canals that served the irrigation of orchards, as argued above (see above [17]).

In addition, dikes are referred to as a part of other elements of the irrigation network. An administrative text records work quotas assigned to individual temple dependents. While the first entry refers to “dikes of the small field” (3c $eg_2 a_5a$ tur, DP 639 obv. i 1), the subscript summarizes them as “(dikes of) the distributor in the small field of Guedena”, thus indicating at the same time that kab_2 -tar distributors basically consisted of eg_2 dikes (šu-niġen₂ ½ e_2e_2 2c ge kab_2 -tar a_5a_3 tur gu₂-eden-na-ka-kam, DP 639 rev. i 1–2). This is confirmed by another survey that summarizes stretches of dike that were part of a kab_2 -tar distributor at the “small field of Guedena” (1 e_2e_2 2c ge kab_2 -tar gu₂ 2c-be₂ ke₃-dam $eg_2 a_5a_3$ tur gu₂-eden₂-na-ka, VS 25, 100 rev. iv 1–2, see above [18], see below [20]). At the same time, these references indicate that kab_2 -tar distributors were situated alongside fields and indicate that they shared embankments with the canals or irrigation ditches (cf. DP 654 obv. i 1-rev. i 1; see below [20]).¹⁸⁷ Finally, it should be highlighted that eg_2 are also mentioned as parts of $durun_x$ ($eg_2 durun_x$ -na-am₆, DP 654 rev. i 2, cf. DP 623 rev. v 2; DP 624 rev. i 1; DP 642 rev. ii 1–2; DP 653 rev. ii 1, see below [21]). This, likewise, supports the meaning being “dike” or “embankment”.

187 Maeda 1984, 44; Steinkeller 1988, 89 n. 23; Civil

1994, 133.

As already mentioned, a large number of references to eg_2 are found in assignments of work, to be performed at “dikes” or “embankments” associated with fields, or their respective acceptance by temple dependents. Often, these texts denote the name and/or the occupation of a person responsible to do irrigation work and include notations such as “1 reed: Malgasu” (1c ma-al-ga-su₃, DP 616 obv. iii 5), “40 rods erected/assigned dike: Damdiġirġu” (40 eg_2 du₃-a niġ₂.DU dam-diġir-ġu₁₀, DP 617 obv. i 1–2). While some entries in fact denote the work quota of single people, others refer to groups of people from certain occupational groups and merely mention their respective overseer by his name. This is evident from some administrative texts that parallel each other, but include varying notations. Two records from the 3rd year of Lugalanda refer to work performed at dikes of the Daterabbar field. While the first records a work assignment of “six reeds: Ġirunkidu, the coachman” (DP 623 obv. ii 2–3 6c ge ġir₂-nun-ki-du₁₀ gab₂-kas₄), the second includes the more detailed notation “six men, their work six reeds, (under) Ġir-nun, the coachman” ([6 lu₂] kiġ₂-be₂ 6c ge ġir₂-nun gab₂-kas₄, VS 25, 86 obv. ii 6–iii 2). Numerous parallels are extant (e.g. DP 653 obv. i 1 1 eše₂ sipa ama šagan_x(GAN)^{ša} and VS 25, 101 obv. i 1–4 4 lu₂ lu₂ 1-še₃ kiġ₂ 5c ge-ta kiġ₂-be₂ 1 eše₂ sipa ama šagan_x(GAN)^{ša}). In the case of the members of the most numerous and most high-ranking corvée troops, the “dependents of the king” (RU-lugal),¹⁸⁸ the texts always mention the number of men in each gang, as well as the per capita work quota, including notations such as “15 men: with three cubits of wok for one man, they took over. Their work (is) seven reed three cubits (under) Uršerda” (15 lu₂ lu₂ 1-še₃ kiġ₂ kuš₃ 3c-ta e-dab₃ kiġ₂-be₂ 7c ge kuš₃ 3c ur-d.še₃šer₇-da, VS 25, 86 obv. i 1–ii 1; cf. TSA 23 obv. iii 5–9; VS 14, 187 = AWL 3 obv. i 1–5). Similar, but mostly abbreviated, notations are, likewise, attested (DP 622 obv. i 1–4; DP 623 obv. i 1–5; DP 625 obv. i 1–4; DP 634 obv. i 1–4; DP 652 obv. i 1–4; TSA 24 obv. i 1–4; VS 25, 84 obv. i 1–4; VS 25, 100 obv. i 1–5; VS 25, 101 obv. i 1–4).¹⁸⁹ Though these texts only record the length of the respective work quotas, but not the volume nor the time-span during which the work would be performed, some observations are possible. The per capita work load for dike work at the ušgal field is computed at 5 reeds or 15 m (DP 622 obv. i 1–4; DP 625 obv. i 1–4; TSA 24 obv. i 1–4). This figure corresponds to the per capita work load attested once for work at the durun_x at the Daterabbar field (VS 25, 101 obv. i 1–4, cf. DP 653 obv. i 1, see below [21]). A work load of 3 reeds or 9 m is attested for dikes at the small field in the Guedena (VS 25, 100 obv. i 1–5), 1 reed 1 cubit or 3.5 m at the Manumanu field (DP 634 obv. i 1–4), 1 reed or 3 m (DP 652 obv. i 1–4) and 3 cubits or 1.5 m, respectively, at the Garamud field (DP 623 obv. i 1–4; VS 25, 86 obv. i 1–ii 1). The lowest figures occur in a text concerning dike work at the Ugeg field, which records a per capita work load of “7 ½ thumbs”; corresponding

188 Schrakamp 2014.

189 Cf. Jagersma 2010, 188.

to a mere $\frac{1}{2}$ span or 12.5 cm (22 lu₂ lu₂ 1-še₃ kiĝ₂ šu-si 7c $\frac{1}{2}$ -ta kiĝ₂-be₂ kuš₃ 5c zipaĥ₂ 1c ses-lu₂-du₁₀, VS 25, 84 obv. i 1-4). Comparably low work quotas are otherwise only attested in assignments of work on “primary canals” (i₇) (see above [13]), but the best parallel is another assignment of dike work at the Ugeg field, which records per capita work quota of 1 cubit or 0.5 m, to be executed on an eg₂ zi-DU, which means some sort of strengthened dike (see below [19]). The remarkably low work quota might indicate that we here, likewise, deal with an assignment of work on a eg₂ zi-DU, and, thus, implies that eg₂ is used here with a more general meaning.

The review of the ED IIIb/Presargonic royal inscriptions and administrative texts from Lagaš confirms that eg₂ basically denotes “two parallel ridges or levées, separated by a raised water channel” or “a broad earthen wall which accommodated a ditch or canal running along its top” and describes “both the ditches and the two ridges of earth”, as suggested by Steinkeller and Pemberton, Postgate, and Smyth.¹⁹⁰ Mostly, it can be translated as “dike” or “embankment”, which can be part of a “secondary canal” (pa₅) or other elements of the irrigation network, such as “distributors” (kab₂-tar), durun_x, and the like. The majority of attestations refers to eg₂ associated with fields. Most likely, these refer to the “dikes” or “embankments” that accommodated the pa₅ canals irrigating the fields on their two banks. A translation, in the sense of “a small canal”, however, can only be applied in very few cases, as an inscription of Enmetena or a ED IIIa/Fara period incantation.

[19]

A designation of a special type of “dike” or “embankment” is eg₂ zi-DU, a rather infrequently attested compound of eg₂ plus zi-DU, though this has recently been questioned.¹⁹¹ A general meaning of “dike” or “embankment” is indicated by the fact that this term only appears in two of fifty-seven Presargonic administrative texts from Lagaš, but not in royal inscriptions. This also applies to the Ur III sources.

The reading and the meaning of eg₂ zi-DU are controversial. Oppenheim, discussing Ur III references, assumed an etymology with zi-da = šaqû “to elevate” and kuĝ₂ zi-da “weir”, “barrage” and translated eg₂ zi-DU as “providing canals with weirs”.¹⁹² This was accepted by Sauren and Salonen, who assumed that eg₂ zi-DU denotes “erhöhen” of a dam or dike.¹⁹³ Preferring an etymology with zi.d “to prepare”, Bauer translated it as “Deichverstärkungen”.¹⁹⁴ Maeda pointed out that ED IIIb/Presargonic texts from Lagaš

190 Steinkeller 1988, 73; Steinkeller 1999, 543; Pemberton, Postgate, and Smyth 1988, 216.

191 See Bauer 2009, 256, who refers to the variant a zi-DU in the Ur III administrative text MVN 14, 312

obv. 2.

192 Oppenheim 1948, 40.

193 Sauren 1966, 41; Salonen 1968, 216, 432.

194 Bauer 1972, 67–68, 73.

associate *eg₂ zi-DU* with the toponym *abbar^{ki}*, which derives from *abbar* “marshes” and, therefore, considered “drainage canal”, likewise, possible.¹⁹⁵ Waetzoldt, in contrast, interpreted *eg₂ zi-DU* as “breiter Wassergraben”, pointing out that the volumes of earth moved hardly allow for an interpretation as a “Damm”.¹⁹⁶ Nissen/Damerow/Englund and LaPlaca/Powell preferred the more general translations “Deichaufbau” and “dike”, respectively.¹⁹⁷ Civil also took into account Old Babylonian lexical evidence, according to which *ge zi-DU*, *ge ġeš-keše₂-da*, *ge kuġ-zi-da* correspond to Akkadian *mibru* “weir” or “dam” (Old Babylonian Forerunner *ĤĤ VIII-IX* [MSL 7, 195] 171–173, cf. *ĤĤ IX* [MSL 7, 52] 315–318 *ge kuġ-zi-da = qa-an mi-iĥ-ri*, *ge keše₂-da = qa-an mi-iĥ-ri*, *ge ġeš-keše₂-da = qa-an mi-iĥ-ri*, *ge ġeš-keše₂-da = qa-an er-re-ti*). As ED IIIb/Presargonic and Ur III texts relate *eg₂ zi-DU* with *kab₂-tar* distributors, mention lengths up to 150 m and refer to earth work performed at *eg₂ zi-DU*, he concluded that “*eg₂ zi-DU* is not a simple dam thrown across a canal to divert its waters” and argued that “[i]f it means a dam or barrage, it has to be an embankment closing a relatively wide reservoir”. As suggested by the aforementioned authors, Civil connected the element *zi-DU* with *zi-da* in *kuġ-zi-da*, however, leaving its precise meaning open to question.¹⁹⁸ Selz translated ED IIIb/Presargonic *eg₂ zi-DU* as “Kanal-damm-Barriere”.¹⁹⁹ Most recently, Rost discussed references from Ur III Umma. As *eg₂ zi-DU* consisted of clay and earth and were located alongside the rivers and primary canals, agricultural domains and drainage ponds (*a-ga-am*), she interpreted *eg₂ zi-DU* as “flood dikes”.²⁰⁰

Only two of fifty-seven ED IIIb/Presargonic administrative texts from Lagaš mention *eg₂ zi-DU*.²⁰¹ The first records an assignment of work on “the *eg₂ zi-DU* of the Ugeg field of the temple of the goddess Nintu”, which adds up to a length of 32 m (*šu-niġen₂ ½ eše₂ kuš₃ 4c kiġ₂ du₃-a eg₂ zi-DU aša₃ u₃-ge₁₇ e₂ ^dnin-dur₁₁-ka*, VS 14, 187 = AWL 3 rev. ii 1–2). This demonstrates that *eg₂ zi-DU* were located at fields and excludes an interpretation as a dam thrown across a canal. The fact that the corvée workers are assigned a per capita work quota of only one cubit or 0.5 m indicates that work on *eg₂ zi-DU* was more labor-intensive than that performed on simple *eg₂* and indicates that *eg₂ zi-DU* were more compact than “simple” *eg₂* (*11 lu₂ lu₂ 1-še₃ kiġ₂ kuš₃ 1c-ta i₃-ši-ti kiġ₂-be₂ 1c ge kuš₃ 5c ur^{d.še₃}šer₇-da*, VS 14, 187 = AWL 3 obv. i 1–5, see above [18]).²⁰² This, in turn, would agree with the interpretation as “barrage embankment” or “flood dike” mentioned above. Assuming that *eg₂* could be used as a generic term referring to several kinds of “dikes” or “embankments”, it could well be true that a work assignment with a

195 Maeda 1984, 39, 42, 50 n. 12.

196 Waetzoldt 1990, 4.

197 Nissen, Damerow, and Englund 1990, 124–125; LaPlaca and Powell 1990, 102.

198 Civil 1994, 129–130. – For some suggestions regarding its etymology see Civil 1994, 139 n. 48.

199 Selz 1996, 671.

200 Rost 2015, 170–176.

201 Bauer 1972, 73; Maeda 1984, 39, 42; Nissen, Damerow, and Englund 1990, 124–125; Civil 1994, 130; Selz 1996, 671.

202 Civil 1994, 130.

comparably low work quota performed on “simple” eg_2 dikes or embankments likewise refers to eg_2 *zi-DU* (VS 25, 84, see above [18]). Another survey text informs that a kab_2 -*tar* distributor was located at an eg_2 *zi-DU* and associates an eg_2 *zi-DU* with the toponym $abbar^{ki}$ (3,30 $ni\hat{G}_2.DU$ kab_2 -*tar*-*ta* eg_2 *zi-DU* $abbar^{ki}$ $\hat{g}al_2$ -*la*, VS 27, 23 obv. ii 2).²⁰³ Maeda considered the possibility that $abbar^{ki}$ refers to “marshland” and took this as an indication for the meaning “drainage canal”.²⁰⁴ However, eg_2 $abbar^{(ki)}$ -*ra* is also attested as a shorthand writing for eg_2 $a\check{s}a_5$ $abbar^{ki}$ -*ka* “dikes of the Abbar field”, as demonstrated by the interchange of eg_2 $abbar$ -*ra* and the more detailed writing eg_2 $a\check{s}a_5$ $abbar^{(ki)}$ -*ka* (DP 616 obv. i 1, rev. ii 1; DP 627 obv. i 1, rev. i 1; cf. DP 645 obv. ii 7).²⁰⁵ eg_2 *zi-DU* $abbar^{ki}$ $\hat{g}al_2$ -*la* could, therefore, likewise refer to a “flood dike” located at the settlement of Abbar. A unique reference to “dikes/embankments of Urub” (eg_2 $urub^{ki}$ -*kam*, DP 623 rev. i 2) could be a possible parallel.

To sum up, eg_2 *zi-DU* is sporadically attested in ED IIIb/Presargonic administrative texts from Lagaš, is associated with a fields once, with a toponym once, and obviously denotes some sort of reinforced dike or embankment. The later lexical evidence cited above could support an interpretation as “flood dike”, or the like, but though certainly to be conceived as a compound with eg_2 , its etymology and precise meaning remains uncertain.

[20]

One of the most frequently-mentioned and most important elements of the irrigation network is written $na\hat{G}.TAR$, which is attested from the ED IIIb/Presargonic to the Ur III period and most probably to be read kab_2 -*tar*. The kab_2 -*tar* are referred to in eight of fifty-seven ED IIIb/Presargonic or 14% of the administrative texts pertaining to irrigation work, providing twenty-three attestations in total (DP 639 rev. i 1; DP 642 obv. i 3; DP 654 obv. ii 1, 5, iii 5; VS 14, 130 = AWL 2 obv. i 2, 3, ii 1, 3, 4, iii 1, rev. ii 2; VS 25, 99 obv. iii 7, rev. i 4, iii 4, 6, 8, iv 1; VS 27, 23 obv. ii 2, rev. i 3, 4; VS 27, 36 obv. i 1, 3). Following eg_2 , it is, therefore, the most frequent element of the irrigation system in the administrative texts. ED IIIb/Presargonic Royal inscriptions from Lagaš, in contrast, do not mention kab_2 -*tar*. This distribution corresponds to that of the Ur III sources, on the one hand,²⁰⁶ and indicates that kab_2 -*tar* operated on a level of the irrigation network comparable to that of eg_2 , on the other.

However, different interpretations have been suggested. Before these are presented, it needs to be mentioned that most scholars, such as Oppenheim and Gelb, entertained

203 Note, however, that “210 rods from the kab_2 -*tar* distributor which is located at the eg_2 *zi-DU* of Abbar” should be written 3,30 $ni\hat{G}_2.DU$ kab_2 -*tar* eg_2 *zi-DU* $abbar^{ki}$ -*ra* $\hat{g}al_2$ -*la*-*ta*.

204 Maeda 1984, 42.

205 Cf. Maeda 1984, 39–40.

206 Steinkeller 1988, 74.

the reading $na\hat{g}-ku_5$, but their arguments were based on misinterpretations or obsolete due to more recent collations.²⁰⁷ Assuming that the term in question denotes a “distributor” (see below [20]), Steinkeller likewise argued for the reading $na\hat{g}-ku_5$, but based his argument on lexical and etymological evidence. He pointed out that Aa III/5 [MSL 14, 344] 29–32 equate $ku-u$ with Akkadian *pe-tu-u ša₂* A.MEŠ, MIN *ša₂ me-e*, MIN *ša₂ butuq-tum*, *batāqu ša₂* A.MEŠ; proposed the reading $na\hat{g}-ku_5$, and translated it as “that which divides/diverts irrigation water.”²⁰⁸ Sallaberger accepted the reading ku_5 , but he pointed out that Ur III administrative texts occasionally write $na\hat{g}^{ab_2}-ku_5$ instead of $na\hat{g}-ku_5$ and thus, established the reading ka_2-ku_5 .²⁰⁹ Bauer likewise preferred ka_2- over $na\hat{g}-$, but based this conclusion on an Ur III letter with an envelope that testifies to an interchange of *ka-tar* and *ka₂-tar-ra*. Based on the latter spelling, Bauer postulated the reading *ka₂-tar-ra* instead of *ka₂-ku₅*.²¹⁰ Civil pointed out that copies of the literary letter allegedly of Ur III dating include the writing $na\hat{g}-ku$ as a variant of $na\hat{g}-ku_5$ and considered $na\hat{g}-ku_5$ to be the correct reading.²¹¹ However, as Civil referred to an early second millennium variant, on the one hand, and did not refer to Sallaberger and Bauer, on the other, the reading ka_2-tar will be adopted in the present paper.

Oppenheim interpreted ka_2-tar as, “long-stretched reservoir leading the stored water of the canals deep into the territory which is to be irrigated and where from the fields are ‘drinking’ [...] when it is opened.”²¹² This was likewise adopted in subsequent discussions that mostly focused on Ur III administrative texts from Umma. Sauren regarded the ka_2-tar as long rectangular storage reservoirs (“Wasserreservoirs [...] flache, rechteckige Becken”) at the banks of the canals that regulated the water flow to the fields.²¹³ Kang assumed that $na\hat{g}-ku_5$ denotes “settling-reservoirs” that washed out sediments.²¹⁴ Gelb, in contrast, connected ka_2-tar with ka_2-ku , a designation for a container used for storing onions, and concluded that it denotes “not a reservoir or channel, but a trough attached to a channel [...] for draining water.”²¹⁵ Salonen tried to harmonize Oppenheim’s and Gelb’s interpretations, suggesting that $na\hat{g}-ku_5$ were flat, rectangular, trough-like water basins of wooden planks that irrigated fields (“flaches, rechteckiges, trogförmiges Wasserbecken mit den dazu gehörigen Wasserleitungstrogen, die aus zwei Seiten bildenden senkrechten und einem Boden bildenden waagrechte bzw. aus

207 Oppenheim 1948, 113 n. 117 and Gelb 1965, 59, see the remarks of Steinkeller 1988, 89 n. 22.

208 See the discussion in Steinkeller 1988, 78, 89 n. 22.

209 Sallaberger 1991, referring e. g. to TPTS 1, 477 obv. 4. It should be noted that Selz 1993a, 37 n. 48, likewise proposed the reading ka_2-ku_5 , but based his proposal on the assumption that ka_2-ku_5 represents a frozen verbal form of the pattern gab_2-il_2 . This, however, was explicitly excluded by Sallaberger, who assumed a nominal element ka_2- .

210 Bauer 1992, citing DAS 24, letter and envelope.

Sallaberger 1991, n. 1, however, objects that ka could likewise be considered as a simplification of $ka_2(ka \times A)$, such as $ka'(ka)$.

211 Civil 1994, 182–183.

212 Oppenheim 1948, 113 n. 117.

213 Sauren 1966, 54–55.

214 Kang 1973, 429–438.

215 Gelb 1965, 58–59. The correct reading of this container, ka_2-ku , was established by Sallaberger 1991.

zwei schräg gegeneinander gestellten Brettern hergestellt und an beide Enden offen und geneigt aufgestellt sind, so dass das Wasser aus dem Wasserreservoir gut ablaufen kann, um das Feld zu bewässern“).²¹⁶ Maeda was the first to discuss the *naĝ-ku₅* in ED IIIb/Presargonic administrative texts from Lagaš. Maeda, likewise, thought the translation “reservoir” plausible, and argued that *naĝ-ku₅* were considered part of the canals they were attached to, noting that fields were watered by several *naĝ-ku₅* with lengths up to 72 m, and added that orchards were likewise irrigated by *naĝ-ku₅*.²¹⁷ Hruška translated *naĝ-ku₅* in various ways as “Wasserbecken”, “Wasserreservoir”, “Wasserbecken mit Schleuse”, and “[z]um Fischfang an das Kanalsystem angeknüpfte Teiche”; “Stauschleuse” and did not clearly differentiate the term from *ĝeš-keše₂-ra₂*.²¹⁸ The most detailed discussion of ED IIIb/Presargonic to Ur III *kab₂-tar* was provided by Steinkeller. In contrast to the aforementioned scholars, he interpreted *kab₂-tar* as a “divisor” or distributor instead of a reservoir. First, he emphasized that *kab₂-tar* was one of the most frequent and, thus, most important elements of third-millennium irrigation networks. Then, he demonstrated that Old Babylonian lexical and first millennium bilingual texts refer to *naĝ-ku₅* in context with *a-e₃-a* “sluice” and *i-zi^{a-ĝu₂}* “water flow” (Proto-Izi I [MSL 13, 29] 366–368 *a-e₃-a*, *kab₂-tar*, *i-zi^{a-ĝu₂}*) and equate *kab₂-tar* with Akkadian *butuqtu* “sluice”. Based on Ur III documents, he pointed out that *kab₂-tar* had a “sluice” (*a-e₃-a*), consisted of piled-up earth, reed, brushwood, and logs of wood and concluded that *kab₂-tar* were, structurally, but a variety of *eg₂* “dike” that were “dug” (*ba-al*) and “cleaned” (*šu-luĥ – AK*) and operated by “opening” (*bad*), “closing” (*keše₂*), and “diverting” (*ku₅*). In addition to this, Steinkeller demonstrated that *naĝ-ku₅* were rectangular structures with a length of 12 m to 72 m and a width of 1 m to 12 m. As their width often corresponded to that of the canals or channels they were attached to, he concluded that *kab₂-tar* were an integral part of the canal or channel they were attached to, instead of a separate basin next to it. Based on these data, he concluded that “the *primary* function of the *nag-kud* was to distribute water;” admitting that this “does not exclude the possibility that water storage was *nag-kud*’s [= *kab₂-tar*] *secondary* objective;” and likewise concluded that the *kab₂-tar* was a “reinforced section of the canal, provided with one or more sluices, whose function was to direct and to regulate the flow of water from the main channel into smaller off-takes and irrigation ditches.” In support of his conclusion, he promoted the reading of *naĝ-ku₅* “that which divides (water)” on the basis of lexical evidence, analogous to Spanish and Syrian flood-divisors or distributors known by the names of *mezzaz*, *almazem*, and *partidor*.²¹⁹ Hunt subsequently supported Steinkeller’s conclusion, pointing out that the comparatively small dimensions of *naĝ-ku₅* mentioned in ED IIIb/Presargonic to Ur III administrative texts rather support an interpretation as a distributor instead of a storage

216 Salonen 1968, 225.

217 Maeda 1984, 44–45.

218 Hruška 1988, 61, 63, 68 n. 28, 70.

219 Steinkeller 1988, 74–79; cf. Steinkeller 1999, 543.

reservoir.²²⁰ Pemberton, Postgate, and Smyth likewise supported Steinkeller's proposal. Estimating that *kab₂-tar* had a height or depth, respectively, of 1 to 3.5 m, they pointed out that a storage reservoir could hardly have been practical in view of the high rate of evaporation during the summer months and the marginal size attested for *kab₂-tar*.²²¹ Waetzoldt, on the contrary, disagreed with Steinkeller. Based on Ur III administrative texts from Umma with month datings, he interpreted *kab₂-tar* as retention basins/flood basins and storage reservoirs ("Flutbecken/Reservoir") that served the diverted excess water from the canal network, on the one hand, and stored water for field irrigation, on the other. As a retention/flood basin necessarily cannot be part of the canal network proper, he likewise disagreed with Steinkeller's conclusion that *kab₂-tar* were part of the canals or channels themselves, in favor of an interpretation of them as lateral basins.²²² Independently, Civil, likewise, assumed that *kab₂-tar* were "diversion ponds", i.e. lateral flood basins. He based this conclusion on an Ur III letter in which the sender informs the military authorities that the Euphrates overflowed near Tummal, and that troops are constructing a huge *kab₂-tar*, in order to divert and dam up an excess of flood water. Taking into account ED IIIb/Presargonic and Ur III administrative texts, he doubted Steinkeller's conclusion that *kab₂-tar* were an integral part of the canals or channels, suggesting that they may merely have shared a bank with these waterways. Finally, Civil argued for a reinterpretation of *butuqtu*, which is attested as the Akkadian equivalent of *kab₂-tar*, arguing that *butuqta batāqu* rather means "to divert water" in the context of a first millennium inscription.²²³ Hruška, in turn, largely subscribed to Oppenheim and Steinkeller, interpreting *kab₂-tar* as "water tank, literally water distributor", assuming "tanks retained and stored flood water [...] drew water from the main sources such as rivers or major canals and functioned as a water-storage facility in individual downstream basins".²²⁴ Dight, in turn, again adopted Steinkeller's interpretation, specifying that *kab₂-tar* regulated the water flow for canals or channels of lower level and fields.²²⁵

A review of the administrative texts from the ED IIIb/Presargonic references indicates that *kab₂-tar* denotes a "distributor" that regulated the flow of water from the canal to the fields (see above [4]). A few texts shed light on of the physical characteristics of *kab₂-tar*. First of all, an assignment of work demonstrates that *kab₂-tar* consisted of stretches of "dikes" or embankments (eg₂). While its first entry records an assignment of work on "dikes of the Ašatur (field)" (3c ge eg₂ aša₅ tur, DP 639 obv. i 1), the subscript records "total: ½ rope 2 reeds [= 36 m] is the *kab₂-tar* of the Ašatur (field) of the

220 Hunt 1988, 194–195.

221 Pemberton, Postgate, and Smyth 1988, 217–218.

222 Waetzoldt 1990, 4–7.

223 Civil 1994, 132–135, 182–183.

224 Hruška 1995, 55.

225 Dight 2002, 115, 121–122.

Guedena” (šu-niġen₂ ½ eše₂ 2c ge kab₂-tar aša₃ tur gu₂-eden-na-ka-kam, DP 639 rev. i 1–2),²²⁶ that indicates that kab₂-tar basically consisted of “dikes” or “embankments.”²²⁷ As mentioned before (see above [18]), eg₂ were occasionally described in terms of length, width and height. A survey describing various sections of a canal at the Daterabbar field shows that this also applies to kab₂-tar (DP 654).²²⁸ The first section describes a stretch of dike or canal with a length of ½ rope or 30 m, a width of 2 reeds or 6 m and a height of 3 cubits or 1.5 m (½ eše₂ 2c ge daġal-be₂ 2c ge-am₆ sukad-be₂ kuš₃ 3c, DP 654 obv. i 1–2, see above [18]). The subsequent sections describe three kab₂-tar. The length, width and height of “that of the kab₂-tar of Damu” are computed at 4 reeds or 12 m, 2 reeds or 6 m and 1 reed or 3 m (4c ge daġal-be₂ 2c ge sukad-be₂ 1c ge kab₂-tar da-mu-ka-kam, DP 654 obv. i 3–ii 1), the length, width and height of the second kab₂-tar are computed at 4 reed or 12 m, 2 reeds or 6 m, and 1 cubit or 0.5 m (4c ge daġal-be₂ 2c ge sukad-be₂ 1c ge kab₂-tar [...-ka-kam], DP 654 obv. ii 3–5), and the length, width and height of the “kab₂-tar of the middle boundary ridge” are computed at ½ rope 5 reeds or 45 m, 2 reeds or 6 m, and 4 cubits or 2 m, respectively (½ eše₂ 5c ge daġal-be₂ 2c ge sukad-be₂ kuš₃ 4c kab₂-tar im-nun mu₅-ru₃-ka-kam, DP 654 obv. iii 3-rev. i 1). While Maeda assumed that the first section of the text likewise describes a kab₂-tar,²²⁹ Steinkeller instead assumed that the first section refers to a stretch of dike (cf. above [18]) and observed that the first to fourth section record an identical width of 2 reeds or 6 m. Thus, he concluded that the kab₂-tar was “an integral part of the canal or channel, and not a separate basin, situated next to it”, and assumed that the document in question describes “six sections of what appears to have been a continuous dike.”²³⁰ An assignment of work on “dikes of the Ašatur (field) of Guedena” (eg₂ aša₃ tur gu₂-eden-na-ka, VS 25, 100 rev. iv 2) supports this. It includes six sections. The first five sections refer to eg₂ and demonstrate that these eg₂ had two banks (gu₂ 2c-be₂, VS 25, 100 obv. i 1–rev. ii 3, see above [18]). The sixth section records a work quota with a length of 1 rope 2 reeds or 36 m to be executed on a kab₂-tar, more precisely “its two banks” (1 eše₂ 2c ge kab₂-tar gu₂ 2c-be₂ ke₃-dam, VS 25, 100 rev. iv 1).²³¹ It is possible that this kab₂-tar at the “Ašatur (field) of Guedena” (aša₃ tur gu₂-eden-na-ka, VS 25, 100 rev. iv 2) is the same as the kab₂-tar at the same field described as eg₂ in a work assignment cited above (kab₂-tar aša₃ tur gu₂-eden-na-ka-kam, DP 639 rev. i 1–2, see above [18], [20]). More importantly, it seems to confirm Steinkeller’s assumption that kab₂-tar were “an integral part of the canal or channel”, especially if one considers that eg₂ does not only refer to the “dike” or “embankment” of a canal, but to the whole of the canal itself.²³² Given that kab₂-tar are

226 Maeda 1984, 44.

227 Steinkeller 1988, 75; Civil 1994, 133.

228 See the edition and discussion in Steinkeller 1988, 74–81. Cf. also Maeda 1984, 44–45; Dight 2002, 115, 121–122.

229 Maeda 1984, 44–45.

230 Steinkeller 1988, 77.

231 Cf. Steinkeller 1999, 543.

232 Cf. VS 25, 100 obv. i 1–rev. ii 3, see above [18].

described in terms of length, width and height (DP 654, see above [20]), it also implies that they had a rectangular outline. The conclusion that *kab₂-tar* were a structure consisting of *eg₂*, on the one hand, and were at the same time part of the canals themselves, finds support in a survey of dikes or embankments (*eg₂*) at the Daterabbar field. One of its entries mentions stretches of dike (*eg₂*), with lengths of 4 reeds or 12 m and 3 reeds or 9 m respectively, of the Enlilepa canal which were “carried away by the water” (4c *ge kab₂-tar 1c-am₆ 3c kab₂-tar 2c-kam-ma-am₆ ^den-lil_x(E₂)-le-pa₃-ta a e-de₆, VS 27, 23 rev. i 3–6, see above [18]). However, Civil doubted that *kab₂-tar* shared any of its banks with their respective canals and preferred an interpretation as lateral pond instead (see above [20]).²³³ Several surveys denote that *kab₂-tar* were located at the side (*za₃-be₂*, literally “at its side”) of waterways or their respective dikes (*eg₂ nu-aka-ta 40 ½ eše₂ kab₂-tar za₃-be₂ eg₂ aka-am₆, VS 14, 130 = AWL 2 obv. i 2; eg₂ še-a₂-[ta] 40 kab₂-tar [x]-ma za₃-be₂, VS 14, 130 = AWL 2 obv. ii 3–4; 6c *ge kiĝ₂ nu-aka kab₂-tar za₃-be₂, VS 27, 36 obv. i 2–3*).²³⁴ The fact that buildings situated along the waterways are likewise said to be located at the side (*za₃-be₂*) of canals supports Civil’s proposal (e.g. *kiĝ₂ <engar>-re₂-ne-ta 1,20 niĝ₂.DU 4c ge durun_x ki-maḥ e₂ nin-maḥ ter-ku₃-ka za₃-be₂ e₂ nin-maḥ-ta 1,30 ½ 4c ge kiĝ₂ ke₃-dam e₂ nin-maḥ za₃-be₂, VS 27, 36 obv. ii 4–iii 1*). Finally, the fact that the subscript of one of the survey texts referred to above summarizes the quota of work on “dikes” (*eg₂*) and those on *kab₂-tar* in distinct entries could perhaps corroborate this conclusion (VS 14, 130 = AWL 2 rev. ii 1–3, see below).**

Various administrative texts record the lengths of *kab₂-tar*. The highest figure is found in a work assignment that records stretches of dike (*eg₂*) and *kab₂-tar* at the Daterabbar field of the goddess Babu. It totals 360 rods ½ rope 4 reeds of dikes or 2382 m and 20 rods minus 4 reeds or 108 m of *kab₂-tar* where work was performed (*aka-am₆*), as well as 20 rods or 120 m of dike where no work had to be done (*šu-niĝen₂ 6,30 niĝ₂.DU ½ eše₂ 4c ge eg₂ aka-am₆ 20 niĝ₂.DU la₂ 4c ge kab₂-tar aka-am₆ 20 niĝ₂.DU eg₂ nu-ke₃-dam eg₂ aša₅ da-ter-abbar^{ki} aša₅ u₂-rum ^dba-bu₁₁, VS 14, 130 = AWL 2 rev. ii 1–iii 3*). This corresponds to the combined length of a first *kab₂-tar* with a length of 1 rope 4 reeds or 72 m (1 *eše₂ 4c ge kab₂-tar, VS 14, 130 = AWL 2 obv. i 3*) and a second one with a length of ½ rope 2 reeds or 36 m (½ *2c ge kab₂-tar 2c-kam-ma-am₆, VS 14, 130 = AWL 2 obv. ii 4*).²³⁵ The *kab₂-tar* of the middle boundary ridge had a length of ½ rope 5 reeds or 45 m (½ *eše₂ 5c ge daġal-be₂ 2c ge sukud-be₂ kuš₃ 4c kab₂-tar im-nun mu₅-ru₅-ka-kam, DP 654 obv. iii 3-rev. i 1*). These are the highest figures in terms of length for *kab₂-tar* in the administrative texts from Lagaš. The *kab₂-tar* of Damu and a third *kab₂-tar* mentioned each had a length of 12 m (4c *ge daġal-be₂ 2c ge sukud-be₂ 1c ge kab₂-tar da-mu-ka-kam, DP 654 obv. ii 3-5; 4c ge daġal-be₂ 2c ge sukud-be₂ 1c ge kab₂-tar [...], DP 654 obv. i 3–ii*

233 Civil 1994, 133.

234 Cf. the translation in Bauer 1972, 57.

235 On these lengths cf. Maeda 1984, 44; Steinkeller 1988, 76.

1). A length of 36 m is attested for a “kab₂-tar of the small field of Guedena” (šu-niġen₂ ½ eše₂ 2c ge kab₂-tar aša₅ tur gu₂-eden-na-ka-kam, DP 639 rev. i 1–2). The smallest figure attested is 4 reeds or 12 m (4c ge kab₂-tar eg₂ a-ġeštīn-na aša₅ urin-du₃-a, DP 642 obv. i 3–ii 1). Similar lengths of 4 reeds or 12 m and 3 reeds or 9 m, respectively, are mentioned for two kab₂-tar at the Enlilepa canal which were damaged by erosion, but whether these figures refer to the total length of these two kab₂-tar remains unknown (4c ge kab₂-tar 1-am₆ 3c ge kab₂-tar 2c-kam-ma-am₆ <i>₇>^den-lil_x(E₂)-le-pa₃-ta a-e de₆, VS 27, 23 rev. i 3–6, see above [18], [20]).²³⁶ Comparably low figures for lengths are also recorded in a list of work quotas at the “new field” (aša₅ gibil-am₆, VS 25, 99 rev. iv 1). Most work quotas are not specified and obviously refer to stretches of dike (eg₂). A handful of entries, however, denotes quotas of work at kab₂-tar with varying lengths of 7 reed or 21 m (7c ge kab₂-tar ur-saġ, VS 25, 99 rev. i 4–5), 2 reeds of 6 m (2c ge kab₂-tar aša₅ niġen₂-na DI.UTU, VS 25, 99 rev. iii 4–5), 5 reeds or 15 m (5c ge kab₂-tar aša₅ niġen₂-na ur-e₂-muš₃, VS 25, 99 rev. iii 6–7), and again 5 reeds or 15 m (5c ge kab₂-tar aša₅ niġen₂-na ur-saġ, VS 25, 99 rev. iii 8–9).²³⁷ Indications that these figures correspond to the total length of the kab₂-tar are lacking, but the work quotas assigned on the various kab₂-tar or stretches of kab₂-tar have similar lengths as the remaining work quotas. The fact that these were most likely performed on “simple” stretches of dike (eg₂) again indicates that kab₂-tar basically likewise consisted of “dikes” (eg₂). The above data thus demonstrates that kab₂-tar consisted of “dikes” (eg₂) with a height of 1 to 2.5 m, were rectangular in shape, measured 12 to 72 m in length, 6 m in width and were most probably located at the side of the waterways which they were attached to.²³⁸

In addition to this, work assignments and survey texts contain data concerning the localization of kab₂-tar in relation to other elements of the irrigation network. A survey mentions a “kab₂-tar of the Enlilepa (canal)” (kab₂-tar^den-lil_x(E₂)-le-pa₃, VS 27, 36 obv. i 1) as a point of reference for dike work. This could perhaps indicate that the water flow from primary canals to waterways of lower rank was controlled by means of kab₂-tar distributors. In addition to that, it refers to a “pa₅ canal of Abzu” (pa₅ abzu) and a “kab₂-tar of (the) Abzu (canal)” (kab₂-tar abzu) (VS 27, 36 obv. i 3–ii 1), thus indicating that kab₂-tar were attached to pa₅ canals (see above [17]).²³⁹ In addition to this, one of the above-mentioned assignments of work on “dikes” (eg₂) at the small field of Guedena” records in its subscript that the work was executed on “kab₂-tar of the small field of

236 Note that Maeda 1984, 44, includes these references, whereas Steinkeller 1988, 76, omits them.

237 The reading kab₂(SAG×A¹)-tar, a compound of SAĠ×DIŠ or SAĠ with a simplified A inscribed, is clearly visible on the photograph (CDLI-no.

PO20305), in contrast to the copy VS 25, 99, which only shows SAĠ/KA.

238 Cf. the remarks in Waetzoldt 1990, 7.

239 Maeda 1984, 45.

Guedena (š_u-niġen₂ ½ eše₂ 2c ge kab₂-tar aša₅-tur gu₂-eden-na-ka-kam, DP 639 rev. i 1–2, see above [18], [20]). This clearly shows that kab₂-tar adjoined the fields, clearly in order to irrigate them.

Maeda made the important observation that fields normally seem to have been irrigated by several kab₂-tar. Two surveys enumerate several kab₂-tar at the Daterabbar field, one of them describing the installations in terms of length, width and height (DP 654, see above [20]). Another survey clearly describes “(stretches of) dike of the Daterabbar field” (eg₂ aša₅ da-ter-abbar^{ki}, VS 14, 130 = AWL 2 rev. iii 1) and mentions the “durun_x of the Imaḥ (canal)” as a point of reference (durun_x i₇-maḥ-ta, VS 14, 130 = AWL 2 obv. i 1). A first kab₂-tar is located at a distance of 60 rods ½ rope or 390 m from the durun_x (durun_x i₇-maḥ-ta 20 niġ₂.DU eg₂ nu-ke₃-dam eg₂ nu-aka-ta 40 ½ kab₂-tar za₃-be₂ eg₂ aka-am₆). This kab₂-tar had a length of 1 rope and 4 reeds or 72 m which it probably shared with the dike of the canal or channel (1 eše₂ 4c ge kab₂-tar, VS 14, 130 = AWL 2 obv. 3). From there, a stretch of dike with a length of 70 rods and 3 reeds or 429 m (kab₂-tar-ta 1,10 3c ge eg₂ še-a₂ en-an-na-tum₂-gen₇ ^{ġeš-tu⁹} ġeštu a-ba ġa₂-ġa₂ za₃-be₂, VS 14, 130 = AWL 2 obv. ii 1–2), another stretch of dike with a length of 40 rods or 240 m, and a kab₂-tar at its side were reworked (eg₂ še-a₂-[ta] 40 kab₂-tar [x]-ma za₃-be₂, VS 14, 130 = AWL 2 obv. ii 3),²⁴⁰ its length being computed at ½ rope and 2 reeds or 36 m (½ 4c ge kab₂-tar, VS 14, 130 = AWL 2 obv. ii 4). The kab₂-tar mentioned here could be the same as those in another survey of “dikes of the Daterabbar field” (eg₂ aša₅ da-ter-abbar^{ki}-ka-kam, VS 27, 23 rev. ii 4), which refers to a kab₂-tar at the “flood dike of Abbar” (kab₂-tar-ta eg₂ zi-DU abbar^{ki} ġal₂-la, VS 27, 23 obv. ii 2) as well as and a “first” and “second kab₂-tar” (kab₂-tar 1c-am₆ kab₂-tar 2c-kam-ma-am₆, VS 27, 23 rev. i 3–4). Though the outline of this stretch of dike at the Daterabbar field is not entirely clear,²⁴¹ it is obvious that this field was irrigated by at least three kab₂-tar. An Ur III text from Lagaš records several sections of dike with lengths up to 2100 m, each interspersed with two kab₂-tar, and confirms this pattern,²⁴² in agreement with the fact that canals irrigating the fields ran along the backslope of the levées.

Finally, some administrative texts that do not belong to the irrigation dossier include some noteworthy references to kab₂-tar. A handful of texts concern the harvest of onions “from the onion grounds of the Ugeg field which is at the kab₂-tar of (the god) Lugaliribar” (ki šum₂-ma aša₅ u₃-ge₁₇-ka kab₂-tar ^dlugal-iri-bar-ka-ka ġal₂-la-ta, DP 383

240 According to the photograph (CDLI-no. Po20129), VS 14, 130 = AWL 2 obv. ii 3–4 read eg₂ še-a₂-[ta] 40 kab₂-tar [x]¹-ma za₃-be ½ 2c ge kab₂-tar 2c-kam-ma-am₆. VS 14, 130 = AWL 2 obv. ii 3 probably included a scribal mistake to be emended to kab₂-tar [x]¹-am₆,¹ cf. the sequence kab₂-tar 1c-am₆ kab₂-tar 2c-kam-ma-am₆ in VS 27, 23 rev. i 3–4.

241 Cf. Maeda 1984, 45, who computes the distance from the durun_x dam of the Imaḥ (canal) to the first kab₂-tar at 130 reeds or 390 m, the second kab₂-tar at a distance of 223 reeds or 669 m from the first, and the third 900 reeds or 2700 m from the Imaḥ canal.

242 Steinkeller 1988, 77, who refers to RTC 412.

rev. iii 1-2; cf. DP 408 rev. iv 5-7 and Nik. 1, 49 = AWEL 49 rev. iii 1-3). This indicates that onion grounds were irrigated by kab₂-tar.²⁴³ A unique document records large amounts of fish caught from three different kab₂-tar (5 sa z1:z1-a agargara^{ku6} kab₂-tar uda_x-a kiri₆ šuš₃-ka-kam (?), Nik. 1, 277 = AWEL 277 obv. i 1-2; cf. obv. i 3-ii 1, ii 2-4). This probably supports the assumption that kab₂-tar were lateral basins of considerable size.²⁴⁴ A delivery of woods mentions tamarisk wood for kab₂-tar that was clearly used for its construction, be it as a means of reinforcement or as a part of a sluice (20 la₂ 3 ġeš-tu⁹šeneg kab₂-tar ġeš-ti, DP 469 obv. i 2).²⁴⁵ Finally, it should be pointed out that an inventory of wood mentions a kab₂-tar at the side of a field that is associated with a personal name, but the significance of this remains to be discussed (kab₂-tar ur-^dnašše-na-silim-ma-ta eg₂ aša₅ ^dinnana za₃-be₂, VS 27, 79 obv. iv 1-2; cf. perhaps kab₂-tar da-mu-ka-kam, DP 654 obv. ii 1).²⁴⁶

To sum up, kab₂-tar most probably denotes “distributors” that regulated water flow from pa₅ canals to the fields. These consisted of “dikes” (eg₂) with a height of up to 2.5 m, had a rectangular outline, a variable length up to 72 m and a width of at least 6 m. It is likely that these basins were attached to the side of the canal from which they drew the water. Given their size and their usage as fishing ponds, kab₂-tar probably also had small storage capacity that depended on their size.²⁴⁷ Thus, the function of kab₂-tar was probably comparable to that of the ġeš-keše₂-ra₂ (see above [15]). But as kab₂-tar are only attested in administrative texts and almost always associated with fields, however, both operated on different levels of the irrigation network.

[21]

Another element of the irrigation network is written KU.KU or DUR₂.DUR₂, most likely to be read durun_x. With the possible exception of a list of fields from archaic Ur (see above [4]), durun_x is exclusively attested in ED IIIb/Presargonic Lagaš. Both its meaning and reading are controversial. Bauer referred to the equation KU.KU-ru = *ka-lu-u ša₂ me-e* “retaining of water” (SIG₇.ALAN = *Nabnitu* IX [MSL 16, 122] 254) as well as Akkadian *kālû* “dam”, or “weir”, and, thus, proposed the reading dur₂-dur₂-ru and translated it as “dam” (“Staudamm”).²⁴⁸ Maeda discussed references in ED IIIb/Presargonic administrative texts from Lagaš, but left both the meaning and reading of the term open to

243 Cf. Maeda 1984, 45.

244 Cf. Bauer 1972, 58-59; Hruška 1988, 68 n. 28.

245 On the usage of wood for the construction of kab₂-tar in Ur III texts, see Kang 1973, 432-433; Steinkeller 1988, 75, 86 n. 26.

246 For Ur III references for kab₂-tar associated with

personal names, see Rost 2015, 140.

247 Another, or other, designation for retention basins in Ur III administrative texts is probably illu(A.KAL), see Waetzoldt 1990, 7; Hruška 1995, 53; Maekawa 1995, 197 and cf. RTC 258, cited by Waetzoldt 1990.

248 Bauer 1972, 58.

question. However, he identified a *durun_x* *ki-maḥ* and another “*durun_x* of the Daterabbar field” (*durun_x* *aša₅* *da-ter-abbar^{ki}-ka*) that had a length of ca. 300 m. Most importantly, he interpreted the sequence *ku eg₂* *ku-na-am₆* (DP 654 rev. i 2) as *ku eg₂* *durun-na-am₆* as “*ku* which is set up on a canal” and concluded “that *ku-ku* was a reservoir-like canal and provided a source of water for the irrigation of the Dater-Ambar field.”²⁴⁹ Steinkeller, in contrast, adopted Bauer’s suggestion, thus translating “dam”. Based on the 1st millennium gloss *dur₂-ru-un* for *ku.ku* as the plural stem of *tuš* “to sit” (NBGT II [MSL 4: 148–149] 11–12, cf. also writings such as *inda₃* *durun_x-na* “oven-bread”, *u₂-durun_x-na* “combustive brushwood”, BiMes. 3, 15 obv. ii 4; DP 368 obv. i 1 etc.) and the writing *ku.ku-na-am₆*, he proposed the reading *durun_x*.²⁵⁰ Hruška pointed out that *ku.ku/DUR₂.DUR₂* reached lengths of ca. 300 m and, therefore, regarded the interpretation as “dam”, impossible. Instead, he assumed that *ku.ku* or *durun_x* denotes a “dike” (“Deich”), “dam, fortified dam”, or even “junction canal (?)”:²⁵¹ The interpretation “dam” was nevertheless adopted by Selz and Bagg (“Wehr”).²⁵²

The distribution of references is remarkable. Eight of fifty-seven administrative texts pertaining to irrigation work, corresponding to 14% of that group, mention *durun_x*, including a total of twelve attestations (DP 623 rev. v 2; DP 624 rev. i 1; DP 642 rev. ii 1, 2; DP 653 rev. ii 1; DP 654 rev. i 2, ii 5; DP 658 rev. i 2 (?); VS 14, 130 = AWL 2 obv. i 1; VS 25, 101 rev. ii 1; VS 27, 36 obv. ii 4, rev. i 3). The fact that royal inscriptions, in contrast, never refer to *durun_x* points at an element that operated on the lower level of the irrigation network. The following review of the administrative texts corroborates this assumption.

A survey of “dikes of the Daterabbar field” (*eg₂* *aša₅* *da-ter-abbar^{ki}*, VS 14, 130 = AWL 2 rev. iii 1) mentions the “*durun_x* of the *Imaḥ* canal” as a point of reference (*durun_x* *i₇-maḥ-ta*, VS 14, 130 = AWL 2 obv. i 1). This could mean that “primary canals” (*i₇*) were provided with *durun_x* and therefore support the interpretation “dam”.²⁵³ In addition to this, a “*durun_x* of the *u₃* of the *Imaḥ* canal” is attested (1,00 *la₂* 5c *ge durun_x* *u₃* *i₇¹* (ENGUR)-*maḥ-kam*, DP 658 rev. i 2–ii 1).²⁵⁴ But as another work assignment refers to this structure

249 Maeda 1984, 39, 46–47.

250 Steinkeller 1988, 74, 77, 79, 81. Cf. also Steinkeller 1999, 543, who transliterates *durun_x* (TUŠ.TUŠ) instead of *ku.ku*. Cf. also Civil 1994, 139 n. 44.

251 Hruška 1988, 70; Hruška 1995, 54. – Note that the differentiation between *durun_x* (TUŠ.TUŠ) “dam, fortified dam” and *ku.ku* “a junction canal (?)” in Hruška 1995, 54, has obviously no basis, see Jagersma 1997, 512.

252 Selz 1996, 677; Bagg 2011–2013, 122.

253 Cf. Steinkeller 1988, 81.

254 The reading *durun_x* *u₃* *i₇¹* (ENGUR)-*maḥ-kam* was likewise suggested by Maeda 1984, 48, and Steinkeller 1988, 81. Note that the interpretation of *ku.ku* in DP 658 rev. i 2 as *durun_x* is not beyond doubt, since all of the previous entries combine the length of a workload and a personal name or name of profession. Thus, 1.00 *la₂* 5c *ge ku.ku* could likewise mean “60 rods minus 5 reeds: *ku.ku* [= personal name]”. For an interpretation of *ku.ku* or *ku-ku* as a personal name, see Foxvog 2011, 92.

as “the U_3 of the *Imaḥ* (canal)” in the first entry (3 lu_2 0.2.0 $kiḡ_2$ -be₂ ½ eše₂ 5 ge $kiḡ_2$ du_3 -a U_3 i_7 -maḥ, DP 647 obv. i 1–2), however, and as “the U_3 -ter of *Abbar*” in the subscript ($ṣu$ -niḡen₂ 3,10 $niḡ_2$.DU 1c ge $kuṣ_3$ 3c $kiḡ_3$ du_3 -a U_3 -ter *abbar*^{ki}-ka, DP 647 rev. v 1), it is rather uncertain that the *Imaḥ* canal itself is referred to. Another administrative text records a workload of 60 rods minus 5 reeds or 345 m at “the *durun_x* of the U_3 of the *Imaḥ* canal” (1,00 la_2 5c ge *durun_x* U_3 i_7 !(ENGUR)-maḥ-kam, DP 658 rev. i 2–ii 1, see above [13]). The fact that this largely corresponds to the length of the *durun_x* of the *Daterabbar* field supports this interpretation; the respective textual data will be discussed below. In addition to this, “dams” or “weirs” of primary canals were designated as ḡeš-keše₂-ra₂ (see above [17]). Finally, it deserves to be mentioned that all of the remaining references associate *durun_x* with fields. This in turn indicates that *durun_x* operated on a lower level of the irrigation system.

This assumption finds support in a memo which locates “a first *durun_x*” of 53 rods or 318 m and “a second *durun_x*” of 30 rods or 180 m length at the *Daterabbar* field (53 $niḡ_2$.DU *durun_x* 1c-am₆ 30 $niḡ_2$.DU *durun_x* 2c-kam-ma aša₅ da-ter-abbar^{ki}, DP 642 rev. ii 1–3). These *durun_x* are clearly also mentioned in another survey, one with a length of 50 rods and 5 reeds or 315 m (50 4c ge $kiḡ_2$ *durun_x*-am₆, VS 27, 36 rev. i 3) and another one referred to as “*durun_x* of the *ki-maḥ*” with a length of 80 rods and 4 reeds or 492 m (1,20 $niḡ_2$.DU 4c ge *durun_x* *ki-maḥ*, VS 27, 36 obv. ii 4). These two *durun_x*, finally, also co-occur in an administrative text recording the survey and acceptance of irrigation work at a continuous (?) stretch of a waterway (or its respective dikes or embankments) at the *Daterabbar* field by *corvée* troops (*sur_x*-re₂ e-dab, $kiḡ_2$ aša₅ da-ter-abbar^{ki}, DP 654 rev. ii 6–iii 1, see above [18], [20]).²⁵⁵ While its first four sections refer to a stretch of dike and three different *kab₂*-tar distributors (DP 654 obv. i 1–rev. i 1, see above [18], [20]), the following sections mention two *durun_x*. The one with a length of 300 m will be discussed first. Maeda translated “50 rods (long) (is) the *KU* which is set up on the canal” and concluded that “*KU-KU* was a reservoir-like canal and provided a source of water for the irrigation of the *Datir-Ambar* field”.²⁵⁶ However, Steinkeller and Civil demonstrated that this was based on the misreading of *KU* eg₂ *durun-na-am₆* and that the passage in question reads “600 cubits (long) is the dike of the dam” (50 $niḡ_2$.DU eg₂ *durun_x*-na-am₆, DP 654 rev. i 2).²⁵⁷ Thus, Maeda’s suggestion that *durun_x* denotes “a reservoir-like canal” has no basis. Instead, it demonstrates that the *durun_x* was a structure consisting of “dikes” or “embankments” (eg₂) with a length of 50 rods or 300 m. A number of administrative texts clearly refer to the same structure and corroborate this conclusion. A work assignment records 50 rods minus 6 reeds or 282 m work at “dikes of the *durun_x*

255 On the assumption that this text records “six sections of what appears to have been a continuous dike”; see Steinkeller 1988, 77.

256 Maeda 1984, 46–48.

257 Steinkeller 1988, 77, 79–80; Civil 1994, 139 n. 44.

of Daterabbar” (šū-niĝen₂ 50 NIĜ₂.DU la₂ 6c ge eg₂ durun_x da-ter-abbar^{ki}-ka, DP 623 rev. v 2–3). The respective acceptance of this work assignment records work at “dikes of the durun_x of the Daterabbar field” that add up to a length of “40 rods ½ rope 5 reeds” or 285 m according to the subscript (šū-niĝen₂ 40 NIĜ₂.DU ½ eše₂ 5c ge eg₂ durun_x aša₅ da-ter-abbar^{ki}-ka, DP 624 rev. i 1–2), or 288 m according to the total of the per capita work quota (DP 624 obv. i 1–v 8). A third text records work on “dikes of the durun_x of Daterabbar” with a total length of 267 m (eg₂ durun_x da-ter-abbar^[ki], DP 653 rev. ii 1). A prosopographically parallel assignment testifies to “50 rods minus 5 reeds”, or 285 m, “assigned work at the durun_x of the Daterabbar field” ([šū]-niĝen₂ 50 NIĜ₂.DU la₂ 5c ge kiĝ₂ du₃-a durun_x aša₅ da-ter-abbar^{ki}-ka, VS 25, 101 rev. ii 1–2). The similar lengths, prosopographical parallels, and localizations demonstrate that the “dike of the durun_x of Daterabbar” (eg₂ durun_x da-ter-abbar^{ki}-ka), “dike of the durun_x of the Daterabbar field” (eg₂ durun_x aša₅ da-ter-abbar^{ki}-ka), “dike of the durun_x of Daterabbar” (eg₂ durun_x da-ter-abbar^[ki]), and “durun_x of the Daterabbar field” (durun_x aša₅ da-ter-abbar^{ki}-ka) refer to the same construction.²⁵⁸ A “durun_x of the u₃ of the Imaḥ canal” with a length of 60 rods minus 5 reeds or 345 m is finally referred to in another administrative text (1.00 la₂ 5c ge durun_x u₃ i₇¹(ENGUR)-maḥ-kam, DP 658 rev. i 2–ii 1, but see above [21]). These lengths indicate that the “durun_x of the Daterabbar field” is the same as the “durun_x of the u₃ of the Imaḥ canal”. Notably, the last-mentioned work assignment computes the work load assigned to the temple dependents at 5 reeds or 15 m per capita (4 lu₂ lu₂ 1-še₃ kiĝ₂ 5c ge-ta kiĝ₂-be₂ 1 eše₂ sipa ama šagan_x(GAN)^{ša}, VS 25, 101 obv. i 1–4). This corresponds to the highest per capita workload attested for work on “dikes” or “embankments” (eg₂) at canals for field irrigation (see above [13], [18]) and is significantly higher than the per capita work quota for the “cleaning” (šū-luḥ – AK) and “hoeing” of “primary canals” (i₇, see above [13]). The “dikes” or “embankments” of a durun_x therefore, did not differ from those accompanying the “secondary canals” (pa₅) at the fields.

This is finally indicated in the last part of the abovementioned record concerning the survey and acceptance of work at Daterabbar field by the corvée troops. It does not only refer to work on the “dikes of a durun_x” (50 NIĜ₂.DU eg₂ durun_x-na-am₆, DP 654 rev. i 2, see above [21]), but also to work on the durun_x ki-maḥ, the second durun_x at the Daterabbar field (40 ½ 2c ge u₃-ter a dab₅-ba aša₅ naĝ-a naĝ-be₂ 6c ge daĝal-be₂ 1c ge u₃ ter-kam ½ eše₂ la₂ 1c a-igi 8c ge a-egir₄ durun_x ki-maḥ, DP 654 rev. i 3–ii 5). The interpretation of this passage is highly controversial. Maeda translated “40 gar-du [= NIĜ₂.DU] ½ šè [= rope] 2 gi [= reeds] long (it is) ù-tir which stores water to irrigate fields. The nag [= naĝ] (is) 6 gi [= reeds] in length and 1 gi [= reed] in breath [i.e. width]. (These are) in ù-tir [= u₃-ter]. 9 gi [= reeds] long (it is) water in front [= a-igi]. 8 gi [= reeds]

258 Cf. Maeda 1984, 41, 46; Steinkeller 1988, 81.

long (it is) water behind [= a-egir₄].²⁵⁹ Thus, Maeda concluded that u₃-ter had a naġ and served the irrigation of the Daterabbar field. Steinkeller, in contrast, translated “552 cubits (long) [= 40 nġ₂.DU ½ rope 2 reeds] (is the reservoir) at the Tir-bridge [= u₃-ter] (?); it stores water (and) irrigates the field; its sluice [= naġ] (is) 36 cubits (long), its (i.e. of the sluice) width (is) 6 cubits – (this) is (the reservoir) at the Tir-bridge [= u₃-ter] (?). 54 cubits (is the width of) water at the back [= a-egir₄] (of the reservoir), 48 cubits (is the width of) water at the front [= a-igi] (of the reservoir), (this is) the Kimah-dam.”²⁶⁰ In this context, it needs to be recalled that Maeda considered durun_x to denote “a reservoir-like canal [...] for the irrigation of the Dater-Ambar field”, whereas Steinkeller suggested “a type of dam [...] provided with a sluice which probably led directly into the field.”²⁶¹ Based on Steinkeller’s translation, Dight proposed a reconstruction of the irrigation device referred to.²⁶²

Though both translations differ, it is clear that a construction “which stores water (and) irrigates fields” (a dab₅-ba aša₅ naġ-a) and “its sluice” (naġ-be₂) are mentioned, but whether this really describes the durun_x ki-maḥ is uncertain. As already mentioned, Steinkeller assumed that the whole document included six sections that describe a continuous dike and argued that the first four sections describe a stretch of dike and three different kab₂-tar distributors. The fifth section, according to Steinkeller, refers to a stretch of dike which measures 300 m and a durun_x (50 nġ₂.DU eg₂ durun_x, DP 654 rev. i 2, see above [21]).²⁶³ According to Steinkeller’s interpretation, the sixth section describes a stretch of dike 276 m in length at u₃-ter and described as “dam of Kimah” (durun_x ki-maḥ). This, Steinkeller argued, was 27 m at its back (a-egir₄), 24 m at its front (a-igi), provided with a sluice (naġ-be₂) 18 m in length, and 3 m in width and served “to store water and to irrigate the field” (a dab₅-ba aša₅ naġ-a).²⁶⁴ This interpretation, however, is problematic since Steinkeller’s subdivision of the passage in question is probably wrong. This is obvious from the fact that each of the first five sections ends with an enclitic copula -am₆ “it is” that denotes the installation on which work was performed.²⁶⁵ The first section thus ends “[...] is (a stretch of dike)” (DP 654 obv. i 1 ...-am₆), the second, third and fourth section end with “[...] is the kab₂-tar distributor of ...” (DP 654 obv. ii 1 kab₂-tar da-mu-ka-kam, obv. ii 5 kab₂-tar [...-ka-kam], obv. iii 5-rev. i 1 kab₂-tar im-nun mu₅-ru₅-ka-kam), and the fifth section ends with “.. (stretch of) dike is the durun_x” (DP 654 rev. i 2 ... eg₂ durun_x-am₆). As it is logical to assume that the sixth section likewise ends with an enclitic copula, this section reads “40 rods ½ rope

259 Maeda 1984, 47–48.

260 Steinkeller 1988, 79–80.

261 Maeda 1984, 47; Steinkeller 1988, 75, 77.

262 Dight 2002, 115, 121–122.

263 Steinkeller 1988, 77.

264 Steinkeller 1988, 77.

265 Note that copular clauses also appear in ED IIIb/Presargonic administrative texts from Lagaš, such as ration lists, as a means of structuring an asyntactical list, cf. Sallaberger 2000.

2 reeds, u_3 -ter which stores water (and) irrigates fields, its *sluice* (is) 6 reeds, its width (is) 1 reed, it is u_3 -ter” (40 ½ 2c ge u_3 -ter a dab₅-ba aša₅ naĝ-a naĝ-be₂ 6c ge daĝal-be₂ 1c ge u_3 -ter-kam, DP 654 rev. i 3–ii 2, see below [22]). The subsequent lines that record work performed on the $durun_x$ ki-maḥ must, therefore, belong to a seventh subsection. This one records that work was executed on a length of ½ rope minus 1 reed or 27 m on its a-igi and on a length of 8 reeds or 24 m on its a-egir₄ (½ eše₂ la₂ 1c ge a-igi 8c ge a-egir₄ $durun_x$ ki-maḥ, DP 654 rev. ii 3–5). Steinkeller assumed that a-igi and a-egir₄ “seem to describe respectively the back (upper) and front (lower) weirs closing the dam ($durun_x$)”.²⁶⁶ However, as argued above, a-igi and a-egir₄ instead describe the inner and outer slope of a “dike” or “embankment” (eg₂) accommodating a canal (see above [18]). This agrees with the abovementioned observation that $durun_x$ were structures of “dikes” or “embankments” (eg₂, see above [21]). If the reinterpretation of the text is correct, the interpretation of $durun_x$ as “dam” has no basis. At the same time, “which stores water (and) irrigates fields” (a dab₅-ba aša₅ naĝ-a, DP 654 rev. i 3) must refer to the function of the u_3 -ter mentioned in the preceding section which is discussed below (see below [22]).

To sum up, $durun_x$ denotes an element of the irrigation network which was closely associated with fields and consisted of “dikes” or “embankments” (eg₂) similar to those of “secondary canals” (pa₅). Two $durun_x$, one with a length of ca. 300 m and another one measuring as much as 492 m, were associated with the Daterabbar field and the u_3 of the Imah canal, respectively. Notably, the interpretation as “dam” merely rests on a single survey texts and can hardly be substantiated. As the fact that $durun_x$ are not attested after the ED IIIb/Presargonic period makes its interpretation especially difficult, the precise nature of $durun_x$ remains unclear.

[22]

The last element of the irrigation network to be discussed is u_3 which is attested in ED IIIb/Presargonic to Ur III administrative texts. Besides the simplex u_3 , it seems to occur in u_3 -ter, which is possibly a genitival compound (cf. u_3 -ter-kam, DP 654 rev. ii 2, see above [21]). These occur in six of fifty-seven administrative texts pertaining to irrigation work, with eight references in total (DP 568 obv. ii 1; DP 646 rev. ii 4; DP 647 obv. i 2, rev. v 1; DP 654 rev. i 3, ii 2; DP 658 rev. ii 1; VS 27, 36 rev. iv 1). As, again, references in royal inscriptions are lacking, the distribution in ED IIIb/Presargonic texts from Lagaš corresponds to that of the Ur III texts. The meaning and reading of u_3 , however, are controversial.

Sauren identified u_3 as an element of the irrigation network that appears in context with the Tigris, primary canals, and lagoons or drainage ponds (a-ga-am) in Ur III administrative texts from Umma, but left it untranslated.²⁶⁷ Discussing ED IIIb/Presargonic administrative texts from Lagaš, Maeda pointed out that u_3 almost exclusively occurs in “ u_3 of the Imaḥ canal” (u_3 i₇-maḥ) and “ u_3 of the Daterabbar field” (u_3 da-ter-abbar^{ki}). As the u_3 i₇-maḥ was distinct from the i₇-maḥ proper and measured more than 20 000 m in length, he considered it to represent the former course of the i₇-maḥ canal, pointing out that the spelling u_3 which also denotes libir “old” could reflect this meaning. Moreover, he assumed that u_3 -ter denotes parts of u_3 planted with trees as a reinforcement against erosion.²⁶⁸ Steinkeller observed that u_3 co-occurs with other elements of irrigation system, such as kuḡ₂ zi-da u_3 šumun₂ “dam of the old u_3 ,” or toponyms like u_3 du₆-tur-ra. Different from Maeda, he proposed the reading duru_x and the meaning “bridge”. His argument based on the observation that an ED IIIa/Fara period geographical list (MEE 3, 234, 126) renders the same place name once as ĜEŠ. u_3 .ku-kul-ab^{ki} and once as ĜEŠ. u_3 -gul-la^{ki}. Assuming that this represents the same toponym as the Old Babylonian BAD₃- u_3 -gul-la₂^{ki} and tu-ur-^d u_3 -gul-la₂^{ki}, respectively, he suggested the readings ĜEŠduru_x(u_3)^{dur₂}-kul-ab^{ki} and ĜEŠduru_x(u_3)-gu-la^{ki}, respectively, and thus proposed the reading duru_x for u_3 and assumed an etymology with e₂-^{du-ru}duru₅^{ki} = *titūrum*, *titurru* “bridge”, and its variants a-dur₂ and addir.²⁶⁹ Civil discussed u_3 mainly on the basis of Ur III administrative texts. He pointed out that u_3 is usually followed by hydronyms, but also dikes, groves, fields, and meadows. In addition, he pointed out that u_3 were susceptible to erosion, occasionally planted with trees, and accommodated fields and orchards. Referring to unorthographic writings such as ĜEŠma₂ ma₂-laḥ₅-be₂ i₃-ib₂- u_3 and interchanges of u_3 and u_5 , such as orthographic variants including du₆-lugal- u_3 , du₆-lugal- u_5 or a- u_3 -ba and a- u_5 -ba = *mīl kiššati* “high tide” and “floodwater”, Civil considered u_3 to represent an unorthographic writing for u_5 = *rakābum* “to ride” connected the latter with ^{u₂} u_5 (HU.SI) = *ši-ip-[ku]^{be-pi}*, ^{u₂} u_5 (HU.SI) = *i-ku i-ku-u₂* “levee”, “embankment” (Aa II/6 iii [MSL 14, 292–293] A 14', B iii 11'). Thus, he concluded that u_3 denotes “high ground, perhaps old levees or even islands, near the river or canal banks” or “banks or islands created by the changes of the river beds resulting from yearly floods”, respectively, and translated “ u_3 grounds” for convenience.²⁷⁰ Hruška assumed that u_3 and u_3 -ter denote “canal banks” that were sometimes “fortified with shrubs”.²⁷¹ Selz considered Maeda’s proposal convincing, translating ED IIIb/Presargonic u_3 i₇-maḥ da-ter-abbar^{ki} as “Deichverstärkungen am Imaḥ an der Waldseite von Ambar”.²⁷² Mander/Notizia, in contrast, adopted

267 Sauren 1966, 65.

268 Maeda 1984, 39, 47–48.

269 Steinkeller 1988, 81.

270 Civil 1994, 131–132.

271 Hruška 1995, 56.

272 Selz 1996, 676–677.

Civil's suggestion ("una amasso di terra, forse un vecchio argine o addirittura una piccola isola, venutasi acreeare a seguito delle piene annuali, e non un 'ponte'").²⁷³ In his edition of assignments of work at the "canal which goes to Niĝen", Studevent-Hickman provided a thorough discussion of u_3 . Referring to field names like $a\text{-}\dot{s}a_3 u_3 gu_2 i_7\text{-}da^d ba\text{-}bu_{11}\text{-}he_2\text{-}\dot{g}al_2$, he argued that u_3 were located at the banks of canals, were delimited by "dikes" or "embankments" according to notations like $u_3 bar\text{-}ra$ "outer u_3 " or $eg_2 u_3 i_7^d sul\text{-}ge\text{-}piri\dot{g}$, accommodated fields and orchards, and reached lengths of up to 80 danna or 28.8 km, perhaps as much as 400 danna or 144 km. Pointing out that earth excavated in irrigation work is traditionally deposited at the banks, he interpreted the u_3 of the "canal which goes to Niĝen" as an earthen structure located alongside the banks of the canal and translated it as "spoil bank". As spoil banks principally kept water at bay and provided a path for land traffic, he considered the translation "bund" or "causeway", thus, harmonizing his interpretation with Steinkeller's translation as "bridge".²⁷⁴ Subsequently, Steinkeller adopted Studevent-Hickman's proposal and translated u_3 as "causeway".²⁷⁵ Most recently, Rost discussed u_3 in Ur III administrative texts from Umma. She argued that " u_3 might have been a managed opening in the river levee that allowed water to be delivered into nearby depressions or wetlands if needed" or "a specific location in/at the Tigris levee that allowed for diverting water as a flood prevention measure".²⁷⁶

The interpretation of the ED IIIb/Presargonic evidence of u_3 is difficult. Most attestations of u_3 mention the " u_3 of the Imaḥ canal" ($u_3 i_7\text{-}maḥ$, DP 568 obv. ii 1; DP 646 rev. ii 4; DP 647 obv. i 2; DP 658 rev. ii 1). An additional reference is found for an " u_3 -ter of Abbar" or " u_3 of Terabbar" ($u_3\text{-}ter abbar^{ki}\text{-}ka$ or $u_3 ter\text{-}abbar^{ki}\text{-}ka$, DP 647 rev. v 1). This is either an abbreviated spelling or a scribal mistake for $u_3 da\text{-}ter\text{-}abbar^{ki}\text{-}ka$ or a reference to an $u_3\text{-}ter$, a writing which is attested twice without being associated to a toponym ($u_3\text{-}ter$, $u_3\text{-}ter\text{-}kam$, DP 654 rev. i 3, ii 2).²⁷⁷ One of these references to $u_3\text{-}ter$ is found in the subscript of an administrative text concerning "assigned work at the $u_3\text{-}ter$ of Abbar" ($ki\dot{g}_2 du_3\text{-}a u_3\text{-}ter abbar^{ki}\text{-}ka$, DP 647 rev. v 1). As the first entry of this text instead records "assigned work at the u_3 of the Imaḥ canal" ($ki\dot{g}_2 du_3\text{-}a u_3 i_7\text{-}maḥ$, DP 647 obv. i 2), the $u_3 i_7\text{-}maḥ$ and the $u_3\text{-}ter abbar^{ki}\text{-}ka$ obviously denote the same structure. Finally, the fact that a third survey mentions the " u_3 of the Imaḥ of Daterabbar" corroborates this assumption ($u_3 i_7\text{-}maḥ da\text{-}ter\text{-}abbar^{ki}$, VS 27, 36 rev. iv 1). In addition to this, a survey text records the inspection of several stretches of dike, $kab_2\text{-}tar$ distributors and two $durun_x$ constructions, the subscript summarizing them as "assigned work of (the goddess) Babu" at "the u_3 of the Imaḥ of Daterabbar" ($u_3 i_7\text{-}maḥ da\text{-}ter\text{-}abbar^{ki} ki\dot{g}_2 du_3\text{-}a^d ba\text{-}bu_{11}$, VS 27, 36 rev. iv 1-2). Thus it is clear that $u_3 i_7\text{-}maḥ$ and $u_3 ter\text{-}abbar^{ki}\text{-}ka$

273 Mander and Notizia 2009, 239-240.

274 Studevent-Hickman 2011, 43-47.

275 Steinkeller 2011, 387.

276 Rost 2015, 108-109 with n. 77.

277 Cf. Maeda 1984, 47.

or U_3 -ter abbar^{ki}-ka denote the same structure. This is also corroborated by the fact that the same survey mentions a $durun_x$ 50 rods minus 4 reeds or 312 m in length (50 4c ge kiĝ₂ $durun_x$ -am₆, VS 27, 36 rev. i 3, see above [21]) that resembles that of the $durun_x$ U_3 i_7 -maḥ, with a length of 60 rods minus 5 reeds or 345 m (1,00 la₂ 5c ge ge $durun_x$ U_3 i_7 ¹(ENGUR)-maḥ, DP 658 rev. i 2–ii 1, see above [21]).²⁷⁸

This same document includes seven entries, each probably denoting the length of a work assignment (16,40 ½ eše₂ lu₂-kur 20,00 la₂ 1,00 saĝ-du₅ 3,00 la₂ 10 nam-maḥ 7,40 ur-igi 11,40 lu₂-^dba-bu₁₁ 1,00 la₂ 5c ge $durun_x$ U_3 i_7 ¹(ENGUR)-maḥ-kam, DP 658 obv. i 1–rev. ii 1). According to Maeda’s interpretation, these lengths add up to a total of 7.065 reeds or 21 195 m. Maeda argued that this length excludes a man-made structure and concluded that U_3 i_7 -maḥ denotes the former course of the Imaḥ canal, pointing out that the sign U_3 also has the reading libir “old” in support of his proposal. A comparatively high workload is recorded in an assignment of work to temple dependents of the goddess Babu on the U_3 i_7 -maḥ, adding up to 720 rods 1 rope or 4350 m. After the reference to the U_3 i_7 -maḥ, the text inserts a last figure of 420 rods and 1 rope or 2580 m. Assuming that this was inserted as an afterthought that also refers to work on the U_3 i_7 -maḥ, the total length of the work on the U_3 i_7 -maḥ would then add up to 6930 m (6,00 1 eše₂ lugal-pa-e₃ 3,00 lugal-mas-su 1,00 *puzur*₄-ma-ma 2,00 la₂ 1 eše₂ ur-dam U_3 i_7 -maḥ lu₂ ^dba-bu₁₁-me 7,00 1 eše₂ ur-^digi-ama-še₃ NU-banda₃, DP 568 obv. i 1–ii 4). In any case, this document corroborates Maeda’s assumption that the U_3 i_7 -maḥ was a huge structure. These figures are reminiscent of the length of the “canal which goes to Niĝen” (i_7 niĝen₆^{ki}-du), which can be estimated at ca. 50 km (see above [14]). A number of Ur III work assignments record work on the U_3 of the “canal which goes to Niĝen” that demonstrate that the U_3 of this waterway likewise had an enormous length,²⁷⁹ a fact that explains why U_3 is associated with “primary canals” (i_7) alone. A survey informs us that work on the U_3 of the Imaḥ canal at the Daterabbar (field) had to be performed on a length of 650 rods and 7 reeds or 3935 m, while a section of 70 rods ½ rope and 4 reeds or 402 m would not be reworked (š_u-niĝen₂ 10,50 NIĜ₂.DU 7c ge kiĝ₂ ke₃-dam 1,10 ½ 4c ge kiĝ₂ nu-ke₃-dam U_3 i_7 -maḥ da-ter-abbar^{ki} kiĝ₂ du₃-a ^dba-bu₁₁, VS 27, 36 rev. iii 1–iv 2). Though these are by far the highest figures attested for irrigation work, the remaining texts, likewise, mention remarkably high figures, such as “total: 190 rods 1 reed 3 cubits [= 1144.5 m] assigned work on the U_3 -ter of Abbar” (š_u-niĝen₂ 3,10 NIĜ₂.DU 1c ge kuš₃ 3c kiĝ₂ du₃-a U_3 -ter abbar^{ki}-ka, DP 647 rev. v 1). The per capita workload assigned to a small gang of three members of the corvée troops is computed at ½ rope 5 reeds or 15

278 See the edition in Maeda 1984, 47–48. On the emendation i_7 ¹(ENGUR) cf. also Steinkeller 1988, 81.

279 BM 93831 and HSM 6485, see the editions and dis-

cussions in Maekawa 1997, 128–130, 142–143; Mander and Notizia 2009, 239–249; Rost 2011, 211–269; Studevent-Hickman 2011.

m, corresponding to the highest per capita figures for work on simple “dikes” or “embankments” (eg₂) (3 lu₂ 0.2.0 kiĝ₂-be₂ ½ eše₂ 5c ge kiĝ₂ du₃-a u₃ i₇-maḥ, DP 647 obv. i 1–2). Finally, an assignment of “canal cleaning” (i₇ šu-luḥ – AK) seems to compute the distance “from the u₃ of the Imah canal to the middle of the field”, thus indicating the distance from the u₃ of the Imah canal to the Urindua field (u₃ i₇-maḥ-ta ša₃ aša₅-ga-še₃, DP 646 rev. ii 4–5) at 60 rods 2 reeds or 366 m (šu-niĝen₂ 1,00 niĝ₂.DU 2c ge kiĝ₂ du₃-a i₇ aša₅ urin-du₃-a ša₃ i₇-da šu-luḥ ke₃-dam, DP 646 rev. i 1–4, see above [13]). These figures demonstrate that u₃ denotes a huge structure. Finally, the abovementioned survey and acceptance of work at the Daterabbar field by the corvée troops illustrates the function of an u₃, more precisely an u₃-ter at the Daterabbar field. As already mentioned, the first sections of this document refer to a stretch of dike, three different kab₂-tar distributors, and two durun_x, (see above [18], [20], [21]). The sixth section relates to an u₃-ter, reading “40 rods ½ rope 2 reeds (is its length), u₃-ter which stores water (and) irrigates fields, its sluice (is) 6 reeds (in length), its width (is) 1 reed, it is (that of(?)) u₃-ter” (40 ½ 2c ge u₃-ter a dab₅-ba aša₅ naĝ₅-a naĝ₅-be₂ 6c ge daĝal-be₂ 1c ge u₃-ter-kam, DP 654 rev. i 3–ii 2, see above [21]). As explicit mention is made of the irrigation of fields (aša₅ naĝ₅-a), Maeda and Steinkeller convincingly translated a – dab₅ as “to store water”.²⁸⁰ In addition, Ur III administrative texts from Umma that record work performed at the “u₃ of the Tigris” (u₃ i₇ idigna-ka) refer to the “seizing of flood water” (a zi-ga dab₅-ba) as a means of flood control through water diversion and could provide a possible parallel.²⁸¹

To sum up, u₃ denotes an earthen structure of huge dimensions that was related to the Imah canal on the one hand, and to the Daterabbar field, on the other. This agrees with the evidence of the Ur III administrative texts that have more amply been discussed. Its precise function, however, is hardly elucidated on the basis of the ED IIIb/Presargonic administrative texts, but a survey indicates that it had an important function in the storage and distribution of irrigation water.

[23]

The discussion of the basic irrigation terminology in ED IIIb/Presargonic royal inscriptions and administrative texts from Lagaš testifies to the existence of a four-level irrigation network:²⁸² From the river, water flowed to the “primary canals” (i₇) that were regulated through “regulators” (ĝeš-keše₂-ra₂), and branched off to “secondary canals” (pa₅) that are mostly referred to indirectly through mention of their respective “dikes” or “embankments” (eg₂). “Distributors” (kab₂-tar) regulated the water flow from the canals

280 Maeda 1984, 48; Steinkeller 1988, 80.

Steinkeller 2011, 387.

281 Rost 2015, 108–109 with n. 78, citing MVN 21, 101; UTI 3, 1807; UTI 4, 2926. On these texts, see

282 Cf. Steinkeller 1988, 73–74.

to the field. The most important additional elements of the irrigation network include eg_2 *zi-DU*, which denotes some sort of strengthened dike, $durun_x$ and u_3 , which played a role in the storage and distribution of irrigation water. Notably, the distribution of these elements in royal inscriptions and administrative texts perfectly reflects their position within the irrigation network. While the construction of “primary canals” (i_7) and “regulators” ($\hat{g}e\check{s}-ke\check{s}e_2-ra_2$) – devices operating on the highest level of the irrigation network – are amply reported in royal inscriptions, they are only rarely referred to in the administrative texts. These texts, instead, mainly testify to the maintenance and construction of “dikes” (eg_2) at the field and their respective canals (pa_5), “distributors” (kab_2-tar) that served their irrigation, and $durun_x$. In addition, the complementary distribution of irrigation devices in royal inscriptions and administrative texts demonstrates that construction and maintenance of the irrigation network were organized on two levels, as will be clear from the following examples of administrative texts documenting the assignment and acceptance of works by temple dependents.

[24]

As a rule, administrative texts consist of two parts.²⁸³ The first is a list of persons, groups of persons or occupational groups that are assigned a specific workload, such as “1 reed (of work): Nammaḥne, the maltser, 1 rope (of work): Urdumuzi, the goat-herd,” ([1c ge] *nam-maḥ-ne₂ munu₄-mu₂ 1 eše₂ ur^d-dumu-zi sipa ud₅, DP 615 obv. i 1-rev. i 1*). The second part, the so-called subscript, usually indicates the total work load and the place where it was executed, e.g. “total: 40 (rods) ½ rope dike of the Dugara field. Subur, the captain, *assigned* it. Year 3” (*šu-niḡen₂ 40 ½ eše₂ eg₂ aša₅ du₆-gara₂ subur nu-banda₃ mu-du₃ 3., DP 615 rev. ii 1–4*). Occasionally, the texts denote both the acceptance of work quotas by the temple dependents and their assignment by the captain of the temple. Thus, one instance of such a subscript reads “total: 60 rods 2 reeds, *assigned* work of the canal of the Urindua field. The canal bed is to be cleaned. The *farmers in service* took it over. Eniggal, the captain assigned it to them from the u_3 of the Imaḥ (canal) to the middle of the field. Year 4” (*šu-niḡen₂ 1,00 niḡ₂.DU 2c ge kiḡ₂ du₃-a i₇ aša₅ urin-du₃-a ša₃ i₇-da šu-luḥ ke₃-dam engar ki-gub-ke₄-ne e-dab₅ en-ig-gal nu-banda₃ u₃ i₇-maḥ-ta ša₃ aša₅-ga-še₃ mu-ne-du₃ 4., DP 646 rev. i 1–ii 6, see above [13], [22]). Though there are many variations in the formulation, it is clear that assignments of work and their respective acceptance were supervised by the “captain” (*nu-banda₃*), the chief administrator of the temple, who was likewise responsible for surveying the irrigation network in order*

283 On the layout of the ED IIIb/Presargonic adminis-

trative texts from Lagaš, see Sallaberger 2000.

to determine which parts were to be worked on.²⁸⁴ The archival context indicates that irrigation work was primarily conducted on parts of the irrigation network that adjoined the fields of the temple of Babu. This is corroborated by occasional annotations that classify the fields as the property of Babu, or her temple, respectively (aša₅ u₂-rum^dba-bu₁₁, VS 25, 74 rev. v 3; šu-niĝen₂ 30 niĝ₂.DU kiĝ₂ du₃-a eg₂ aša₅ da-ter-ra [a]bbar^{ki}-ka aša₅ ^dba-bu₁₁-ka, VS 25, 105 rev. ii 1–4). Occasionally, the texts refer to fields and orchards of the household of the wife of the ruler (e₂-mi₂, VS 14, 100 = AWL 1 obv. i 5; eg₂ aša₅ da-ter-abbar^{ki}-ka-kam aša₅ e₂-mi₂-kam, VS 27, 23 rev. ii 4–iii 2). Only very rarely, fields belonging to other households are mentioned; these include the temple of Nintu (aša₅ u₃-ge₁₇ e₂ ^dnin-dur₁₁-ka, VS 14, 187 = AWL 3 rev. ii 2) and the temple of Ninĝirsu (eg₂ ĝeš-AN.TUR aša₅ ^dnin-ĝir₂-su-ka-kam, VS 27, 23 rev. iii 3–4).²⁸⁵ Thus, the administrative texts document a very local level of the irrigation network that was related to the temple of Babu, as already indicated by the fact that administrative texts mostly refer to “dikes” or “embankments” (eg₂) and “distributors” (kab₂-tar) (see above [18], [24]).

[25]

At the same time, it is clear that the people drafted for irrigation work, likewise, belonged to the Babu temple. The identification of the workers is more difficult and only possible by means of systematic observations on personal names, abbreviated name-forms, co-occurrences and cluster of names and professions, and so on. However, the fact that almost all texts refer to the well-known “captains” (nu-banda₃) of the household of the ruler’s wife (e₂-mi₂), or the temple of the goddess Babu (e₂ ^dba-bu₁₁) respectively, indicates that the gangs drafted for irrigation work likewise were recruited from the dependents of this household.²⁸⁶ Occasionally, the texts refer to work “to the men of the goddess Babu” (lu₂ ^dba-bu₁₁-ke₄-ne, DP 637 rev. iv 3, cf. lu₂ ^dba-bu₁₁(?), DP 658 rev. i 1), “completed work of the men of the goddess Babu” (kiĝ₂ aka lu₂ ^dba-bu₁₁-ka, DP 636 rev. i 1), or simply “own work of the goddess Babu” (kiĝ₂ u₂-rum^dba-bu₁₁, DP 659 rev. i 4–5) and, thus, confirm this. As prosopography corroborates this assumption,²⁸⁷ it is sufficient to say that those obliged to carry out irrigation work can mostly be identified as the “men who have received a subsistence field” (lu₂ šuku dab₅-ba) or “corvée troops” (sur_x) of the temple that are well-known from ration lists.²⁸⁸ Occasionally, gangs

284 Cf. Bauer 1998, 534.

285 A list of fields attested in administrative text is provided by LaPlaca and Powell 1990, for a discussion of fields belonging to this temple, see Selz 1995, 41–45.

286 Schrakamp 2014.

287 On the criteria for prosopographical identification, see Selz 2003, 500–501; Foxvog 2011, 60; Schrakamp 2015a, 19–20.

288 Schrakamp 2010, 65–66.

of workers are explicitly referred to as “corvée troops”, e.g. in an assignment and acceptance of work in “canal hoeing” (i_7 al du_3) on the LUMmagendu canal ($\dot{s}u$ -niġen₂ ½ eše₂ kuš₃ 2c kiġ₂ bala-am₆ sur_x-re₂ e-dab₅ i_7 al du_3 kiġ₂ u₂-rum^dba-bu₁₁, DP 659 rev. i 1–5, see above [13]; see also DP 622 rev. iii 4; DP 654 rev. ii 6; VS 25, 77 rev. i 1).

The “men who have received a subsistence field” (lu_2 šuku dab₅-ba) or “corvée troops” (sur_x) constituted a bi-partite class of temple dependents.²⁸⁹ Among them, the “subordinates of the king (?)” (RU-lugal) and the “followers” (aga₃-us₂), i.e. the militia, enjoyed the highest status and income and were the first to be drafted for public work and military service.²⁹⁰ Thus, some texts show that these groups were drafted for irrigation work alone (DP 614; DP 634; DP 652; Nik. 1, 8 = AWEL 8; VS 25, 100), while others refer to them in the first place, assigning them the highest workloads (DP 622 obv. i 1–4; DP 623 obv. i 1–ii 9; DP 625 obv. i 1–4; DP 630 obv. i 1–3; DP 637 obv. i 1–6). The second subgroup of the corvée troops consisted of “farmers” (engar, engar ki-gub), various groups of shepherds, and herdsmen in charge of sheep, goats, swine, and mares (sipa, sipa ama šagan_x(GAN)^{ša}, sipa u₅, sipa uda_x siki-ka, sipa šaĥa, unu₃), “fishermen” (šukud₂) as well as the different groups of “craftsmen” (ġeš-kiġ₂-ti), such as “carpenters” (naġar), “leatherworkers” (ašgab), “reedworkers” (^{ad}adgub), “felters” (tu₈-du₈), “foresters” (lu_2 -ter), “potters” (baĥar₂), and others. Notably, these were exactly the same groups that were called for public work, such as harvest or temple building, and military service. In addition, irrigation work was also compulsory for “scribes” (dub-sar), high-ranking court personnel, such as “cupbearers” (sagi), “cooks” (muĥaldim), “cleaners” (azlag, gab₂-tan₆), “brewers” (lu_2 -BABIR₃), and cult personnel that likewise held allotments of subsistence fields, but were exempt from military duty. These rather high-ranking temple dependents were subsumed as “men who look around” (lu_2 igi-niġen₂) and, thus, differentiated from the bulk of the corvée troops, as in a work assignment recording “work taken over by *the men who look around*. The corvée troops took over its rest” (kiġ₂ lu_2 igi-niġen₂-ne dab₅-ba-am₆ eger₄-be₂ sur_x zu₂ keše₂-ra₂ e-dab₅, DP 622 rev. iii 3–4).²⁹¹ Lower-ranking groups that were not entitled to receive fields for subsistence, on the contrary, were not obliged to perform irrigation work. Therefore, irrigation work could also be considered some sort of “labor tax”.²⁹² The fact that administrative texts mention an irrigation tax (maš ki-duru₅, maš aša₅-ga, še gub-ba maš ga-be₂) that was due for prebends from fields of the goddess Babu or the ruler’s family, respectively supports this assumption (aša₅ u₂-rum^dba-bu₁₁ aša₅ u₂-rum lugal-AN-da ensi₂ lagas_x(NU₁₁.BUR)^{la.ki}-ka, aša₅ u₂-rum para₁₀-nam-tar-ra dam lugal-AN-da ensi₂ lagas_x(NU₁₁.BUR)^{la.ki}-ka, RTC 75;

289 See the discussion in Schrakamp 2010, 61–95, esp. 63–66.

290 Schrakamp 2010, 170–190; Schrakamp 2014.

291 On lu_2 igi-niġen₂, see Selz 1995, 74; Beld 2002, 129–

130; Schrakamp 2014, 720–721; on the reading, see Bauer 2003; Sjöberg 2003, 259–260.

292 Cf. Paoletti and Schrakamp 2011–2013, 161.

Nik. 1, 170 = AWEL 170; VS 14, 170 = AWL 7).²⁹³ This could mean that temple dependents were obliged to participate in irrigation work on canals, dikes, and the like that adjoined the fields they held prebends on, and in fact a handful of correspondences between irrigation texts and field allotments can be observed. An assignment of work on the “dikes of the Dugara field” (eg₂ aša₅ du₆-gara₂, DP 615 rev. ii 1), datable to the 3rd year of Enentarzi, records a work quota of 1 rope or 30 m for the “goat-herd” Urdumuzi (1 eše₂ ur^d-dumu-zi sipa ud₅, DP 615 obv. i 4–5) and 5 reeds or 15 m for Ningirsutešĝu, a high-ranking “cupbearer” (sagi) (5c^d nin-ĝir₂-su-teš₂-ĝu₁₀, DP 615 obv. ii 6).²⁹⁴ Both appear as subsistence holders in a field allotment from Enentarzi’s reign (O.I.2 GANA₂ še mu₂-a^d nin-ĝir₂-su-teš₂-ĝu₁₀, Nik. 1, 30 = AWEL 30 obv. i 1–2; O.O.3 GANA₂ O.O.2 4c i₃-šub ur^d-dumuzi sipa ud₅ aša₅ du₆-gara₂-kam, Nik. 1, 30 = AWEL 30 obv. ii 8–iii 3).²⁹⁵ Though this could mean that temple dependents were drafted for irrigation work at those fields where their subsistence plots were located, it has been considered more likely that irrigation work was performed *en masse*.²⁹⁶ A ratio between the size of their fields and their respective work quotas is not conceivable,²⁹⁷ and as Urdumuzi is assigned a comparatively high work load of 30 m (see above [18]), it is most likely that he acted as the overseer of a gang of several persons. Several parallel work assignments demonstrate that some texts only denote the total work load of an occupational group by reference to its overseer, whereas others include more detailed notations specifying the number of their subordinates. This attested, e.g., for the gangs of “subordinates of the king (?)” (ru-lugal) and the “followers” (aga₃-us₂) (see above [25]), the “herders of the mares” (sipa ama šagan_x(GAN)^{ša}), or the workers under the “coachman” (gab₂-kas₄) Ĝirnunkidu (6c ge ĝir₂-nun-ki-du₁₀ gab₂-kas₄, DP 623 obv. ii 2–3; [6 lu₂] kiĝ₂-be₂ 6c ge ĝir₂-nun, VS 25, 86 obv. ii 6–iii 2; 3 lu₂ O.2.0 kiĝ₂-be₂ ½ eše₂ 5c ge kiĝ₂ du₃-a u₃ i₇-mah ĝir₂-nun gab₂-kas₄, DP 647 obv. i 1–4). What is clear, however, is that the allocations of subsistence fields obliged the prebend holders to partake in irrigation work.

A unique document records the assignment of work on “dikes of the Daterabbar field, the field of the goddess Babu, to the men who have leased fields” by the captain and indicates that this also holds true for the lease of land (eg₂ aša₅ da-ter-ra [a]bbar^{ki}-ka aša₅ ^dba-bu₁₁-ka en-ig-gal nu-banda₃ lu₂ aša₅ apin-la₂-ke₄-ne mu-ne-du₃, VS 25, 105 rev. ii 2–iii 3).²⁹⁸ In all, eleven lessees are mentioned. Only one, a “herder of the mares of the goddess Babu” by the name of Enku (en-ku₄ sipa ama šagan_x(GAN)^{ša} ^dba-bu₁₁, VS 25, 105 obv. ii 1–3) is known as a dependent of the Babu temple and also attested in other administrative texts pertaining to irrigation (DP 617 obv. i 3–4; DP 622 obv. iv 9–10;

293 Steinkeller 1981; Selz 1989, 322–323, 394–395; Waetzoldt 1990, 11; Paoletti and Schrakamp 2011–2013, 162.

294 On the dating, see Maeda 1984, 49 n. 5.

295 Visicato 1996, n. 6.

296 Steinkeller 1999, 303, 320 n. 52.

297 Cf. Maekawa 1987, 53–60.

298 On lu₂ aša₅ apin-la₂, see Marzahn 1989, (1) 42–43; Marzahn 1991, 15; Bauer 1993, 180; Selz 1996, 704.

VS 25, 83 obv. iii 1–2; VS 25, 105 obv. ii 1–2, probably also DP 623 rev. iv 5; DP 624 obv. iv 5; DP 637 obv. iv 2; DP 647 obv. ii 7; DP 653 obv. i 1; DP 657 rev. i 3; TSA 23 obv. vi 10; VS 14, 187 = AWL 3 rev. i 2; VS 25, 74 obv. v 5; VS 25, 84 rev. i 1–2). A field allotment includes him among the holders of parcels of subsistence and leased land at the Daterabbar field (0.0.4 GANA₂ su₃-la en-ku₄ sipa [ama šagan_x(GAN)^{ša}] d^dnin-ġir₂-su, DP 592 obv. iv 6–rev. i 1). This field allotment also mentions another lessee, the high-ranking “boatman” Kišigabituš (kišig₂-a-bi₂-tuš ma₂ gal-gal, VS 25, 101 obv. iii 5–6), as a holder of leased land on the Daterabbar field (0.0.4 ½ ¼ GANA₂ su₃-la kišig₂-a-bi₂-tuš ma₂ gal-gal, DP 592 obv. iv 3–5). In view of these correspondences, it is reasonable to identify a third lessee, a “follower” by the name of Diutu (4c di-utu aga₃-us₂, VS 25, 101 obv. ii 8–9), with a namesake holder of parcels of land in the same field allotment (0.0.3 ½ ¼ GANA₂ šuku di-utu, DP 592 rev. ii 6–7). This evidence indicates that lessees of fields had to partake in irrigation work at exactly those fields where their parcels were located. In this connection, an administrative text that refers to the completion of “dike work at the Daterabbar field” needs to be mentioned (kiġ₂ eg₂ aša₃ da-ter-abbar^{ki}-ka ur-dam engar [e]-a₅, VS 25, 103 rev. ii 1–3). It refers to a number of persons who belonged to households other than the temple of the goddess Babu, including Lugaluma from the Ebabbar temple, Urdu, the lamentation priest of the Ebabbar temple, and another person from the same sanctuary (VS 25, 103 obv. ii 6–9, rev. i 2–3). A lamentation singer from the Igiġal (gala igi-ġal₂) is also referred to (DP 637 rev. ii 7). Whether these persons likewise held parcels of leased land or were drafted for irrigation work for other reasons, however, remains unknown.

Thus, it can be stated that the usufruct of subsistence fields, as well as the lease of land were intrinsically connected to the obligation to conduct irrigation work. Both, however, remained a prerogative of those occupational groups that enjoyed a higher status.

[26]

As already mentioned, the subscripts of almost all work assignments demonstrate that normally the “captain” (nu-banda₃) of the temple of Babu assigned the work quota to the temple dependents and included notations such as “Suburtur, the captain, assigned it to them [i.e. the temple dependents]” (subur-tur nu-banda₃ mu-ne-du₃, VS 25, 83 rev. ii 3–5), “Eniggal, the captain, *assigned* it to the ses tuš-a/ša₄ corvée troops” (en-ig-gal nu-banda₃ ses tuš-a/ša₄ e-ma-du₃, DP 652 rev. i 3–ii 1 and Nik. 1, 8 = AWEL 8 rev. iii 1–4), and the like.²⁹⁹ This demonstrates that the organisation and planning of irrigation work at

299 On ses tuš-a/ša₄ and ses gub-ba, see Maeda 1983; Maekawa 1987, 55–57; Selz 1989, 100; Bauer 1993,

178; Maeda 1993, 293–294; Selz 1993b, 308–309;

the temple level was the responsibility of its chief administrator.³⁰⁰ Three work assignments, however, are an exception and record that the ruler (*ensi*₂, *lugal*) assigned the work to the captain of the temple,³⁰¹ thus, including notations such as “Enentarzi, the ruler of Lagaš, assigned it to Subur, the captain” (*en-en₃-tar-zi ensi₂ lagas_x(NU₁₁.BUR)^{la.ki}-ke₄ subur NU-banda₃ mu-na-du₃*, DP 614 rev. i 2–ii 2), “total: 5 reeds assigned work (at the Lummagendu canal, Urukagina, the ruler of Lagaš, assigned it [= the work]” (*šu-niĝen₂ 5c ge kiĝ₂ du₃-a i₇ LUM-ma-gen₇-du₁₀ eri-enim-ge-na ensi₂ lagas_x(NU₁₁.BUR)^{la.ki}-ke₄ mu-du₃*, DP 628 rev. i 1–ii 1), and “Urukagina, the king of Lagaš assigned it [= the work] at the outlet at the Ubur field to Eniggal, the captain [of the temple]” (*[(eri)-nim-ge-na [lu]gal lagas_x(NU₁₁.BUR)^{la.ki}-ke₄ kuĝ₂ aša₅ ubur₂-ra-ka en-ig-gal NU-banda₃ mu-na-du₃ 1.*, TSA 23 rev. v 3–vi 1). These last two work assignments can confidently be related to the royal irrigation projects that Urukagina conducted during his first two or three years of reign (see above [13]). Thus, they demonstrate that the temple had to recruit the corvée troops for royal irrigation projects. A perfect parallel is provided by a group of perforated clay bullae that, unlike the vast majority of the ED IIIb/Presargonic texts from Lagaš, derive from the archive of the palace, i.e. the ruler. They demonstrate that the king mustered the corvée troops recruited from various temples for military service (FAOS 5/1 Ukg. 17–33),³⁰² on the one hand, and can be related to muster lists from the Babu temple itself, on the other (e.g., DP 135; DP 136; Nik. 1, 3 = AWEL 3; Wengler 2 = Deimel 1926: 39–40).³⁰³

[27]

Southern Mesopotamian societies were essentially agrarian and therefore depended on artificial irrigation (see above [1]–[4]). Though evidence for water management in the earliest cuneiform records (ca. 3300–2575 BC) is virtually absent, it is probable that references are masked behind the ambiguities of early orthography (see above [5]–[7]). The first evidence for fully-developed irrigation networks, however, stems from the Sumerian city-state of Lagaš (ca. 2475–2315 BC) and includes royal inscriptions and administrative texts (see above [8]–[12]). The Early Dynastic state of Lagaš maintained a four-level irrigation network that was operated on two levels (see above [23]). Large irrigation projects, such as the excavation of “(major) canals” (*i₇*) or the construction of “regulators” (*ĝeš-keše₂-ra₂*), are almost exclusively reported in royal inscriptions and were, there-

Bauer 1998, 534. Civil 1994, 128, assumes that *ses tuš-a/ša₄* and *ses gub-ba* (“*šeš gub-ba*”, “*šeš dur₂-ra*”) designate types of dike, but overlooks the arguments of Bauer 1993 and Maeda 1993.

300 See Maeda 1984, 34, 51 pl. 3 for additional references; Bauer 1998, 534.

301 Maeda 1984, 34, 51 pl. 3.

302 Schrakamp 2010, 285–295; Schrakamp 2013, 450–451.

303 See the editions in Schrakamp 2010, 255–285, 297–308; cf. Schrakamp 2013, 450–451.

fore, conducted by the ruler, who drew on the contingents of *corvée* troops mobilized by the temples of the state (see above [13]–[16], [23], [26]). These institutions, however, were primarily responsible for the maintenance of lower-level irrigation structures (see above [24]–[25]). These included “dikes” (eg_2) and canals (pa_5) located on their landed property, distributors regulating water flow on the fields (kab_2 -tar), strengthened dikes (eg_2 zi-DU), as well as $durun_x$ and u_3 , which played a role in the storage and distribution of irrigation water (see above [17]–[22]). Thus, the irrigation texts testify to a bipartite administrative and economic structure that was typical of the entire state (see above [26]). Moreover, the fact that the construction of new primary canals is almost exclusively reported in the inscriptions of Urnanše and his grandson Eanatum probably reflects their attempt to establish a four-level irrigation network upon the unification of the cities of Lagaš into a single state (see above [13]).

Bibliography

- ATU 3
 See Englund and Nissen 1993.
 AWAB
 See Selz 1996.
 AWAS
 See Selz 1993b.
 AWEL
 See Selz 1989.
 AWL
 See Bauer 1972.
 BFE
 See Krebernik 1984.
 BiMes. 3
 See Biggs 1976.
 BM
 British Museum London.
 CDLI
 Cuneiform Digital Library Initiative.
 <<http://cdli.ucla.edu/>>.
 CUSAS 14
 See Monaco 2011.
 CUSAS 33
 See Notizia and Visicato 2016.
 DAS
 See Lafont 1985.
 DP
 See Fuÿe 1908–1920.
 FAOS 5
 See Steible 1982.
 HSM
 Harvard Semitic Museum.
 MEE 3
 See Pettinato 1981.
 MSL 4
 See Landsberger et al. 1956.
 MSL 7
 See Landsberger 1959.
 MSL 13
 See Civil, Güterbock, et al. 1971.
 MSL 14
 See Civil, Green, and Lambert 1979.
 MSL 16
 See Finkel and Civil 1982.
 MSL SS 1
 See Civil, Gurney, and Kennedy 1986.
 MSVO 1
 See Englund and Grégoire 1991.
 MVN 3
 See Owen 1975.
 MVN 14
 See Yıldız, Waetzoldt, and Renner 1988.
 MVN 21
 See Koslova 2000.
 Nik. 1
 See Nikolskij 1908.
 RIM E1
 See Frayne 2008.
 RTC
 See Thureau-Dangin 1903.
 SF
 See Deimel 1923.
 STH 1
 See Hussey 1912.
 TPTS 1
 See Sigrist 1990.
 TSA
 See de Genouillac 1909.
 TSS
 See Jestin 1937.
 UET 2
 See Burrows 1935.
 UTI 3
 See Gomi and Yıldız 1993.
 UTI 4
 See Gomi and Yıldız 1997.
 VS 14
 See Förtsch 1916.
 VS 25
 See Marzahn 1991.
 VS 27
 See Marzahn 1996.
 WF
 See Deimel 1924.
 WVDOG 143
 See Steible and Yıldız 2015.

Bibliography

Adams and Nissen 1972

Robert McC. Adams and Hans J. Nissen. *The Uruk Countryside. The Natural Setting of Urban Societies*. Chicago: University of Chicago Press, 1972.

Andersson 2012

Jakob Andersson. *Kingship in the Early Mesopotamian Onomasticon 2800–2200 BCE*. *Studia Semitica Upsaliensia* 28. Uppsala: Uppsala Universitet, 2012.

Attinger 2005

Pascal Attinger. “A propos de AK ‘faire’ (II). Liste des ‘composés’ de AK et des expressions idéomatiques formées avec AK”. *Zeitschrift für Assyriologie und Vorderasiatische Archäologie* 95 (2005), 208–275.

Bagg 2012

Ariel M. Bagg. “Irrigation”. In *A Companion to the Archaeology of the Ancient Near East*. Ed. by D. T. Potts. Malden and Oxford: Wiley-Blackwell, 2012, 261–278.

Bagg 2011–2013

Ariel M. Bagg. “Staudamm”. In *Reallexikon der Assyriologie und Vorderasiatischen Archäologie*. Ed. by M. P. Streck. 13. Berlin and New York: De Gruyter, 2011–2013, 121–122.

Balke 2006

Thomas E. Balke. *Das sumerische Dimensionalkassystem*. *Alter Orient und Altes Testament* 331. Münster: Ugarit-Verlag, 2006.

Barrelet 1965

Marie-Thérèse Barrelet. “Une ‘construction énigmatique’ à Tello”. *Iraq* 27 (1965), 100–118.

Bauer 1971

Josef Bauer. “Altsumerische Beiträge (1–3): 1. Ein Wollverkauf der Šagšag, der Frau Uru’inimginas von Lagas; 2. ‘Schnell fließende’ Kanäle; 3. Ein altsumerischer Brief”. *Die Welt des Orients* 6 (1971), 143–152.

Bauer 1972

Josef Bauer. *Altsumerische Wirtschaftstexte aus Lagasch*. *Studia Pohl* 9. Rome: Biblical Institute Press, 1972.

Bauer 1973

Josef Bauer. “Altsumerische Beiträge (4–6): 4. giš-kéš-DU ‘Staubecken’; 5. NINAKI; 6. Das Ende der Regierung Lugalandas”. *Die Welt des Orients* 7 (1973), 9–15.

Bauer 1978

Josef Bauer. “Eine Wortliste zu IHL 26”. *Eine Wortliste zu IHL 26* 5–8 (1978), 9–16.

Bauer 1985

Josef Bauer. “Bemerkungen zu H. Steible, Die altsumerischen Bau- und Weihinschriften”. *Altorientalistische Notizen* 21–30 (1985). Teil 1 und 2, Wiesbaden 1982 (= *Freiburger Altorientalistische Studien*, Bd. 5), 2–13.

Bauer 1992

Josef Bauer. “ka-tar, káb-tar”. *Altorientalistische Notizen* 45–54 (1992), 1–2.

Bauer 1993

Josef Bauer. “Review Joachim Marzahn, Altsumerische Verwaltungstexte aus Girsu/Lagáš. Vorderasiatische Schriftdenkmäler der staatlichen Museen zu Berlin. Neue Folge, Heft IX (Heft XXV). Berlin: Akademie Verlag 1991”. *Bibliotheca Orientalis* (1993).

Bauer 1995

Josef Bauer. “Review of The Sumerian Dictionary of the University of Pennsylvania, vol. 1: A, Part 1. Edited by Åke Sjöberg. Philadelphia: The Babylonian Section of the University Museum 1992”. *Journal of the American Oriental Society* 115 (1995), 293–297.

Bauer 1998

Josef Bauer. "Der vorsargonische Abschnitt der mesopotamischen Geschichte". In *Mesopotamien. Späturuk-Zeit und Frühdynastische Zeit. Annäherungen* 1. Ed. by P. Attinger and M. Wäfler. *Orbis Biblicus et Orientalis* 160/1. Freiburg and Göttingen: Vandenhoeck & Ruprecht, 1998, 429–585.

Bauer 2003

Josef Bauer. "LÚ-IGI-NÍGIN(-NA)". *Nouvelles assyriologiques brèves et utilitaires* 38 (2003).

Bauer 2009

Josef Bauer. "Review of Catherine Mittermayer unter Mitarbeit von Pascal Attinger, Altbabylonische Zeichenliste der sumerisch-literarischen Texte. *Orbis Biblicus et Orientalis* Sonderband, Freiburg/Schweiz: Universitätsverlag, Göttingen: Vandenhoeck & Ruprecht 2006". *Die Welt des Orients* 39 (2009), 247–256.

Behrens and Steible 1983

Hermann Behrens and Horst Steible. *Glossar zu den altsumerischen Bau- und Weihinschriften*. Freiburger Altorientalische Studien 6. Wiesbaden: Franz Steiner, 1983.

Beld 2002

Scott G. Beld. *The Queen of Lagash: Ritual Economy in a Sumerian State*. PhD Dissertation University of Michigan. Ann Arbor: ProQuest Information and Learning, 2002.

Biggs 1973

Robert D. Biggs. "Pre-Sargonic Riddles from Lagash". *Journal of Near Eastern Studies* 32 (1973), 26–33.

Biggs 1976

Robert D. Biggs. *Inscriptions from Al-Hiba – Lagash. The First and Second Seasons*. Bibliotheca Mesopotamica. Primary Sources and Interpretive Analyses for the Study of Mesopotamian Civilization and its Influences from Late Prehistory to the End of the Cuneiform Tradition 3. Malibu: Undena Publications, 1976.

Burrows 1935

Eric Burrows. *Ur Excavations. Texts 2. Archaic Texts. Publications of the Joint Expedition of the British Museum and of the University Museum, University of Pennsylvania, Philadelphia, to Mesopotamia* 2. London and Philadelphia: British Museum, University of Pennsylvania Press, 1935.

Carroué 1986

François Carroué. "Le 'Cours-d'Eau-Allant-à-NINAKI'". *Acta Sumerologica* 8 (1986), 13–57.

Cavigneaux and Krebernik 1998–2001

Antoine Cavigneaux and Manfred Krebernik. "dNin-RÉC107.AB". In *Reallexikon der Assyriologie und Vorderasiatischen Archäologie*. Ed. by M. P. Streck. Vol. 9. Berlin and New York: De Gruyter, 1998–2001, 483.

Ceccarelli 2015

Manuel Ceccarelli. "Again on Ent. 28 iv 30-33 // 29 v 17-20 (= RIM E1.9.5.1)". *Nouvelles assyriologiques brèves et utilitaires* 27 (2015).

Charles 1988

M. P. Charles. "Irrigation in Lowland Mesopotamia". In *Irrigation and Cultivation in Mesopotamia Part I*. Ed. by J. N. Postgate and M. A. Powell. *Bulletin on Sumerian Agriculture* 4. Cambridge: Sumerian Agriculture Group, 1988, 1–39.

Charpin 2002

Dominique Charpin. "La politique hydraulique des rois paléo-babyloniens". *Annales. Histoire, science sociales* 57/3 (2002), 545–559.

Civil 1994

Miguel Civil. *The Farmer's Instructions. A Sumerian Agricultural Manual*. *Aula Orientalis Supplementa* 5. Barcelona: Editorial Ausa, 1994.

Civil 2010

Miguel Civil. *The Lexical Texts in the Schøyen Collection. Manuscripts in the Schøyen Collection Cuneiform*. Vol. Texts V. *Cornell University Studies in Assyriology and Sumerology* 12. Bethesda: CDL Press, 2010.

Civil 2013

Miguel Civil. "Remarks on AD-GI4 (A.K.A. 'Archaic World List C' or 'Tribute')". *Journal of Cuneiform Studies* 65 (2013), 13–67.

Civil, Green, and Lambert 1979

Miguel Civil, Margaret W. Green, and Winfred G. Lambert. *Ea A = nāqu, Aa A = nāqu, with their Forerunners and Related Texts*. Materialien zum Sumerischen Lexikon 14. Rome: Pontificium Institutum Biblicum, 1979.

Civil, Gurney, and Kennedy 1986

Miguel Civil, Oliver R. Gurney, and Douglas A. Kennedy. *The Sag-Tablet. Lexical Texts in the Ashmolean Museum. Middle Babylonian Grammatical Texts. Miscellaneous Texts*. Materialien zum Sumerischen Lexikon Supplementa Series 1. Rome: Pontificium Institutum Biblicum, 1986.

Civil, Güterbock, et al. 1971

Miguel Civil, Hans G. Güterbock, William W. Hallo, Harry A. Hoffner, and Reiner Erica. *A Reconstruction of Sumerian and Akkadian Lexical Lists. Izi = išātu, Ká-gal = abullu and Níg-ga = makkūru*. Materialien zum Sumerischen Lexikon 13. Rome: Pontificium Institutum Biblicum, 1971.

Cooper 1983

Jerrold S. Cooper. *Reconstructing History from Ancient Inscriptions: The Lagash-Umma Border Conflict*. Sources from the Ancient Near East Monographs 2/1. Malibu: Undena Publications, 1983.

Cooper 1986

Jerrold S. Cooper. *Presargonic Inscriptions. Sumerian and Akkadian Royal*. Vol. Inscriptions 1. The American Oriental Society Translation Series 1. New Haven: The American Oriental Society, 1986.

De Maaijer 1996

Remco De Maaijer. "Land Tenure in Ur III Lagaš". In *Landless and Hungry? Access to Land in Early and Traditional Societies. Proceedings of a Seminar held in Leiden 20 and 21 June 1996*. Ed. by B. Haring and R. De Maaijer. Leiden: Research School CNWS, Leiden University, 1996, 50–73.

Deimel 1923

Anton Deimel. *Die Inschriften von Fara II: Schultexte aus Fara. Ausgrabungen der Deutschen Orient-Gesellschaft in Fara und Abu Hatab*. Wissenschaftliche Veröffentlichungen der Deutschen Orient-Gesellschaft 43. Leipzig: J. C. Hinrichs, 1923.

Deimel 1924

Anton Deimel. *Die Inschriften von Fara III: Wirtschaftstexte aus Fara. Ausgrabungen der Deutschen Orient-Gesellschaft in Fara und Abu Hatab*. Wissenschaftliche Veröffentlichungen der Deutschen Orient-Gesellschaft 45. Leipzig: J. C. Hinrichs, 1924.

Dight 1998

Richard J. W. Dight. "Re appum and káb-kud". *Nouvelles assyriologiques brèves et utilitaires* 85 (1998).

Dight 2002

Richard J. W. Dight. "The Construction and Use of Canal Regulators in Ancient Sumer". In *Homenaje a alberto Estrada-Vilarrasa editor de Aula Orientalis*. Ed. by G. del Olmo Lete. Aula Orientalis. Revista de estudios del Próximo Oriente Antiguo 20. Barcelona: Editorial AUSA, 2002, 115–122.

Edzard 1957

Dietz Otto Edzard. *Die ‚Zweite Zwischenzeit‘ Babylonians*. Wiesbaden: Harrassowitz, 1957.

Edzard, Farber, and Sollberger 1977

Dietz Otto Edzard, Gertrud Farber, and Edmond Sollberger. *Die Orts- und Gewässernamen der prä-sargonischen und sargonischen Zeit*. Répertoire Géographique des Textes Cunéiformes 1. Beihefte zum Tübinger Atlas des Vorderen Orients Reihe B (Geisteswissenschaften) 7/1. Wiesbaden: Ludwig Reichert, 1977.

Englund 1988

Robert K. Englund. "Administrative Timekeeping in Ancient Mesopotamia". *Journal of the Economic and Social History of the Orient* 31 (1988), 121–185.

Englund 1998

Robert K. Englund. "Texts from the Late Uruk Period". In *Mesopotamien. Späturuk-Zeit und Frühdynastische Zeit. Annäherungen 1*. Ed. by P. Attinger and M. Wäfler. Orbis Biblicus et Orientalis 160.1. Freiburg and Göttingen: Vandenhoeck & Ruprecht, 1998, 13–233.

Englund and Grégoire 1991

Robert K. Englund and Jean-Paul Grégoire. *The Proto-Cuneiform Texts from Jemdet Nasr I*. Vol. Copies, Transliterations and Glossary. Materialien zu den frühen Schriftzeugnissen des Vorderen Orients 1. Berlin: Dietrich Reimer, 1991.

Englund and Nissen 1993

Robert K. Englund and Hans J. Nissen. *Die lexikalischen Listen der archaischen Texte aus Uruk*. Archaische Texte aus Uruk 3. Ausgrabungen der Deutschen Forschungsgemeinschaft in Uruk-Warka 13. Berlin: Dietrich Reimer, 1993.

Finkel and Civil 1982

Irving Finkel and Miguel Civil. *The Series SIG7.ALAN = Nabnitu*. Materialien zum Sumerischen Lexikon 16. Rome: Pontificium Institutum Biblicum, 1982.

Förtsch 1916

Wilhelm Förtsch. *Altbabylonische Wirtschaftstexte aus der Zeit Lugalanda's und Urukagina's*. Texte 1–195. Vorderasiatische Schriftdenkmäler der Königlichen Museen zu Berlin 14. Leipzig: J. C. Hinrichs, 1916.

Foxvog 1986

Daniel A. Foxvog. "A Summary of Non-Sealed Labor Assignments from Umma". *Acta Sumerologica* 8 (1986), 59–75.

Foxvog 2011

Daniel A. Foxvog. "Aspects of Name-Giving in Presargonic Lagash". In *Strings and Threads. A Celebration of the Work of Anne Draffkorn Kilmer*. Ed. by W. Heimpel and G. Frantz-Szabó. Winona Lake: Eisenbrauns, 2011, 59–97.

Frayne 1989

Douglas R. Frayne. "A Struggle for Water: A Case Study from the Historical Records of the Cities Isin and Larsa (1900–1800 BC). Lecture Delivered to the Society's Symposium entitled 'From Heroes to History' 26 September 1987". *The Canadian Society for Syro-Mesopotamian Studies Bulletin* 17 (1989), 17–28.

Frayne 2008

Douglas R. Frayne. *Presargonic Period (2700–2350 BC)*. The Royal Inscriptions of Mesopotamia Early Periods 1. Toronto, Buffalo, and London: University of Toronto Press, 2008.

Fuÿe 1908–1920

Allotte de la Fuÿe. *Documents présargoniques*. Paris: Ernest Leroux, 1908–1920.

Gelb 1965

Ignace J. Gelb. "The Philadelphia Onion Archive". In *Studies in Honor of Benno Landsberger on his Seventy-Fifth Birthday, April 21, 1965*. Ed. by H. G. Güterbock and T. Jacobsen. *Assyriological Studies* 16. Chicago: University of Chicago Press, 1965, 57–62.

Genouillac 1909

Henri de Genouillac. *Tablettes sumériennes archaïques. Matériaux pour servir à l'histoire de la société sumérienne*. Paris: Librairie Paul Geuthner, 1909.

Gomi and Yıldız 1993

Tohru Gomi and Fatma Yıldız. *Die Umma-Texte aus den Archäologischen Museen zu Istanbul*. Band III. Istanbul Arkeoloji Müzelerinde bulunan Umma metinleri. Cilt III. Nr. 1601–2300. Bethesda: CDL Press, 1993.

Gomi and Yıldız 1997

Tohru Gomi and Fatma Yıldız. *Die Umma-Texte aus den Archäologischen Museen zu Istanbul*. Band IV. Istanbul Arkeoloji Müzelerinde bulunan Umma metinleri. Cilt IV. Nr. 2301–3000. Bethesda: CDL Press, 1997.

Heimpel 1990

Wolfgang Heimpel. "Ein zweiter Schritt zur Rehabilitierung der Rolle des Tigris in Sumer". *Zeitschrift für Assyriologie und Vorderasiatische Archäologie* 80 (1990), 204–213.

Heimpel 2009

Wolfgang Heimpel. *Workers and Construction Work at Garšana*. Cornell University Studies in Assyriology and Sumerology 5. Bethesda: CDL Press, 2009.

Hruška 1988

Blahoslav Hruška. "Die Bewässerungsanlagen in den altsumerischen Königsinschriften von Lagaš". In *Irrigation and Cultivation in Mesopotamia*. Ed. by J. N. Postgate and M. A. Powell. Vol. I. *Bulletin on Sumerian Agriculture* 4. Cambridge: Sumerian Agriculture Group, 1988, 61–72.

Hruška 1991

Blahoslav Hruška. "Die altsumerischen Nikol'skij-Texte aus der Leningrader Eremitage". *Archiv Orientalní. Quarterly Journal of African and Asian Studies* 59 (1991), 414–426.

Hruška 1995

Blahoslav Hruška. *Sumerian Agriculture: New Findings*. Max Planck Institut für Wissenschaftsgeschichte 26. Berlin: Max Planck Institut für Wissenschaftsgeschichte, 1995.

Huh 2008

Su Kyung Huh. *Studien zur Region Lagaš. Von der Ubaid- bis zur altbabylonischen Zeit*. Alter Orient und Altes Testament 345. Münster: Ugarit-Verlag, 2008.

Hunt 1988

Robert C. Hunt. "Hydraulic Management in Southern Mesopotamia in Sumerian Times". In *Irrigation and Cultivation in Mesopotamia*. Ed. by J. N. Postgate and M. A. Powell. Vol. I. Bulletin on Sumerian Agriculture 4. Cambridge: Sumerian Agriculture Group, 1988, 189–206.

Hussey 1912

Mary I. Hussey. *Sumerian Tablets in the Harvard Semitic Museum*. Vol. I. Chiefly from the reigns of Lugaland and Urukagina of Lagaš. Harvard Semitic Series 3. Leipzig: J. C. Hinrichs, 1912.

Jacobsen 1960

Thorkild Jacobsen. "The Waters of Ur". In *Ur in Retrospect. In Memory of Sir C. Leonard Woolley*. Ed. by M. E. L. Mallowan and D. J. Wiseman. Iraq 22. London: British Institute for the Study of Iraq, 1960, 174–185.

Jacobsen 1982

Thorkild Jacobsen. *Salinity and Irrigation Agriculture in Antiquity: Diyala Basin Archaeological Report on Essential Results, 1957–1958*. Bibliotheca Mesopotamica. Primary Sources and Interpretive Analyses for the Study of Mesopotamian Civilization and its Influences from Late Prehistory to the End of the Cuneiform Tradition 14. Malibu: Undena Publications, 1982.

Jagersma 1997

Abraham H. Jagersma. "Review of B. Hruška, *Sumerian Agriculture: New Findings*, Preprint Max Planck Institut für Wissenschaftsgeschichte 26, Berlin 1996". *Orientalistische Literaturzeitung* 92 (1997), 508–512.

Jagersma 2010

Abraham H. Jagersma. *A Descriptive Grammar of Sumerian*. PhD Dissertation. Leiden: University of Leiden, 2010. URL: <https://openaccess.leidenuniv.nl/handle/1887/16107> (visited on 25/05/2018).

Jestin 1937

Raymond Jestin. *Tablettes sumériennes de Šuruppak conservées au Musée de Stamboul*. Mémoires de l'Institut Français d'Archéologie de Stamboul 3. Paris: De Boccard, 1937.

Kang 1973

Shin T. Kang. *Sumerian Economic Texts from the Umma Archive*. Sumerian and Akkadian Cuneiform Texts in the Collection of the World Heritage Museum of the University of Illinois II. Chicago: University of Illinois Press, 1973.

Keetman 2014

Jan Keetman. "Review of Rykle Berger, *Mesopotamisches Zeichenlexikon*. Zweite, revidierte und aktualisierte Auflage. Alter Orient und Altes Testament 305, Münster 2010". *Bibliotheca Orientalis* 71 (2014), 455–460.

Keetman 2015

Jan Keetman. "Indirect Reflexive in Sumerian and the Conflict between Enmetena and II?". *Nouvelles assyriologiques brèves et utilitaires* 57 (2015).

Keetman 2016

Jan Keetman. "Zur Schreibung des Wortes idigna ‚Tigris‘ und der möglichen Bedeutung ‚Reiherfluss‘". *Bibliotheca Orientalis* 73 (2016), 7–12.

Koslova 2000

Natalia Koslova. *Neusumerische Verwaltungstexte aus Umma aus der Sammlung der Ermitage zu St. Petersburg – Rußland*. Materiali per il vocabolario neosumerico 21. Rome: Multigrafica Editrice, 2000.

Krebernik 1984

Manfred Krebernik. *Die Beschwörungen aus Fara und Ebla. Untersuchungen zur ältesten keilschriftlichen Beschwörungsliteratur*. Texte und Studien zur Orientalistik 2. Zürich and New York: Georg Olms, 1984.

Krebernik 1998

Manfred Krebernik. "Die Texte aus Fāra und Tell Abū Šalābiḥ." In *Mesopotamien. Späturuk-Zeit und Frühdynastische Zeit*. Ed. by P. Attinger and M. Wäfler. Annäherungen 1. Orbis Biblicus et Orientalis 160.1. Freiburg and Göttingen: Vandenhoeck & Ruprecht, 1998, 235–427.

Krebernik 2007

Manfred Krebernik. "Zur Entwicklung des Sprachbewusstseins im Alten Orient." In *Das geistige Er-fassen der Welt im Alten Orient. Sprache, Religion Kultur und Gesellschaft*. Ed. by C. Wilcke. Wiesbaden: Harrassowitz, 2007, 39–61.

Kupper and Sollberger 1971

Jean-Robert Kupper and Edmond Sollberger. *Inscriptions royales sumériennes et akkadiennes*. Litté-ratures Anciennes du Proche-Orient. Paris: Cerf, 1971.

Lafont 1980

Bertrand Lafont. "Un nouveau texte d'Ur III sur l'irrigation." *Revue d'assyriologie et d'archéologie orientale* 74 (1980), 29–42.

Lafont 1985

Bertrand Lafont. *Documents administratifs sumériens provenant du site de Tello et conservés au Musée du Louvre*. Éditions Recherche sur les Civilisations Mémoire 61. Paris: Éditions des Recherche sur les civilisations, 1985.

Landsberger 1959

Benno Landsberger. *The Series HAR-ra = hubullu*. Tablets VIII–XII. Materialien zum Sumerischen Lexikon 7. Rome: Pontificium Institutum Biblicum, 1959.

Landsberger et al. 1956

Benno Landsberger, Richard Hallock, Thorkild Jacobsen, and Adam Falkenstein. *Emesal Vocabulary (Series dimir = dingir = ilum)*. *Old Babylonian Grammatical Texts. Neobabylonian Grammatical Texts*. Nachträge zu MSL III. Materialien zum Sumerischen Lexikon 4. Rome: Pontificium Institutum Biblicum, 1956.

LaPlaca and Powell 1990

P. J. LaPlaca and Marvin A. Powell. "The Agricultural Cycle and the Calendar at Pre-Sargonic Girsu." In *Irrigation and Cultivation in Mesopotamia Part II*. Ed. by J. N. Postgate and M. A. Powell. Bulletin on Sumerian Agriculture 5. Cambridge: Sumerian Agriculture Group, 1990, 75–104.

Laurito and Pers 2002

Rosita Laurito and Mariapaola Pers. "Attestations of Canals in the Royal Sources from the Sumerian to the Paleobabylonian Period?" *Egitto e Vicino Oriente* 25 (2002), 275–325.

Lecompte 2012

Camille Lecompte. "De chiffres et des digues: à propos de deux textes présargoniques de Ĝirsu et d'une notation numérique inhabituelle." *Altorientalische Forschungen* 39 (2012), 81–86.

Liverani 1990

Mario Liverani. "The Shape of Neo-Sumerian Fields." In *Irrigation and Cultivation in Mesopotamia Part II*. Ed. by J. N. Postgate and M. A. Powell. Bulletin on Sumerian Agriculture 5. Cambridge: Sumerian Agriculture Group, 1990, 147–186.

Maeda 1983

Tohru Maeda. "Subgroups of lú-KUR6-dab5-ba (II) – šeš-gub-ba and šeš-tuš-a –." *Acta Sumerologica* 5 (1983), 67–79.

Maeda 1984

Tohru Maeda. "Work Concerning Irrigation Canals in Pre-sargonic Lagash." *Acta Sumerologica* 6 (1984), 33–53.

Maeda 1993

Tohru Maeda. "šeš-tuš-a and šeš-bir-ra." *Acta Sumerologica* 15 (1993), 293–294.

Maekawa 1987

Kazuya Maekawa. "Collective Labor Service in Girsu-Lagash: The Pre-Sargonic and Ur III Periods." In *Labor in the Ancient Near East*. Ed. by M. A. Powell. American Oriental Series 68. New Haven: American Oriental Society, 1987, 49–71.

Maekawa 1992

Kazuya Maekawa. "The Agricultural Texts of Ur III Lagash of the British Museum (VIII)." *Acta Sumerologica* 14 (1992), 173–243.

Maekawa 1995

Kazuya Maekawa. "The Agricultural Texts of Ur III Lagash of the British Museum (X)". *Acta Sumerologica* 17 (1995), 175–231.

Maekawa 1997

Kazuya Maekawa. "The Agricultural Texts of Ur III Lagash of the British Museum (XI)". *Acta Sumerologica* 19 (1997), 113–145.

Mander and Notizia 2009

Pietro Mander and Palmiro Notizia. "Testi relativi all'agricoltura e a lavori di manutenzione fluviale dallo Harvard Semitic Museum". In *Dallo Stirone al Tigri, dal Tevere all'Eufrate. Studi in Onore di Claudio Saporetti*. Ed. by P. Negri Scafa and S. Viaggio. Rome: Aracne, 2009, 233–251.

Marchesi 2006

Gianni Marchesi. *LUMMA in the Onomasticon and Literature of Ancient Mesopotamia*. History of the Ancient Near East/Studies 10. Padova: Sargon Editrice e Libreria, 2006.

Marchesi 2015

Gianni Marchesi. "Toward a Chronology of Early Dynastic Rulers in Mesopotamia". In *History & Philology*. Ed. by W. Sallaberger and I. Schrakamp. Associated Regional Chronologies for the Ancient Near East and the Eastern Mediterranean 3. Turnhout: Brepols, 2015, 139–156.

Margueron 2005

Jean-Claude Margueron. "Notes d'archéologie et d'architecture orientales. 11 – Un pont enjambant un canal à Tello?" *Syria* 82 (2005), 63–92.

Marzahn 1989

Joachim Marzahn. *Grundlagen der Getreideproduktion in Lagaš (24. Jh. v. Chr.)*. Unpublished PhD Dissertation. Friedrich-Schiller Universität Jena, 1989.

Marzahn 1991

Joachim Marzahn. *Altsumerische Verwaltungstexte aus Girsu/Lagaš*. Vorderasiatische Schriftdenkmäler der staatlichen Museen zu Berlin. Neue Folge Heft X (Heft XXV). Berlin: Akademie Verlag, 1991.

Marzahn 1996

Joachim Marzahn. *Altsumerische Verwaltungstexte und ein Brief aus Girsu/Lagaš*. Vorderasiatische Schriftdenkmäler der staatlichen Museen zu Berlin. Neue Folge Heft XI (Heft XXVII). Mainz: Philipp von Zabern, 1996.

Monaco 2011

Salvatore F. Monaco. *Early Dynastic mu-iti Cereal Texts in the Cornell University Cuneiform Collections*. Cornell University Studies in Assyriology and Sumerology 14. Bethesda: CDL Press, 2011.

Monaco 2014

Salvatore F. Monaco. "Proto-Cuneiform and Sumerians". *Rivista degli Studi Orientali* 87 (2014), 277–281.

Nikolskij 1908

M. V. Nikolskij. *Dokumenty chozjajstvennoj oščetnosti drevnejšej epochi Chaldei iz sobranija N. P. Lichačeva*. Drevnosti Vostočnyja 3.2. St. Petersburg: Moskva Gateuk, 1908.

Nissen 1976

Hans J. Nissen. "Geographie". In *Sumerological Studies in Honor of Thorkild Jacobsen on his Seventieth Birthday June 7, 1974*. Ed. by S. J. Lieberman. Assyriological Studies 20. Chicago and London: University of Chicago Press, 1976, 9–40.

Nissen 2015

Hans J. Nissen. "The Development of Urban Life in Mesopotamia and the Implementation of Canal Systems". In *Water of Life*. Ed. by J. K. Madsen, N. Overgaard, and I. Thuesen. Proceedings of the Danish Institute in Damascus 11. Copenhagen: Orbis, 2015, 86–96.

Nissen, Damerow, and Englund 1990

Hans J. Nissen, Peter Damerow, and Robert K. Englund. *Frühe Schrift und Techniken der Wirtschaftsverwaltung im alten Vorderen Orient. Informationsspeicherung und -verarbeitung vor 5000 Jahren*. Bad Salzdetfurth: Franzbecker, 1990.

Notizia and Visicato 2016

Palmiro Notizia and Giuseppe Visicato. *Early Dynastic and Early Sargonic Administrative Texts Mainly from the Umma Region*. Cornell University Studies in Assyriology and Sumerology 33. Bethesda: CDL Press, 2016.

Oppenheim 1948

A. Leo Oppenheim. *Catalogue of the Cuneiform Tablets of the Wilberforce Eames Babylonian Collection in the New York Public Library. Tablets of the Time of the Third Dynasty of Ur*. American Oriental Series 32. New Haven: The American Oriental Society, 1948.

Owen 1975

David I. Owen. *The John Frederick Lewis Collection. Texts from the Third Millennium in the Free Library of Philadelphia. Part I: Catalogue and Texts*. Materiali per il Vocabolario Neosumerico 3. Rome: Multi-grafica Editrice, 1975.

Paoletti and Schrakamp 2011–2013

Paola Paoletti and Ingo Schrakamp. “Steuer. A. Babylonien im 3. Jahrtausend”. In *Reallexikon der Assyriologie und Vorderasiatischen Archäologie*. Vol. 13. Ed. by M. P. Streck. Berlin and New York: De Gruyter, 2011–2013, 161–164.

Parrot 1948

André Parrot. *Tello. Vingt campagnes de fouilles (1877–1933)*. Paris: Éditions Albin Michel, 1948.

Pemberton, Postgate, and Smyth 1988

W. Pemberton, J. Nicholas Postgate, and R. F. Smyth. “Canals and Bunds, Ancient and Modern”. In *Irrigation and Cultivation in Mesopotamia Part I*. Ed. by J. N. Postgate and M. A. Powell. Bulletin on Sumerian Agriculture 4. Cambridge: Sumerian Agriculture Group, 1988, 207–221.

Pettinato 1981

Giovanni Pettinato. *Testi lessicali monolingui della biblioteca L. 2769*. Materiali Epigrafici di Ebla 3. Napoli: Istituto Universitario Orientale, 1981.

Postgate 1988

J. Nicholas Postgate. “Introduction”. In *Irrigation and Cultivation in Mesopotamia*. Ed. by J. N. Postgate and M. A. Powell. Part I. Bulletin on Sumerian Agriculture 4. Cambridge: Sumerian Agriculture Group, 1988, vii–x.

Postgate 1992

J. Nicholas Postgate. *Early Mesopotamia. Society and Economy at the Dawn of History*. London and New York: Routledge, 1992.

Pournelle 2003

Jeniffer Pournelle. *Marshland of Cities: Deltaic Landscape and the Evolution of Early Mesopotamian Civilization*. Unpublished PhD Dissertation. University of California at San Diego, 2003.

Renger 1970

Johannes Renger. “Zur Lokalisierung von Karkar”. *Archiv für Orientforschung* 23 (1970), 73–78.

Renger 1990

Johannes Renger. “Rivers, Watercourses and Irrigation Ditches and Other Matters Concerning Irrigation Based on Old Babylonian Sources (2000–1600 B.C.). Part II”. In *Irrigation and Cultivation in Mesopotamia*. Ed. by J. N. Postgate and M. A. Powell. Bulletin of Sumerian Agriculture 5. Cambridge: Sumerian Agriculture Group, 1990, 31–46.

Rey 2016

Sébastien Rey. *For the Gods of Girsu. City-State Formation in Ancient Sumer*. Oxford: Archaeopress, 2016.

Röllig 1980–1983

Wolfgang Röllig. “Landkarten”. In *Reallexikon der Assyriologie und Vorderasiatischen Archäologie*. Ed. by M. P. Streck. Vol. 6. Berlin and New York: De Gruyter, 1980–1983, 464–467.

Rost 2011

Stephanie Rost. “Irrigation Management in the Ur III Period: A Reconstruction Based on a Case Study of the Maintenance of the ÍD-NINA-ŠÈ-DU canal of the Province Lagas”. In *The Empirical Dimension of Ancient Near Eastern Studies. Die empirische Dimension altorientalischer Forschungen*. Ed. by G. J. Selz and K. Wagensohn. Wiener Offene Orientalistik 6. Wien: LIT Verlag, 2011, 211–269.

Rost 2015

Stephanie Rost. *Watercourse Management and Political Centralization in Third-Millennium B.C. Southern Mesopotamia: A Case Study of the Umma Province of the Ur III Period (2112–2004 B.C.)*. Unpublished PhD Dissertation. State University of New York at Stony Brook, 2015.

Rost and Abdulmir 2011

Stephanie Rost and Hamdani Abdulmir. "Traditional Dam Construction in Modern Iraq: A Possible Analogy for ancient Mesopotamian Irrigation Practices". *Iraq* 73 (2011), 201–220.

Rubio 2010

Gonzalo Rubio. "Reading Sumerian Names, I: En-suhkešdanna and Baba". *Journal of Cuneiform Studies* 62 (2010), 29–43.

Sallaberger 1991

Walther Sallaberger. "Zur Lesung der Bewässerungseinrichtung NAG-kud = káb-kud". *Nouvelles assyriologiques brèves et utilitaires* 47 (1991).

Sallaberger 1996

Walther Sallaberger. *Der babylonische Töpfer und seine Gefäße. Nach Urkunden altsumerischer bis altbabylonischer Zeit sowie lexikalischen und literarischen Zeugnissen. Mit einem Beitrag von M. Civil: HAR-ra = hubullu: Tablet X. dug = karpatu. Mesopotamian History and Environment Memoirs* 3. Ghent: University of Ghent, 1996.

Sallaberger 2000

Walther Sallaberger. "Textformular und Syntax in sumerischen Verwaltungstexten". In *Special Volume in Honor of Professor Mamoru Yoshikawa, 1: The Study of Diachronic and Synchronic Variation in Sumerian: Papers Presented at the 6th Meeting of the Sumerian Grammar Discussion Group, Oxford, 17th and 18th September 1999*. Ed. by J. A. Black and G. Zólyomi. *Acta Sumerologica* 22. Hiroshima: The Middle Eastern Culture Center Japan, 2000, 249–277.

Sallaberger 2005

Walther Sallaberger. "The Sumerian Verb *na de*5(-g) 'to clear'". In *'An Experienced Scribe who neglects Nothing'*. *Ancient Near Eastern Studies in Honor of Jacob Klein*. Ed. by Y. Sefati, P. Artzi, C. Cohen, B. L. Eichler, and V. A. Hurowitz. Bethesda: CDL Press, 2005, 229–253.

Sallaberger 1993/1994

Walther Sallaberger. "Keilschrifttexte einer Privatsammlung". *Archiv für Orientforschung* 40/41 (1993/1994), 52–63.

Sallaberger and Schrakamp 2015a

Walther Sallaberger and Ingo Schrakamp. "Conclusion". In *History & Philology*. Turnhout: Brepols, 2015.

Sallaberger and Schrakamp 2015b

Walther Sallaberger and Ingo Schrakamp. "Philological Data for a Historical Chronology of Mesopotamia in the 3rd Millennium". In *History & Philology*. Ed. by W. Sallaberger and I. Schrakamp. Associated Regional Chronologies for the Ancient Near East and the Eastern Mediterranean 3. Turnhout: Brepols, 2015, 1–136.

Salonen 1968

Armas Salonen. *Agricultura Mesopotamia nach sumerisch-akkadischen Quellen. Eine lexikalische und kulturgeschichtliche Untersuchung*. *Annales Academiae Scientiarum Fennicae* 149. Helsinki: Suomalainen tiedeakatemia, 1968.

Sauren 1966

Herbert Sauren. *Topographie der Provinz Umma nach den Urkunden aus der Zeit der III. Dynastie von Ur*. Unpublished PhD Dissertation. Ruprecht-Karls-Universität Heidelberg, 1966.

Schrakamp 2010

Ingo Schrakamp. *Krieger und Waffen im frühen Mesopotamien. Organisation und Bewaffnung des Militärs in frühdynastischer und sargonischer Zeit*. PhD Dissertation. Philipps-Universität Marburg, 2010. URL: <https://archiv.ub.uni-marburg.de/diss/z2010/0486/> (visited on 25/05/2018).

Schrakamp 2013

Ingo Schrakamp. "Die ‚Sumerische Tempelstadt‘ heute. Die sozioökonomische Rolle eines Tempels in frühdynastischer Zeit". In *Tempel im Alten Orient. 7. Internationales Colloquium der Deutschen Orient-Gesellschaft 11.–13. Oktober 2009, München*. Ed. by K. Kaniuth, A. Löhnert, J. L. Müller, A. Otto, M. R. Roaf, and W. Sallaberger. *Colloquien der Deutschen Orient-Gesellschaft* 7. Wiesbaden: Harrassowitz, 2013, 445–465.

Schrakamp 2014

Ingo Schrakamp. "Krieger und Bauern. RU-lugal und aga₃/aga-us₂ im Militär des altsumerischen Lagaš". In *Krieg und Frieden im Alten Vorderasien. 52e Rencontre Assyriologique Internationale. International Congress of Assyriology and Near Eastern Archaeology Münster, 17.–21. Juli 2006*. Ed. by H. Neumann, R. Dittmann, S. Paulus, G. Neumann, and A. Schuster-Brandis. Alter Orient und Altes Testament 401. Münster: Ugarit-Verlag, 2014, 691–724.

Schrakamp 2015a

Ingo Schrakamp. "Urukagina, Sohn des Engilsa, des Stadtfürsten von Lagaš: Zur Herkunft des Urukagina, des letzten Herrschers der 1. Dynastie von Lagaš". *Altorientalische Forschungen* 42 (2015), 15–23.

Schrakamp 2015b

Ingo Schrakamp. "Urukagina und die Geschichte von Lagaš am Ende der präsaragonischen Zeit". In *It's a Long Way to a Historiography of the Early Dynastic Period(s)*. Ed. by G. J. Selz and R. Dittmann. Altertumskunde des Vorderen Orients. Archäologische Studien zur Kultur und Geschichte des Alten Orients 15. Münster: Ugarit-Verlag, 2015, 303–386.

Selz 1989

Gebhard J. Selz. *Altsumerische Verwaltungstexte aus Lagaš. Vol. 1. Die altsumerischen Wirtschaftsurkunden der Eremitage zu Leningrad*. Freiburger Altorientalische Studien 15.1. Stuttgart: Franz Steiner, 1989.

Selz 1993a

Gebhard J. Selz. "kaparru(m); ein sumerisches Lehnwort im Akkadischen?" *Revue d'assyriologie et d'archéologie orientale* 87 (1993), 29–45.

Selz 1993b

Gebhard J. Selz. *Altsumerische Verwaltungstexte aus Lagaš. Vol. 2. Altsumerische Wirtschaftsurkunden aus amerikanischen Sammlungen*. Freiburger Altorientalische Studien 15.2. Stuttgart: Franz Steiner, 1993.

Selz 1995

Gebhard J. Selz. *Untersuchungen zur Götterwelt des altsumerischen Stadtstaates von Lagaš*. Occasional Publications of the Samuel Noah Kramer Fund 13. Philadelphia: The Samuel Noah Kramer Fund and The University of Pennsylvania Museum, 1995.

Selz 1996

Gebhard J. Selz. *Altsumerische Verwaltungstexte aus Lagaš Teil 3: Die altsumerischen Wirtschaftsurkunden aus Berlin*. Unpublished manuscript, Freiburg, 1996.

Selz 2003

Gebhard J. Selz. "Aka, König von Ĝiš(š)a: zur Historizität eines Königs und seiner möglichen Identität mit Aka, König von Kiš". In *Festschrift für Burkhard Kienast zu seinem 70. Geburtstag dargebracht von Freunden, Schülern und Kollegen*. Ed. by G. J. Selz. Alter Orient und Altes Testament 274. Münster: Ugarit-Verlag, 2003, 499–518.

Selz 2011

Gebhard J. Selz. "Zur Holzwirtschaft im altsumerischen Lagaš". In *U4 du 11-ga-ni sa mu-ni-ib-du 11. Ancient Near Eastern Studies in Memory of Blahoslav Hruška*. Ed. by L. Vacín. Dresden: ISLET, 2011, 213–246.

Sigrist 1990

Marcel Sigrist. *Tablettes du Princeton Theological Seminary. Epoque d'Ur III*. Occasional Publications of the Samuel Noah Kramer Fund 10. Philadelphia: The Babylonian Section of the University Museum, Philadelphia, 1990.

Sjöberg 1998

Åke W. Sjöberg. *The Sumerian Dictionary of the University of Pennsylvania Museum*. Vol. A/3. Philadelphia: The Babylonian Section of the University Museum, 1998.

Sjöberg 2003

Åke W. Sjöberg. "Notes on Selected Entries from the Ebla Vocabulary eš2-bar-kin5 (IV)". In *Literatur, Politik und Recht in Mesopotamien. Festschrift für Claus Wilcke*. Ed. by W. Sallaberger, K. Volk, and A. Zgoll. *Orientalia Biblica et Christiana* 14. Wiesbaden: Harrassowitz, 2003, 251–266.

Steible 1982

Horst Steible. *Die altsumerischen Bau- und Weibinschriften*. Freiburger Altorientalische Studien 5. Wiesbaden: Franz Steiner, 1982.

Steible and Yıldız 2015

Horst Steible and Fatma Yıldız. *Wirtschaftstexte aus Fara II. Texte der Viehverwaltung von Šuruppak. Ausgrabungen der Deutschen Orient-Gesellschaft in Fara und Abu Hatab*. Die Inschriften von Fara Band 4. Wissenschaftliche Veröffentlichungen der Deutschen Orient-Gesellschaft 143. Wiesbaden: Harrassowitz, 2015.

Steiner 1986

Gerd Steiner. "Der Grenzvertrag zwischen Lagaš und Umma". *Acta Sumerologica* 8 (1986), 219–300.

Steinkeller 1978

Piotr Steinkeller. "On the Reading and Meaning of a-ZAR-la". *Revue d'assyriologie et d'archéologie orientale* 72 (1978), 73–76.

Steinkeller 1981

Piotr Steinkeller. "The Renting of Fields in Early Mesopotamia and the Development of the Concept of 'Interest' in Sumerian". *Journal of the Economic and Social History of the Orient* 24 (1981), 113–145.

Steinkeller 1987

Piotr Steinkeller. "Review of Å. Sjöberg with the collaboration of Barry L. Eichler/Margaret W. Green/Erle Leichty/Darlene M. Loding, The Sumerian Dictionary of the University Museum of the University of Pennsylvania Vol. 2 B". *Journal of Near Eastern Studies* 46 (1987), 55–59.

Steinkeller 1988

Piotr Steinkeller. "Notes on the Irrigation System in Third Millennium Southern Babylonia". In *Irrigation and Cultivation in Mesopotamia Part I*. Ed. by J. N. Postgate and M. A. Powell. Bulletin on Sumerian Agriculture 4. Cambridge: Sumerian Agriculture Group, 1988, 73–92.

Steinkeller 1999

Piotr Steinkeller. "Land-Tenure Conditions in Third-Millennium Babylonia: The Problem of Regional Variation". In *Urbanization and Land Ownership in the Ancient Near East. A Colloquium Held at New York University, November 1996, and the Oriental Institute, St. Petersburg, Russia, May 1997*. Ed. by M. Hudson and B. A. Levine. Peabody Museum Bulletin 7. Cambridge, MA: Peabody Museum of Archaeology and Ethnology at Harvard University, 1999, 289–329.

Steinkeller 2001

Piotr Steinkeller. "New Light on the Hydrology and Topography of Southern Babylonia in the Third Millennium". *Zeitschrift für Assyriologie und Vorderasiatische Archäologie* 91 (2001), 22–84.

Steinkeller 2011

Piotr Steinkeller. "On the Location of the Town of GARšana and Related Matters". In *Garšana Studies*. Ed. by D. I. Owen. Cornell University Studies in Assyriology and Sumerology 6. Bethesda: CDL Press, 2011, 373–390.

Steinkeller 2015

Piotr Steinkeller. "A Group of Girsu/Lagaš Texts Dealing with Irrigation". *Nouvelles assyriologiques brèves et utilitaires* 61 (2015).

Stol 1976–1980

Marten Stol. "Kanal(isation). A. Philologisch". In *Reallexikon der Assyriologie und Vorderasiatischen Archäologie*. Vol. 5. Ed. by M. P. Streck. Berlin and New York: De Gruyter, 1976–1980, 355–365.

Stol 2012

Marten Stol. "Bitumen in Ancient Mesopotamia. The Textual Evidence". *Bibliotheca Orientalis* 69 (2012), 355–365.

Studevent-Hickman 2011

Benjamin Studevent-Hickman. "New Grounds for the Ü". *Journal of Cuneiform Studies* 63 (2011), 35–49.

Thureau-Dangin 1903

François Thureau-Dangin. *Recueil de tablettes chaldéennes*. Paris: Ernest Leroux, 1903.

Thureau-Dangin 1932

François Thureau-Dangin. "Notes assyriologiques". *Revue d'assyriologie et d'archéologie orientale* 29 (1932), 21–28.

Veldhuis 2006

Niek Veldhuis. "How Did They Learn Cuneiform? Tribute/Word List C as an Elementary Exercise". In *Approaches to Sumerian Literature. Studies in Honour of Stip (H. L. J. Vanstiphout)*. Ed. by P. Michalowski and N. Veldhuis. Cuneiform Monographs 35. Leiden and Boston: Brill, 2006, 181–200.

Veldhuis 2014

Niek Veldhuis. *History of the Cuneiform Lexical Tradition*. Guides to the Mesopotamian Textual Record 6. Münster: Ugarit-Verlag, 2014.

Visicato 1996

Giuseppe Visicato. "The Dating for Nik I, 30". *Nouvelles assyriologiques brèves et utilitaires* 116 (1996).

Waetzoldt 1990

Hartmut Waetzoldt. "Zu den Bewässerungseinrichtungen in der Provinz Umma". In *Irrigation and Cultivation in Mesopotamia Part II*. Ed. by J. N. Postgate and M. A. Powell. Bulletin of Sumerian Agriculture 5. Cambridge: Sumerian Agriculture Group, 1990, 1–29.

Wilcke 1996

Claus Wilcke. "Neue Rechtsurkunden der Altsumerischen Zeit". *Zeitschrift für Assyriologie und Vorderasiatische Archäologie* 86 (1996), 1–67.

Wilcke 1999a

Claus Wilcke. "Flurschäden, verursacht durch Hochwasser, Unwetter, Militär, Tiere und schuldhaftes Verhalten zur Zeit der 3. Dynastie von Ur?". In *Landwirtschaft im Alten Orient. Ausgewählte Vorträge der XLI. Rencontre Assyriologique Internationale Berlin, 4.–8.7.1994*. Ed. by H. Klengel and J. Renger. Berliner Beiträge zum Vorderen Orient 24. Berlin: Dietrich Reimer, 1999, 301–339.

Wilcke 1999b

Claus Wilcke. "Korrekturen zu ‚Flurschäden‘". *Nouvelles assyriologiques brèves et utilitaires* 70 (1999).

Wilkinson 2003

Tony J. Wilkinson. *Archaeological Landscapes of the Near East*. Tucson: University of Arizona Press, 2003.

Wilkinson 2012

Tony J. Wilkinson. "Hydraulic Landscapes and Irrigation Systems of Sumer". In *The Sumerian World*. Ed. by H. Crawford. London and New York: Routledge, 2012, 33–54.

Wilkinson, Rayne, and Jotheri 2015

Tony J. Wilkinson, Louise Rayne, and Jafaar Jotheri. "Hydraulic Landscapes in Mesopotamia: The Role of Human Niche Construction". *Water History* 7.4 (2015), 397–418.

Yıldız, Waetzoldt, and Renner 1988

Fatma Yıldız, Hartmut Waetzoldt, and Hubert Renner. *Die Umma-Texte aus den Archäologischen Museen zu Istanbul*. Vol. 1–600. Materiali per il vocabolario neosumerico 14. Rome: Multigrafica Editrice, 1988.

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Christopher Gerrard and Alejandra Gutiérrez

The *Qanat* in Spain: Archaeology and Environment

Summary

This article defines the elements of *qanat* technology in Spain and describes some recent projects which have advanced our understanding. A brief bibliography is provided that exposes some of the confusion surrounding classification, nomenclature, numbers, and distribution of the *qanat*. Some examples taken from recent fieldwork illustrate the complexities and show how different elements of hydraulic technology are combined. Hydraulic features at Citruénigo (Navarre), Bureta, Bulbuenta and Daroca (all Aragón), Madrid, and Toledo (Castile-La Mancha) are all described. Finally, the paper focuses on recent research into dating these features and highlights a recently completed project that dated episodes of construction and maintenance using optically stimulated luminescence (OSL). This technique seems to offer significant potential for future research.

Keywords: *qanat*; medieval archaeology; optically stimulated luminescence; hydraulic archaeology

Dieser Artikel definiert die Elemente der *qanat*-Technologie in Spanien und beschreibt einige neuere Projekte, die unser Verständnis dort vorangebracht haben. Es wird eine kurze Bibliographie vorgelegt, die einige der Verwirrungen um die Klassifikation, Nomenklatur, Zahlen und Verteilung der *qanat* offenlegt. Einige Beispiele aus der jüngsten Feldforschung verdeutlichen die Komplexität der Anlagen und zeigen, wie unterschiedliche Elemente der hydraulischen Technologie kombiniert werden. Hydraulische Merkmale bei Citruénigo (Navarra), Bureta, Bulbuenta und Daroca (alle Aragón), Madrid, Toledo (Kastilien-La Mancha) werden beschrieben. Schließlich werden jüngste Forschungen zur Datierung der *qanats* diskutiert und ein kürzlich abgeschlossenes Projekt vorgestellt, in dem Bauphasen und Phasen der Instandhaltung mittels Optisch Stimulierter Luminiszenz (OSL) datiert wurden. Diese Technik scheint ein erhebliches Potenzial für die Zukunft zu bieten.

Keywords: *qanat*; Mittelalterarchäologie; optisch stimulierte Lumineszenz; hydraulische Archäologie

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siastic approach to OSL; and Miguel Antequera, Emilio Iranzo (Valencia University), and Gegorio Romero (Gobierno de Murcia) for their help with *qanats* in Murcia. The dating of *qanats* at Bureta and Jumilla is part of a research project funded by the Leverhulme Trust and Durham University, under the direction of Ian Bailiff and Chris Gerrard, with the participation of Nathan Jankowski, entitled *Developing New Approaches to Dating Ancient Irrigation Features* (<https://www.dur.ac.uk/archaeology/research/projects/all/?mode=project&cid=752>; visited on 25/05/2018).

It is commonly accepted that Islamic irrigation systems with their hydraulic infrastructure of canals, diversion dams, and water-raising machines form the basis for later medieval Spanish agriculture.¹ According to this model, certain elements of irrigation technology first came to Spain as part of a technology ‘package’ in the first decades of the Arab conquest. This package was established around the great cities of Valencia, Murcia, and Toledo, where cultivars such as cotton and oranges were first planted and new models of water distribution and maintenance were practiced. One particular element of this package was the *qanat*, which was later transferred across the Atlantic and took root in the Americas; in Peru, Chile, and Mexico, among other places.

While the impact of Islam on irrigation is not in doubt, every single one of the above statements could, and should, be questioned. In this article, we examine the Spanish *qanat* in more detail, addressing some of the challenges of classification and nomenclature, and describing the preliminary results from a recent fieldwork project that is attempting to refine the chronological context.

I What is a *qanat*?

A *qanat* (also called *khattara*, *foggara*, or *karez* in other regions) is an underground tunnel, almost horizontal, which bores into an aquifer and guides the water out through an outlet, usually via a storage pond (Fig. 1). The construction process begins with the digging of a ‘mother well’ that is drilled downwards to the aquifer; other vertical breather shafts (sometimes called ‘aeration shafts’) are then excavated at regular intervals along the length of the tunnel, their function being to allow the excavated sediments and rock to be more easily removed, to provide light and air to the tunnel, to provide convenient points of access to make repairs, and sometimes to extract water along the length of the water course. In some *qanats*, a water ‘conveyor’ channel may be carved out in the center or to one side of the underground tunnel, not only creating a walking path that remains

1 Al-Hassan and Hill 1986.

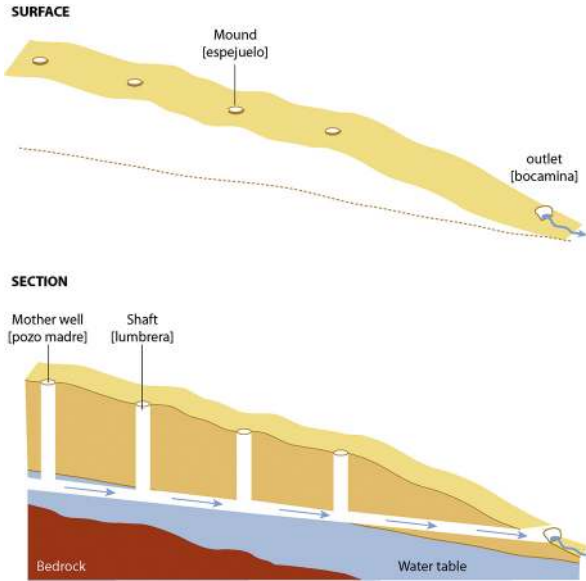


Fig. 1 A schematic view of a *qanat* as seen on the surface and as a cross section.

dry underfoot except in times of flood, but also in order to increase the speed of the water and to avoid the accumulation of sediment. Up on the surface, the distinctive feature of the *qanat* is the set of breather shafts that often have a ring of soil compacted around them (sometimes referred to as a ‘doughnut’), thereby, marking their position in the landscape, as well as serving to protect the mouths of the vertical shafts from surface flooding.

Qanats are still widely employed across the world, and are the main source of water in many communities in Oman, Afghanistan, Pakistan, China, and Azerbaijan, for example; there are more than 1500 km of *qanat* tunnels in Libya alone and perhaps 200 times that length in Iran. Unlike pumped wells, which can withdraw too much water and thereby reduce the capacity of the aquifer to supply the wells, *qanats* operate continuously and yet they cannot remove more water from the aquifer than the aquifer can naturally supply. They, therefore, offer a sustainable water supply. There are, however, some constraints: *qanats* are usually constructed in regions where the surface topography is not too mountainous and where the groundwater lies at a relatively shallow depth.

2 Research into Spanish *qanats*

Irrigation, including *qanats*, has attracted a considerable amount of interest in Spain recently. Monumental works by Pavón Maldonado, for example, provide a comprehensive

introduction to the subject, as well as multiple descriptions of so-called ‘water galleries’ from different dates, many of them repeatedly modified.² Much valuable work has also been undertaken in coastal regions in Almería by Patrice Cressier; in Valencia and Murcia by André Bazzana; and in Catalonia and Mallorca by Miguel Barceló and Helena Kirchner, where irrigation studies have a high profile inspired by earlier historians such as Thomas Glick. The list of case studies in what has been termed ‘hydraulic archaeology’ is rich and impressive.³

Most recently, a European-funded project, designed and run by geographers from Valencia University, has aimed to catalogue all the *qanats* in south-eastern Spain under the title *Foggara: Inventory, Analysis and Valorisation of Traditional Water Techniques of European and Saharan Drainage Tunnels (2003–2007)*. This project comprised a bibliographic and cartographic search that produced a database and mapping of sites which have since been visited and described, thereby, creating a checklist of topographic information. Although the project was not intended to provide any historical, social, or legal context to the sites it identified, the result is a new inventory and typology of what are referred to as ‘water galleries’, which itself provides a solid basis for further research. Exceptionally useful, are the map resources provided online through the Spanish Government (Ministerio de Agricultura, Alimentación y Medio Ambiente).⁴

3 Classification and nomenclature

In Spain, *qanats* go by many names, and this is part of the confusion surrounding the true number and distribution of them across the Peninsula. They may be known as ‘water ways’ (*viajes de agua*) in the center of the country, ‘underground aqueducts’ (*acueductos subterráneos*), ‘water galleries’ (*galerías de agua*), ‘draining galleries’ (*galerías drenantes*), ‘narrow channels’ (*canalizos*), and ‘horizontal wells’ (*pozos horizontales*) in the south and south-east. In the Murcia region they are called ‘galleries with small mirrors’ (*galerías con espejuelos*), with the mirrors referring to the reflective effect of the water that is visible at the bottom of the breather shafts. Some of this terminology directly reflects the traditional names employed in 18th-century treatises (for example, when describing the “water [...] and its subterranean ways”),⁵ but also reflects recent definitions adopted by geographers, as well as translations from other languages.

2 Pavón Maldonado 1990, 185–340.

3 Cressier 1989; Cressier 1991; Cressier 2006; Bazzana and Guichard 1986; Bazzana, Guichard, and Montmessin 1987; Bazzana and Meulemeester 1998; Barceló 1989; Kirchner 2010; Glick 1970; Glick 1979; Glick 1988; Glick 1996.

4 <https://www.chj.es/es-es/ciudadano/libros/Paginas/Libros.aspx?Seccion=Cartograf%C3%ada+de+regad%C3%ados+hist%C3%B3ricos+de+regad%C3%ados+hist%C3%B3ricos+de+regad%C3%ados+hist%C3%B3ricos> (visited on 25/05/2018); Iranzo and Hermosilla 2015.

5 Aznar de Polanco 1727, 198; Ardemens 1724, 76–77.

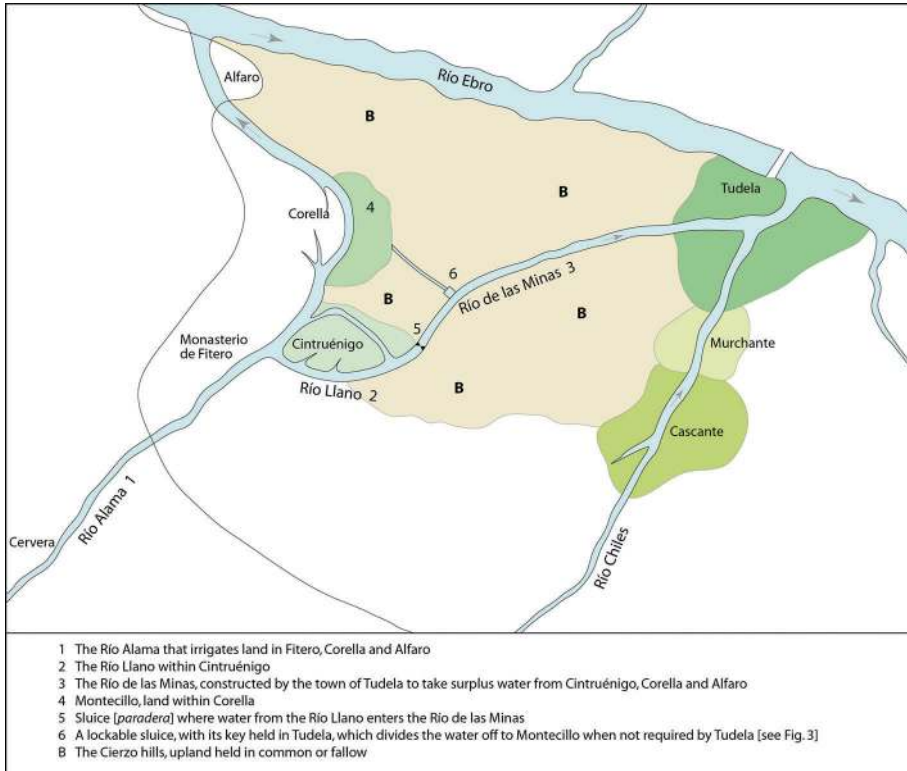


Fig. 2 Río de las Minas in Cintruénigo, Navarre, according to a map drawn before 1772 (the date when the map was donated to the Archive; *Mapas y planos de varios autores contenidos en este II tomo*, Madrid, 1798, no. 8). The 'Partidor de los Fieles' is located at number 6 (the drawing uses modern spelling).

The use of Spanish terms for *qanats* is, therefore, far from consistent. To add a further complication, some of these terms can also refer to the conveyance or transfer of water more generally; the 'water way' designed in 1772 for Hervás (Cáceres), for example, is merely the transfer of water through ceramic pipes from the spring to ponds that feed fountains in the village. The water, in this case, moves by gravity along pipes that are trenched into the ground; there is no underground tunnel.⁶ A particular source of confusion related to establishing clear definitions is the presence of vertical breather holes. While these are certainly one of the essential criteria in the identification of a true *qanat*, there are other kinds of underground tunnels with breather holes that do not drain water from an aquifer. A good illustration of this is the so-called *qanat* at Citruénigo in

6 Abujeta Martín 2010.



Fig. 3 'Partidor de los Fieles' in Cintruénigo, Navarre. Cintruénigo in the distance.

Navarre,⁷ which was constructed in the 17th century to resolve a dispute over the division of water between four neighboring communities (Fitero, Corella, Cintruénigo, and Tudela). This clash had begun centuries earlier, but in 1550, Tudela started to press in earnest for a share of the water from the irrigation channels stemming from the nearby Río Alhama, which were already in use by nearby parishes. However, it was not until 1623 that Tudela obtained permission to cut its new irrigation channel and, following further protests by neighbors wishing to protect their rights, not until 1625 was permission finally confirmed. Only then did Tudela purchase the land it needed to construct the “open and closed channels.”⁸ A map, perhaps contemporary with the opening of this system or just slightly later than that, recorded all its main elements, as well as the dry land to the west of Tudela that were to be irrigated (schematized in Fig. 2). This shows that the new channel was to be called the Río de las Minas, and that it took its water from the Río Llano, an *acequia* or artificial irrigation channel that derived from the Río Alhama. In this context, it should be noted, both the ‘natural’ river system (the Río Alhama) and the artificially cut channels (the Llano and the Río de las Minas) use the prefix ‘río’ or ‘river.’

On the ground today, the Río Llano is a single irrigation channel which trifurcates at a water divider called the Partidor de los Fieles (Fig. 3, number 6 in Fig. 2), with three branches running off towards Corella, Cintruénigo, and Tudela. This last branch is the Río de las Minas, dug shortly after 1625 and now referred to as a *qanat*.

In order to drive the water to the drylands in the Campo de la Sierpe on the opposite side of the Cierzo hills, where it is needed, the new channel is forced to dive

7 Hernández Charro 2006.

8 Yanguas 1823, 23–26.

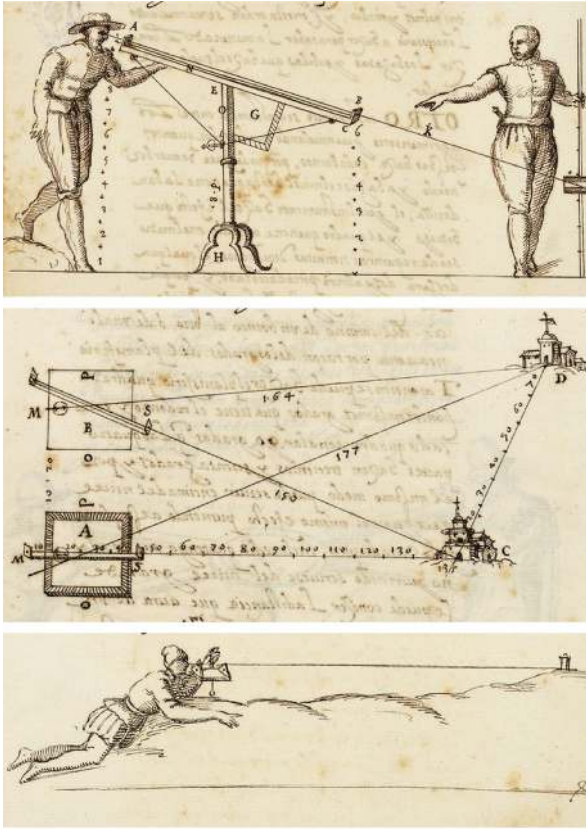


Fig. 4 How to calculate the correct level in order to convey water across the landscape in the 16th century, according to Lastanosa (1601).

underground in a tunnel for a distance of 1.5 km. There are 15 vertical shafts about 50 m apart before the water channel makes use of the interleaved hard geology and softer marls to cap its exit point (the *bocamina* in Spanish) to re-appear at El Boquerón. Here, the water is yet again divided between several channels that irrigate about 1077 hectares of olives, vineyards, and cereal fields before terminating at a reservoir (Balsa del Pulguer) close to Tudela. Although it is true that elements of the Cintruénigo water system are shared with the true *qanat*, such as the breather shafts and the underground channel, the Río de las Minas does not actually tap into the aquifer and must fall outside the strict definition of a *qanat* provided above. The construction of galleries to move water across ranges of hills in this way was already described in the 16th century, most famously by Aragonese Pedro Juan de Lastanosa (died 1576), who illustrated the method of opening the underground tunnels, here called *minas*, in his treatise on water (Figs. 4, 5, 6).⁹

⁹ Lastanosa 1601.

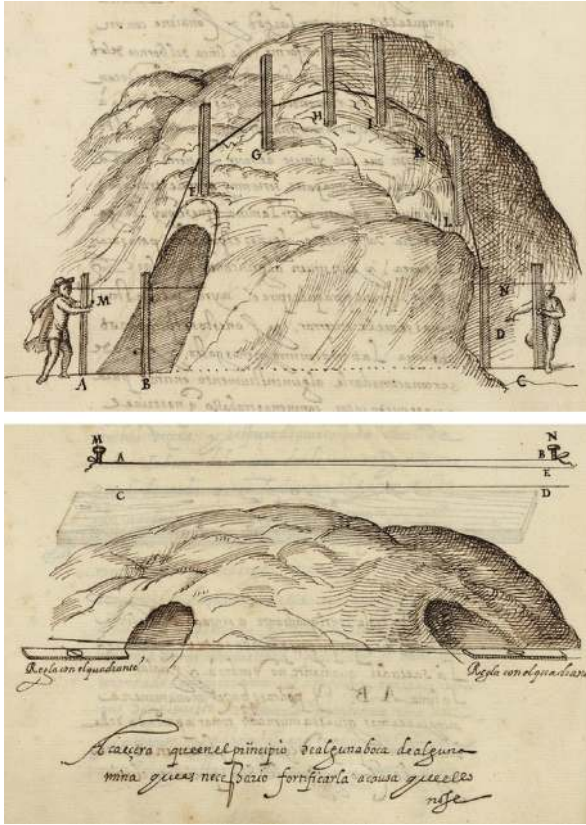


Fig. 5 How to dig a 'mine' in order to tunnel a water channel under a hill in the 16th century, according to Lastanosa (1601).

Equally common are underground galleries with shafts which tap into the water at surface level, rather than to the aquifer, in what is traditionally defined as an *adit* or 'water mine' (*mina de agua*, *minado*); confusion between these and *qanats* is quite common and the terms are sometimes used interchangeably in the literature. This is one of the *qanat*-type structures that have been documented extensively by the European *foggara* project, including some 2000 in the province of Almería alone.¹⁰ In high mountainous areas there are many *adits* or tunnels cut back into the water table, mainly short in length, but up to 820 meters in the case of 19th and 20th century examples, where there is evidence for the use of dynamite, machinery, concrete reinforcements, and modern materials. Some of these mines do have vertical shafts (called in Spanish *pozos de aireación* or *lumbres*); others have a mother well at the head of the *adit*, presumably to establish the depth of the water table initially before being blocked off later. Identical micro-systems

¹⁰ Hermosilla et al. 2004.



Fig. 6 How to line the tunnel in the 'mine' in the 16th century, according to Lastanosa (1601).

targeting particular points in the water table have been documented in the Alpujarras area, where true *qanats* are also unknown.¹¹ Those in the Alpujarras are dated to the 15th century, and some of the water cisterns associated with these systems have 16th century graffiti.¹²

'Water-mining' is documented in the Roman, Islamic, and later periods, and *adits* like these were still being built in Spain as late as 1969.¹³ Manuals of the 20th century describe the ideal conditions for digging a 'water mine': an underground gallery about 1.80 m high by 0.80 m width to allow for comfortable access, an inclination between 1 and 5/1000, with shafts (*lumbreras*) every 40 to 70 m to remove the excavated soil.¹⁴ While

11 Cressier 1989.

12 Cressier 1985.

13 For example in López Fernández, Gómez Espín, and

Gil Meseguer 2015.

14 Murcia Viudas 1958, 90.

the *adits* are, in themselves, quite simple applications of mining technology, they could also be combined with other features: at Vélez-Málaga (Málaga) the water system served the Islamic city until the 18th century and included wells, storage cisterns (*aljibes*), and galleries cut into the rock and built in brick.¹⁵ Mines were also used to bring water to the royal palace at Aranjuez (Madrid) and to its extensive gardens; the renovation works ordered by King Phillip V in the middle of the 18th century were well documented at the time and have been investigated archaeologically in considerable detail.¹⁶ *Adits* were excavated at the site of four natural springs, first by digging a channel in the bedrock, then using ceramic pipes; the first part of the channel had a brick floor, barrel vault and shaft holes capped by a shaped ashlar stone (with a cubic or pyramidal form). The holes are of different sizes, the smaller ones probably being used merely to check water levels, or for obtaining water samples to test for purity. The system was opened in 1751, flooded and repaired in 1753.¹⁷

Underground tunnels with breather holes were already being built in the Roman period. Some are even mentioned in Islamic texts from the mid-10th century, where they are described as ‘ancient’ works; examples are known at Badajoz and Jerez.¹⁸ One of the better-known Roman case studies is that at Mérida (Badajoz), but others include Albarracín (Teruel), Osma and Tiermes (both Soria), and Huelva.¹⁹ Most of these underground galleries form a part of larger, more complex systems of water transfer that may include aqueducts; in these cases, the underground galleries have barrel-, pointed- or flat-vaulted ceilings, and are generally lined with ashlar and other traditional Roman building techniques, such as *opus caementicium* and *opus signinum*. The presence of hydraulic features of Roman manufacture or even Roman settlements nearby helps date them. Segóbriga (Saelices, Cuenca) has been excavated, revealing buried features and materials associated with its construction and use in the 1st–2nd centuries AD.²⁰ Shorter *adits*, generally without breather holes and without a ‘mother well’, and terminating at a storage pond, can also date to the Roman period; in some cases they are spatially associated with Roman farmsteads or villas, such as in Granada.²¹

The general technology for the construction of underground galleries was clearly linked to mineral mining and it was long-lived, re-appearing periodically in written documents and manuals, albeit with a range of different purposes in mind.²² The ‘mine’ at Daroca (Zaragoza), for example, was built in 1555–1560 by Frenchman Pierre Vedel to collect and drive floodwater safely away from the town (Fig. 7).

15 Cabello Lara 2011.

16 Martínez Calvo and López Jiménez 2012.

17 Martínez Calvo and López Jiménez 2012, 45.

18 Khalaf Ibn Ḥayyān 1981; Muñoz Vicente 1991.

19 Chamizo and S. Rodríguez 2009; Ezquerro Lebrón

2007; García and Rufete 1996; García Merino 2007;

Martínez 2007.

20 Morín de Pablos 2014, 213–237.

21 Bertrand and Sánchez Viciano 2009, 159.

22 For example Cuchi Oterino et al. 2006.



Fig. 7 The 'mine' at Daroca (Zaragoza), built in 1555–1560 to collect and drive floodwater safely away from the town.

Daroca's houses lay at the end of a ravine and the town had expanded from the hill slopes down onto the dry river plain and up onto the facing hill, where the Franquería quarter had been built around a main street (Calle Mayor). Although this is an arid region (ca. 393 mm precipitation per year), which suffers from drought, in times of very heavy rain and hail between June and September the area is affected by flash floods, so much so that by the mid-16th century the Calle Mayor was occasionally converted into a dangerous water channel, which was a threat to people and their houses. The purpose of Vedel's underground channel was therefore to divert the surface flow back to the river (Fig. 8).

To do this, a 300 m long retaining wall, called La Barbacana, was constructed to deflect water into a 900 m long tunnel that was carved right through the hill of San Jorge and down into the River Jiloca. At more than 8 m wide and 9.5 m high, the 'mine' took 5 years to complete and involved the manual excavation of some 30 000 cubic

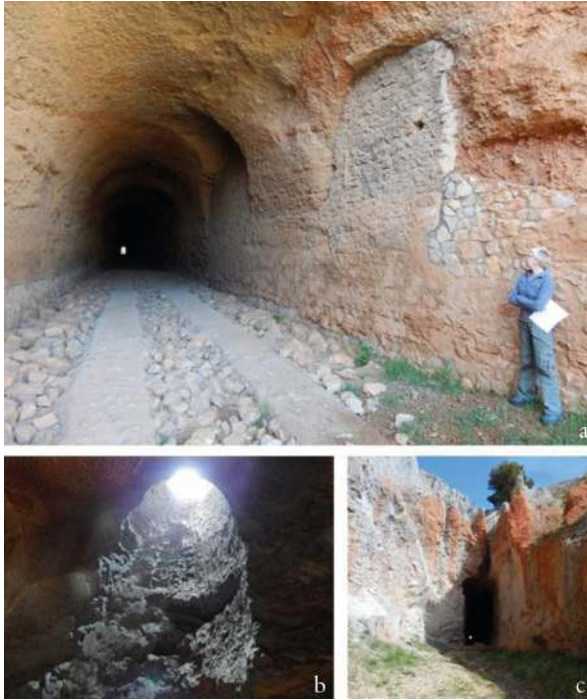


Fig. 8 The 'mine' at Daroca (Zaragoza): (a) start of tunnel, (b) shaft, and (c) tunnel exit.

meters of soil and rock.²³ In its day, the mine was something of an attraction and the diarist Henry Cock, an archer in the Flemish royal guard, described how the gallery was visited by King Philip II and his family during their trip through Aragón in 1585.²⁴ The Daroca mine was later mapped by Sebastián de Rodophe in 1742²⁵ and repaired in 1790.²⁶ Vedel himself was a renowned sculptor and an architect active in Aragón in the 16th century. His projects mainly entailed religious buildings, but he was also involved in at least one other important hydraulic construction projects, the Acueducto de los Arcos, which brought drinking water to the town of Teruel in 1551–1558, again using mines to transfer the water.²⁷ The mine at Daroca is just one illustration of the range of hydraulic works carried out in Aragón and the rest of Spain in the 16th, some of which were only modest projects, whereas, others were large engineering enterprises promoted and developed by civic authorities working for the benefit of town communities.²⁸

23 Olcina Cantos 2012, 99–100; Mateos Royo 2005, 144–145; Almagro 1998.

24 Cock 1876, 28.

25 The map and profile are in the Archivo General de Simancas (MPD, 22, 067; MPD, 27, 042). Available at www.mcu.es (visited on 25/05/2018), under 'Ma-

terial cartográfico AGS'.

26 Forniés Casals 1980, 236.

27 Ibáñez Fernández 2005; Ibáñez Fernández 2006; Mateos Royo 2005, 143–144.

28 Mateos Royo 2005.

Another water feature that shares some characteristics with the *qanat* appears on the lower ground of the fluvial terraces; these are the filtration galleries called *cimbras* in Spanish, such as those in Granada (where documents already mention them in the 15th and 16th centuries)²⁹ and Almería province.

The *cimbras* are near-horizontal tunnels that lie beneath a watercourse, usually a dry riverbed or *rambla*, so that the rain and stream water percolates down. While the shortest of these tunnels may be 50–75 m in length, the longest are up to 13 km. Again, *cimbras* can have regular aeration shafts which may be circular or rectangular and are sometimes reinforced with dry-stone walling. Some of the tunnels are also dry-stoned and over 2 m high in some places, with variable widths depending upon geology and hydrology. Along the wider river courses, the *cimbra* is usually aligned at a diagonal to the course of the river and the water emerges on the lateral terraces; where the course of the river is narrow, the *cimbra* may criss-cross the river course in a zigzag, in order to maximize the potential for water filtration. However, not all *cimbras* have breather shafts and not all take their water exclusively from percolating stream water. Fig. 9 shows an example from Bulbunte, Zaragoza, where the water is captured first from a spring and then the flow is seasonally augmented by fluvial waters, as the *cimbra* runs beneath the stream bed of the River Huecha (dry for most of the year).

In addition, there are also *zanjas*, a variant of the *cimbra*, which are open trenches dug back into the water table, then covered with a lintel of flagstones and fluvial sediments. *Zanjas* have no breather holes, so to be cleaned the lintel stones have to be pulled up to enter the gallery below.

This wide range of different sorts of water galleries amply illustrates the problem of identification and definition. A similar range of technological or engineering features are always present, but they can be combined in different ways. If the defining characteristic of the *qanat* is that it should take its water from an aquifer, then *cimbras* must be excluded. Likewise, if breather shafts are a prerequisite, *zanjas* do not qualify. The same can be said of the Roman examples, at least in Spain, which in the cases we have examined, are either *adits* or simply part of a longer channel that sometimes runs under the ground and sometimes above it. Finally, it is also worthwhile stressing that this is a technology that was practiced until quite recently. In Murcia many of the identified examples seem to date to the second half of the 19th century and even early 20th, coinciding with a rise in population associated with lead, zinc, and silver mining, of which numerous archaeological structures of interest still remain. The boom in mining activity brought about an increased demand for vegetables and fruit and a need for more extensive irrigation. Many of these water galleries then fell out of use again in the second half of the 20th century when mining declined as a result of falling metal

29 Bertrand and Sánchez Viciano 2009, 155.



Fig. 9 *Cimbra* at Bulbunte, Zaragoza, running beneath the stream bed of the River Huecha.

prices and as intensive agricultural production for international markets led to water pumping and the lowering of water tables. This over-exploitation of the water resource has been made worse by the demand for urban water, massive tourism, and associated recreational facilities, such as swimming pools and golf courses.

4 A few case studies of the Spanish *qanat*

4.1 Madrid

Madrid means ‘place of *qanats*’ and, in all, some 124 km of *viajes de agua* have now been recorded beneath Spain’s capital. 70 km of water capture and 54 km convey water to the city, providing water to 750 fountains. These *qanats* vary in shape and size, some are unlined, others lined in brick with arched ceilings to improve their stability and prevent contamination; most are of a sufficient height for a person to walk inside them, about

60–80 cm wide.³⁰ Other notable details seen here are grooved floors with a conveyor channel to carry the water and permit pedestrian access alongside the channel. Some *qanats* also have large cisterns incorporated along their lengths to facilitate water storage and distribution, others have low ‘break dams’ along their course to slow down the rate of water flow, as well as smaller cisterns and checks that act to dissipate the current at corners. There are frequent breather shafts, every 40–50 paces, which are about 0.8 m in diameter and between 5 and 50 m deep. They are capped today with stones or brick covers.³¹

The origins of Madrid’s water network lie in the 9th century, when an Islamic water system was first developed in association with a fortress and later consolidated after the Christian reconquest of Toledo in 1083; at least one archaeological excavation has produced associated Islamic material. In 1561, Madrid became the capital of Spain. Its population grew considerably and, with it, there was increased demand for water. Documentary evidence indicates several new galleries were opened up at this time. The 17th century was the golden age of Madrid’s *qanats* and their water features: a dedicated ‘Fountain Committee’ (*Junta de Fuentes*) was created in 1617.³² An account from 1727 describes every gallery, every beneficiary, and public fountain.³³ The last branch was opened in 1855, at the same time as the dam Pontón de la Oliva, but by then, the system was under pressure, from an ever-increasing population and because of problems of quality and health, mainly due to groundwater contamination. These groundwater sources were the only source of water in the capital until 1858, when water from the River Lozoya was channelled and exploited, bringing water along the Canal de Isabel II. Many other points of interest could be noted, but one subtlety often seen in sophisticated water networks of this kind is the distinction made in contemporary documentation, for example in the 13th century, between *qanats* used for ‘fine’ or ‘coarse’ water; fine being used as drinking water and coarse for cleaning and irrigation.

4.2 Fuente Grande de Ocaña (Toledo)

The *qanat* at Ocaña is still in use today and supplies water to the village and its ‘Great Fountain’ (Fig. 10).

The fountain was built in 1573–1578, and is now a protected monument. Its design has been attributed to the famous Renaissance architect Juan de Herrera,³⁴ and although built in the style he is known for, the only documented builder is Francisco

30 López-Camacho 2002; Martínez-Santos and Martínez-Alfaro 2012.
31 Guerra Chavarino 2006; López-Camacho, Bustamante, and Iglesias 2005; Martínez Alfaro 1966; Martínez-Santos 2013; Oliver Asín 1959; Solesio de

la Presa 1975; Troll and Braun 1974.

32 Ardemans 1724.

33 Aznar de Polanco 1727.

34 López-Camacho, Bustamante, and Iglesias 2005.



Fig. 10 The 'Great Fountain' at Ocaña, Toledo, constructed in 1573–1578.

Hernández.³⁵ The underground infrastructure is thought to make use of Roman, Arab, medieval, and Renaissance elements, along a 400 m length of tunnels and well preserved vaulted chambers. Inserted into this system, there are rooms used for distribution, access, and to decant and clarify the water; these are all rendered in brick and considered to be contemporary with the construction of the 'Great Fountain'.

Like Madrid, other features of this system include conical caps (*madamas*) to the vertical shafts that are between 7 and 11 m deep, and 40 m apart; the caps are made of stone or brick with a central hole covered by a round stone. The floor of the gallery has a central raised path and two channels, just 30 cm wide, one on either side of the path, which allow for water of two different qualities to flow unmixed with one other. The superior quality water was used for human consumption, the worst for animals and washing clothes, etc. Once the water had reached the monumental stone fountain, it poured out through two taps (converted to ten in 1879) that faced a cobbled plaza some 1600 m square that could be accessed either by going down a ramp or two staircases. Alongside the taps, a stone trough was reserved for livestock and two further water troughs (*lavaderos*) were for use by up to 300 people for the washing of clothes, etc. Excess water was channelled from here beyond the square, and recycled for watering the local fields. Water had to be transported by hand from the square to the houses in the village until 1888, when water was elevated by a machine.³⁶

35 J. Rodríguez and Gascó Pedraza 1996.

36 López-Camacho, Bustamate, and Iglesias 2005;

Pavón Maldonado 1990.



Fig. 11 The *qanat* at Bureta, Zaragoza, includes: (A) a pond, (B) outlets for the *adit* and *qanat*, (C) shafts, plus (D) the mother well.

4.3 Bureta (Zaragoza)

Bureta is a very short *qanat*, only 164 m in length with 6 vertical access shafts, 20 to 28 meters apart, roughly one meter in diameter, ringed by upcast spoil on the surface (Fig. 11). A channel around 1.45 m high and 0.68 m wide runs seven meters below the ground and feeds water from the aquifer into a storage pond.

About 80 tons of fill would have been removed during its construction in all. Immediately adjacent is an *adit*, a horizontal tunnel with no vertical access shafts, which runs towards a local spring. This unlined tunnel is ca. 100 m long, 2.12 m high from its mud-choked base, and 0.9 m wide, with an inclined base and slightly rounded head (Fig. 12). Adze marks are still visible where the side faces have not fallen away.

The gradients of both the *qanat* and the *adit* are designed to intersect the surface as nearly as possible to an arrow-shaped storage pond, called the Albarquete, though the obvious differences in their construction imply that they are probably from a different date (Fig. 13). The pond, whose northern side is an earthen bund, retains the water before it is delivered down channels to a sub-circular area immediately to the north, traditionally an oasis of 33 hectares of irrigated land amid arid scrub pasture. Today, this tongue of irrigated land is almost a monoculture of vines, with some olive groves, but fifty years ago it provided maize, beetroot, alfalfa for grazing sheep, and market garden crops such as tomatoes.

In many respects, Bureta is typical of water infrastructure generally in Spain. Neither the *adit* nor the *qanat* are documented, there are no early maps, and the local archaeology is equivocal. A detailed field survey at high resolution has identified a late Iron Age site, a Roman villa and a number of Visigothic settlements, all within close proximity to the storage pond. None of these sites can be convincingly linked with either the *adit* or the *qanat* or indeed the natural spring site. Logic would suggest that the earliest settlement in the area was dependent upon the spring, whose flow was later augmented by the *adit*, possibly in Roman times. The chronology of the *qanat*, meanwhile, might be Islamic (i.e. 10th or 11th centuries in this region) or later. The fact that it is undocumented



Fig. 12 The *adit* at Bureta is some 100 m long, 2 m high and c.9 m wide.



Fig. 13 The unlined tunnel in the *qanat* at Bureta, Zaragoza.



Fig. 14 Sections cut through the spoil at the top of the breather shafts at the *qanat* in Bureta, in order to collect samples for OSL.

suggests that it cannot be recent (Fig. 14).

5 Dating

Qanats and other water features are in general difficult to date in their own right. As we have seen above, in the case of Citruénigo, some *qanats* already have a documented date of construction. The vast majority, however, cannot be directly dated and the archaeologist must use proxies of one sort or another. The first of these is to identify an associated monument or settlement which can itself be dated by other means. One example here is the system linked to the cave dwellings at Las Hafas, Benamaurel (Granada), which is dated to the end of the 12th century, providing a date for the use of the gallery.³⁷ It is, however, rare to find settlements of a single period or clearly defined date and, as in

³⁷ Bertrand and Sánchez Viciano 2009.

the case of the *qanat* at Ocaña, the construction date of the existing fountain does no more than provide a *terminus ante quem* for the system as a whole. Detailed archaeological field survey information can also sometimes help. When archaeological materials, particularly pottery, are collected field-by-field on a timed system of survey, it is possible to produce mapped densities which can be compared against the arable spaces irrigated by each irrigation channel or *acequia*. In theory, the abundance of sherds should indicate the irrigated areas at different periods. It might reveal, for example, the spatial relationship between Roman sites and the irrigation network. There are other indirect proxies for irrigation too, among them: the development of plant seeds; the increased deposition of silica in cereal plants when they grow under irrigation; and the presence of weeds which are sensitive to irrigation practice.³⁸ As previous Spanish studies for Bronze Age and Neolithic sites have demonstrated,³⁹ carbon isotope discrimination is also affected by water availability and one aim would be to analyze carbon isotopes in cereals from late Roman, Islamic, and later medieval contexts from a set of archaeological sites in one region where the hydraulic network is well understood.

Difficulties in dating also derive from the repair and reuse of older systems. In most recent repairs there is little interest in either recording or preserving the original features that are often altered to include concrete mouths, cement caps, the rebuilding of access, and interiors, etc. Alterations themselves can also be old. Roman underground galleries were reused in the Islamic period, including those feeding water to Seville and Córdoba, for example. In the first case, Roman Seville received its water from a system that drew water off springs at Alcalá de Guadaíra, some 17 km away. The channeling of water began here as an underground gallery with shafts opening every 80–100 m, then the water came to the surface in channels built over walls, and finally in a proper aqueduct that had over 400 arches, bridging more than 4 km. The water arrived in Seville at what was later called the Caños de Carmona to the north of the city. A chronicle describes how in 1189 an Almohad engineer uncovered and dug out the system, recognized it to be a *qanat*, had it repaired, built a branch to feed the Bohaira Palace, and then constructed a cistern to store the water.⁴⁰ Another example is the aqueduct that brought water to the Islamic palace of Madinat al-Zahra and to Córdoba. Early references to the 16th century suggest that whole system is Islamic, given that the last recorded works dated to this period. In the 16th century, for example, Morales described the good stonework and the interior render of red mortar on top of pitch, together with the shafts or breathing holes (*lumberas*), made to “avoid the tunnel collapsing.”⁴¹ It is only much later that two

38 For example Bogaard et al. 2007.

39 For example Araus and Buxó 1993.

40 Fernández Casado 1970; Ibn Sāhib al-Salāt 1969, 190–191; Jiménez Martín 1975; Montes Romero-

Camacho 1993; Carrasco Gómez and Jiménez Hernández 2008.

41 Morales 1575, 124v–125.

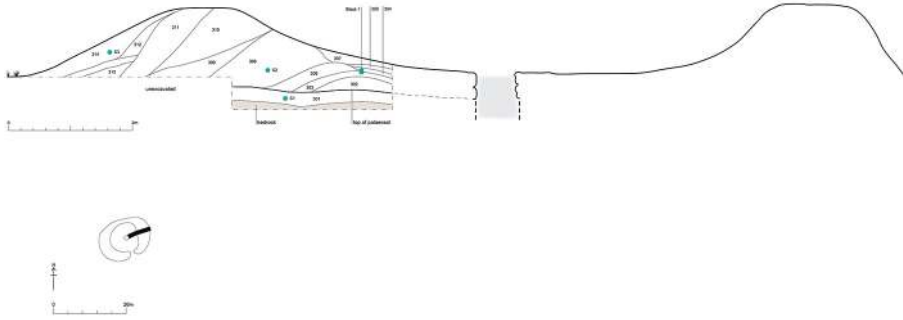


Fig. 15 North-facing section excavated through one of the mounds at Jumilla, Murcia (Mound 3), showing the stratigraphy, location of the samples for OSL and the palaeosol.

building episodes were identified: Roman and Islamic.⁴² The first system, known as Valdepuentes, was built during the Roman period in 27 BC–AD 14; with a total length of 42 km, it includes sections of aqueduct as well as underground galleries with 40 shafts, some of them with decanting pits, and all finished with prismatic turrets and capped with a flat stone. When this collapsed after an earthquake, the hydraulic system was rebuilt with new branches in the middle of the 3rd century, and later reused in the 10th century by the Arabs.⁴³

Another technique, now being experimented with, is dating through optically stimulated luminescence (OSL). A Leverhulme Trust project involving a team from Durham and Winchester Universities (UK)⁴⁴ has been sampling the episodes of upcast around the mouths of breather shafts at a selection of sites, including Jumilla and Totana (both Murcia; Figs. 15 and 16) and on the west coast of sub-Saharan Morocco, where a series of archaeological sites associated with *cimbras* are being investigated by joint Spanish and Moroccan teams.⁴⁵ Further fieldwork is planned in Oman and the United Arab Emirates later in 2016. These sites have been selected only after preliminary testing of the sediments demonstrated that they would be suitable for dating using OSL and where the permission of local authorities and landowners could be obtained.

One set of results is now available for Bureta (Zaragoza), where three mounds of upcast were sampled. Two of these produced younger dates than expected, quite possibly due to the weathering and slumping process that has eroded the mounds and the lip of the shaft.⁴⁶ Mound 2, however, produced evidence for three phases of upcast made up

42 Cean-Bermúdez 1832, 341.

43 Moreno et al. 1997; Ventura Villanueva 1993; Ventura Villanueva 2002; Ventura Villanueva and Pizarro Berengena 2010.

44 “Developing new approaches to dating ancient irri-

gation features”; <https://www.dur.ac.uk/archaeology/research/projects/all/?mode=project&id=752> (visited on 25/05/2018).

45 Onrubia Pintado et al. 2014.

46 Bailiff et al. 2015.

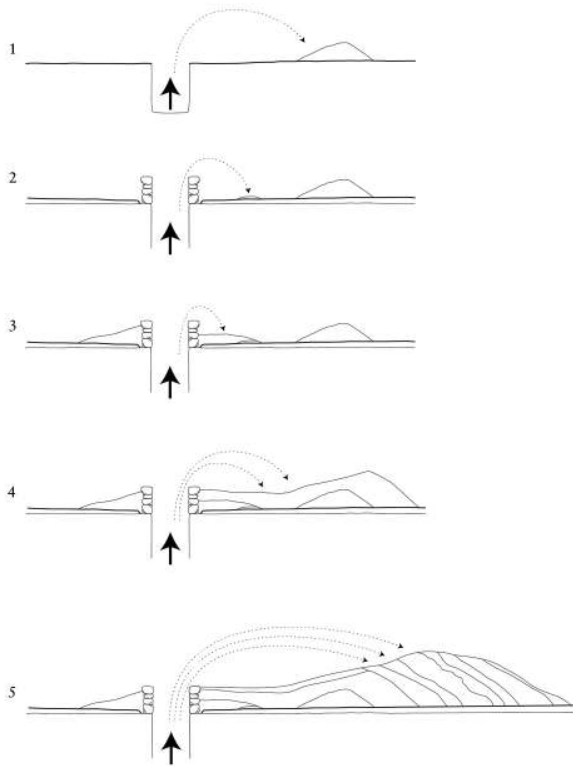


Fig. 16 An interpretation of mound formation for Mound 3 at Jumilla (see Fig. 15).

of loose, poorly sorted, clay aggregates, sandstone, and mudstone. Occasional fine roots were also present where a more humic layer had built up, presumably following an episode of cleaning. These three layers lay above a compact silty palaeosol. The OSL dates for the basal deposits from two samples from this mound are in agreement with each other, and they place construction in the first half of the 13th century. The key dates are 1230 ± 70 and 1310 ± 65 with a first phase of cleaning in the 15th century. This *qanat* is, therefore, not Islamic but would seem to date to a period at least 100 years after the Christian conquest of the region in ca. 1118. It would seem that it was not in the interests of the new Christian authorities to disrupt farming, quite the opposite in fact; higher rents could be demanded from better irrigated land and where re-settlement demanded it, and new irrigation systems were a fundamental investment.

6 Conclusion

We are beginning to perceive a rather more complex picture of *qanat* chronology in the western Mediterranean but, as yet, we are not exactly sure where this new understanding will take us. In the Arabian Peninsula, archaeologists now claim *qanats* from the early first millennium,⁴⁷ though some doubt has been cast on the precision of the dating of the pottery which provides these dates.⁴⁸ In Egypt, the evidence is more convincing, with finds and the recording of water rights suggesting that *qanats* were present by the mid-5th century BC, while in the Libyan Sahara at Fazzān, a late first millennium date (2nd century BC–4th century AD) has been suggested for the *foggara* there on the basis of their spatial and stratigraphical relationship to archaeological features of better known date (e.g. stone tumuli, settlement sites dated by pottery) and other accumulated evidence including archaeobotany which suggests irrigated crops.⁴⁹ Assuming diffusion into Roman North Africa, it is no surprise to find these various elements of *qanat* technology in a Roman Spanish context, although no independently dated examples of true *qanats* are known to these authors from Roman Spain and, even when there is plentiful evidence for Roman irrigation projects, for example around Valencia, questions of population and economic crises in the 5th and 6th centuries put any direct continuity of practice in doubt.

The Arab contribution is undeniable in enhancing hydraulic practices, intensifying them, and spreading them across al-Andalus after the 8th century; these were the multiple small-scale solutions that transformed a landscape. Arab texts seemingly provide conclusive proof that *qanat* technology was known in al-Andalus in AD 753–754, but even here the paucity of documentation is a problem and the institutional and technological aspects of Islamic irrigation tend to be examined from subsequent Christian documents (such as litigations and regulations) or by archaeologists for whom, as we have seen, dating is a major issue. Certainly, there were further changes to hydraulic networks following the Christian conquest, as the Bureta example seems to illustrate, and it is even possible that some developments in Spain were influenced by practises on the other side of the Atlantic by the end of the 16th century. It is difficult to talk with any conviction about the transmission of an Islamic technological package to the New World (for one thing, Spain is simply not the same cultural entity in the 15th century as it was 700 years previously). So, the picture that emerges is not one of linear development but of continuous reinvention and adaption of a successful and simple engineering technology in response to local pressures of population and the demand for

47 Magee 2005.

48 Wilson 2008.

49 Wilson and Mattingly 2003.

cultivation. The vast majority of true *qanats* in Spain are probably 16th–19th century in date.

‘Hydropolitics’ is a hugely contentious issue in Spain; in October 2000, 400 000 people demonstrated in Zaragoza against the government’s National Water Plan, which proposed a diversion of the River Ebro to the Mediterranean coast. This is a country in which ancient irrigation systems compete all the time with urban land uses, and no country in Europe has lost such a high proportion of its highest quality soils due to urbanisation. Traditional systems like *qanats* are said by some to be unsustainable and inefficient; local tensions run high. Water is heavily subsidized, but maize, alfalfa, and other crops unsuitable to the local climate simply could not be farmed at a profit without financial help. As yet, to treat *qanats* and other hydraulic features as a heritage worth conserving and protecting on a par with palaces and castles is a step too far for many.

Bibliography

Abujeta Martín 2010

Antonia Esther Abujeta Martín. "Un viaje de agua en Hervás del siglo XVIII". *NORBA-ARTE XXX* (2010), 89–104.

Almagro 1998

Antonio Almagro. "La mina de Daroca". In *La ciudad. Recorrido por su historia*. Ed. by J. M. Blázquez. Madrid: Grupo FCC, 1998, 153.

Araus and Buxó 1993

J. L. Araus and R. Buxó. "Changes in Carbon Isotope Discrimination in Grain Cereals from the North-Western Mediterranean Basin during the past Seven Millennia". *Functional Plant Biology* 20.1 (1993), 117–128.

Ardemans 1724

Teodoro Ardemans. *Fluencias de la tierra y curso subterráneo de las aguas*. Madrid: Francisco del Hierro, 1724.

Aznar de Polanco 1727

Juan Claudio Aznar de Polanco. *Arithmetica inferior y geometrica practica y especulativa: Origen de los nacimientos de las aguas dulces y gordas de esta coronada villa de Madrid*. Madrid: Francisco Martínez Abad, 1727.

Bailiff et al. 2015

Ian K. Bailiff, Christopher Gerrard, Alejandra Gutiérrez, Lisa Snape-Kennedy, and Keith Wilkinson. "Luminescence Dating of Irrigation Systems: Application to a Qanat in Aragón, Spain". *Quaternary Geochronology* 30 (2015), 452–459.

Barceló 1989

Miquel Barceló. "El diseño de espacios irrigados en al-Andalus: un enunciado de principios generales". In *El agua en zonas áridas: arqueología e historia, I Coloquio de Historia y Medio Físico*. Almería: Instituto de Estudios Almerienses, 1989, xv–xlvii.

Bazzana and Guichard 1986

André Bazzana and Pierre Guichard. "Irrigation et société dans l'Espagne orientale au Moyen Age". *Travaux de la Maison de l'Orient* 2.1 (1986), 115–140.

Bazzana, Guichard, and Montmessin 1987

André Bazzana, Pierre Guichard, and Yves Montmessin. "L'hydraulique agricole dans al-Andalus: données textuelles et archéologiques". In *L'homme et l'eau en Méditerranée et au Proche-Orient. IV. L'eau dans l'agriculture*. Ed. by P. Louis and J. Metral. Lyon: Maison de l'Orient, 1987, 57–76.

Bazzana and Meulemeester 1998

André Bazzana and Johnny de Meulemeester. "Les irrigations médiévales du Moyen Segura (Murcie, Espagne)". *Actes du VIe Congrès international d'Archéologie Médiévale* 6.1 (1998), 51–56.

Bertrand and Sánchez Viciano 2009

Maryelle Bertrand and José Ramón Sánchez Viciano. "Canaligos y tajeas, dos sistemas de captación de agua mediante galerías subterráneas en las altiplanicies granadinas. Andalucía Oriental". *Arqueología y Territorio Medieval* 16 (2009), 151–178.

Bogaard et al. 2007

Amy Bogaard, Tim H. Heaton, P. Poulton, and Ines Merbach. "The Impact of Manuring on Nitrogen Isotope Ratios in Cereals: Archaeological Implications for Reconstruction of Diet and Crop Management Practices". *Journal of Archaeological Science* 34.3 (2007), 335–343.

Cabello Lara 2011

Francisco Javier Cabello Lara. "Aproximación histórico-arqueológica al sistema de abastecimiento y captación de agua de la Vélez-Málaga musulmana". In *Escenarios urbanos de al-Andalus y el Occidente musulmán*. Ed. by V. Martínez. Málaga: Repertorio Español de Bibliografía Árabe e Islámica, 2011, 237–256.

Carrasco Gómez and Jiménez Hernández 2008

Inmaculada Carrasco Gómez and Alejandro Jiménez Hernández. "Arqueología de la arquitectura en el Convento de la Concepción de Carmona (Sevilla)". *Carel: Carmona, revista de estudios locales* 6 (2008), 2499–2581.

Cean-Bermúdez 1832

Juan Agustín Cean-Bermúdez. *Sumario de las antigüedades que hay en España, en especial las pertenecientes á las Bellas Artes*. Madrid: Miguel de Burgos, 1832.

Chamizo and S. Rodríguez 2009

J. J. Chamizo and S. Rodríguez. "¿Una nueva conducción en Augusta Emérita?" *FORO. Boletín informativo del Consorcio de la Ciudad Monumental, Histórico-Artística y Arqueología de Mérida* 57 (2009), 4–5.

Cock 1876

Enrique Cock. *Relación del viaje hecho por Felipe II en 1585 a Zaragoza, Barcelona y Valencia*. Madrid: A. Morel-Fatio and A. Rodríguez, 1876.

Cressier 1985

Patrice Cressier. "Graffiti cristianos sobre monumentos musulmanes de la Andalucía oriental: Una forma de exorcismo popular?" In *I Congreso de Arqueología Medieval Española I*. Zaragoza: Diputación General de Aragón, 1985, 273–291.

Cressier 1989

Patrice Cressier. "Agricultura e hidráulica medievales en el antiguo Reino de Granada. El caso de la Alpujarra costera." In *Coloquio de Historia y Medio Físico 14–16 de diciembre de 1989*. Almería: Instituto de Estudios Almerienses de la Diputación de Almería, 1989, 545–553.

Cressier 1991

Patrice Cressier. "Agua, fortificaciones y poblamiento: el aporte de la arqueología a los estudios sobre el sureste peninsular." *Aragón en la Edad Media* 9 (1991), 403–427.

Cressier 2006

Patrice Cressier. *La maîtrise de l'eau en al-Andalus: paysages, pratiques et techniques*. Madrid: Casa de Velázquez, 2006.

Cuchí Oterino et al. 2006

Jose Antonio Cuchí Oterino, José Luis Villarroya Salcedo, Carlos Garcés Manau, Santiago Fábregas Reigosa, Rocío Hurtado Roa, and Julio Bernués Pardo. "La localización de la mina de Bonés: una obra hidráulica inacabada de la Huesca del siglo XVII." *Argensola: Revista de Ciencias Sociales del Instituto de Estudios Altoaragoneses* (2006), 171–185.

Ezquerria Lebrón 2007

Beatriz Ezquerria Lebrón. "Acueducto romano de Albarracín-Gea-Cella. Abastecimiento de agua a la antigua ciudad de Cella (Teruel)." In *Fragments de historia. 100 años de arqueología en Teruel*. Ed. by P. Atrián Jordán. Teruel: Museo de Teruel, 2007, 219–223.

Fernández Casado 1970

Carlos Fernández Casado. "Acueducto de Sevilla." *Informes de la Construcción* 23 (1970), 51–98.

Forniés Casals 1980

José Francisco Forniés Casals. "Fuentes para el estudio de la sociedad y la economía aragonesas entre 1776 y 1808: Los documentos citados en las actas de la real Sociedad Económica Aragonesa de Amigos del País." *Cuadernos de Historia Jerónimo Zurita* 35–36 (1980), 173–319.

García Merino 2007

Carmen García Merino. "Problemas y soluciones en el abastecimiento de agua a Uxama Argaela." In *El agua y las ciudades romanas*. Ed. by J. Mangas Manjarrés and S. Martínez Caballero. Móstoles: Ediciones, 2007, 213–235.

García and Rufete 1996

C. García and P. Rufete. "Sistema de abastecimiento de agua a la ciudad de Huelva en época antigua. La Fuente Vieja." In *El agua en la Historia de Huelva*. Huelva: Empresa Municipal de Aguas de Huelva, 1996, 19–58.

Glick 1970

Thomas F. Glick. *Irrigation and Society in Medieval Valencia*. Cambridge, MA: Belknap Press of Harvard University Press, 1970.

Glick 1979

Thomas F. Glick. *Islamic and Christian Spain in the Early Middle Ages*. Princeton: Princeton University Press, 1979.

Glick 1988

Thomas F. Glick. "El sentido arqueológico de las instituciones hidráulicas. Regadío bereber y regadío español." In *II Jornadas de Cultura Islámica*. Teruel: Editorial Al-Fadila, 1988, 165–171.

Glick 1996

Thomas F. Glick. *Irrigation and Hydraulic Technology: Medieval Spain and Its Legacy*. Aldershot: Variorum, 1996.

Guerra Chavarino 2006

Emilio Guerra Chavarino. "Los viajes de agua de Madrid". *Anales del Instituto de Estudios Madrileños* 46 (2006), 419–466.

Al-Hassan and Hill 1986

Aḥmad Yūsuf Al-Hassan and Donald Routledge Hill. *Islamic Technology: An Illustrated History*. Cambridge: Cambridge University Press, 1986.

Hermosilla et al. 2004

J. Hermosilla, E. Iranzo, A. Pérez, M. Antequera, and J. A. Pascual. "Las galerías drenantes de la provincia de Almería: Análisis y clasificación tipológica". *Cuadernos de Geografía* 76 (2004), 125–154.

Hernández Charro 2006

María Carmen Hernández Charro. "Agua y poblamiento. Notas sobre la configuración del territorio de Tudela andalusí". *BIBLID* 24 (2006), 315–339.

Ibáñez Fernández 2005

Javier Ibáñez Fernández. *Arquitectura aragonesa del siglo XVI. Propuesta de renovación en tiempos de Fernando de Aragón (1539–1575)*. Zaragoza: Institución Fernando el Católico, 2005.

Ibáñez Fernández 2006

Javier Ibáñez Fernández. "Tratadística, antigüedad y práctica constructiva: La traída de aguas a Teruel (ca. 1551–1559), Pierres Vedel en el contexto de la ingeniería española del Quinientos". *Artigrama* 21 (2006), 395–416.

Ibn Sāhib al-Salāt 1969

Abd al-Malik ibn Muhammad Ibn Sāhib al-Salāt. *Al-Mann bil-imāma*. Textos Medievales 24. Valencia: Anubar Instituto Hispano-Árabe de Cultura, 1969.

Iranzo and Hermosilla 2015

Emilio Iranzo and Jorge Hermosilla. "Los mapas de regadío histórico en el Mediterráneo occidental: Instrumentos para el análisis de la estructura de los paisajes culturales del agua". In *Análisis espacial y representación geográfica: innovación y aplicación*. Ed. by J. de la Riva, P. Ibarra, R. Montorio, and M. Rodrigues. Zaragoza: Universidad de Zaragoza, 2015, 1027–1036.

Jiménez Martín 1975

Alfonso Jiménez Martín. "Los caños de Carmona: Documentos olvidados". *Historia, Instituciones, Documentos* 2 (1975), 317–328.

Khalaf Ibn Ḥayyān 1981

Abū Marwān Ḥayyān ibn Khalaf Ibn Ḥayyān. *Crónica del califa Abdarrahmān III An-Nāsir entre los años 912 y 942 (al-Muqtabis V), Ibn Ḥayyān, de Córdoba*. Zaragoza: Anubar Instituto Hispano-Árabe de Cultura, 1981.

Kirchner 2010

Helena Kirchner. *Por una arqueología agraria. Perspectivas de investigación sobre espacios de cultivo en las sociedades medievales hispánicas*. British Archaeological Reports International Series 2062. Oxford: Archaeopress, 2010.

Lastanosa 1601

Pedro Juan de Lastanosa. *Los veintinueve libros de los ingenios y de las máquinas*. Manuscript. Biblioteca Nacional de España, MSS.MICRO/8198; Biblioteca Digital Hispánica Ms 3372, 1601.

López Fernández, Gómez Espín, and Gil Meseguer 2015

José Antonio López Fernández, José María Gómez Espín, and Encarna Gil Meseguer. "Proyectos para aumentar el caudal en el nacimiento del río Mula a través de la técnica del pozo horizontal". *Revista Murcia de Antropología* 22 (2015), 137–160.

López-Camacho 2002

Bernardo López-Camacho. "Pasado y presente del abastecimiento de agua a Madrid". In *La ingeniería del agua en España en el siglo XIX: ciclo de conferencias*. Ed. by A. Rumeu de Armas and F. Sáenz Ridruejo. Madrid: Fundación Canal de Isabel II, 2002, 143–212.

López-Camacho, Bustamate, and Iglesias 2005

Bernardo López-Camacho, Irene de Bustamate, and José A. Iglesias. "El viaje de agua (qanat) de la Fuente Grande de Ocaña (Toledo): Pervivencia de una reliquia histórica." *Revista de Obras Públicas* 3451 (2005), 43–54.

Magee 2005

Peter Magee. "The Chronology and Environmental Background of Iron Age Settlement in South-eastern Iran and the Question of the Origin of the Qanat Irrigation System?" *Iranica Antiqua* 40 (2005), 217–231.

Martínez 2007

Santiago Martínez. "El agua en Tiermes." In *El agua y las ciudades romanas*. Ed. by J. Mangas and S. Martínez. Madrid: Ediciones, 2007, 257–314.

Martínez Alfaro 1966

Pedro Emilio Martínez Alfaro. "Historia del abastecimiento de aguas a Madrid. El papel de las aguas subterráneas." *Anales del Instituto de Estudios Madrileños* 14 (1966), 29–51.

Martínez Calvo and López Jiménez 2012

Victoria Martínez Calvo and Óscar López Jiménez. *El agua del Rey. Historia y arqueología de los acuíferos de la Mesa de Ocaña y su conducción al Real Sitio de Aranjuez*. Madrid: Adif, 2012.

Martínez-Santos 2013

Pedro Martínez-Santos. *El viaje de aguas de Amanuel*. Madrid: Asociación Cultural de Amigos de la Dehesa de la Villa, 2013.

Martínez-Santos and Martínez-Alfaro 2012

Pedro Martínez-Santos and Pedro Emilio Martínez-Alfaro. "A Brief Historical Account of Madrid's Qanats." *Ground Water* 50.4 (2012), 645–653.

Mateos Royo 2005

José Antonio Mateos Royo. "Expansión económica, intervención pública y desarrollo tecnológico preindustrial: La política hidráulica municipal en Aragón durante el siglo XVI?" *LLULL: Revista de la Sociedad Española de Historia de las Ciencias y de las Técnicas* 28 (2005), 131–159.

Montes Romero-Camacho 1993

Isabel Montes Romero-Camacho. "El trabajo de los mudéjares en el abastecimiento de agua a la Sevilla bajomedieval: Los moros cañeros y el acueducto de los Caños de Carmona." In *VI Simposio Internacional de Mudéjarismo*. Teruel: Instituto de Estudios Turolenses, 1993, 231–256.

Morales 1575

Ambrosio de Morales. *La crónica general de España III*. Alcalá de Henares: Juan Iñíguez de Lequerica, 1575.

Moreno et al. 1997

Maudillo Moreno, Juan Francisco Murillo Redondo, Angel Ventura Villanueva, and Siliva Carmona Berenguer. "Nuevos datos sobre el abastecimiento de agua a la Córdoba romana e islámica." *Arte, Arqueología e Historia* 4 (1997), 13–23.

Morín de Pablos 2014

Jorge Morín de Pablos. *Los paisajes culturales en el valle del Cigüela*. Madrid: Auditores de Energía y Medio Ambiente, 2014.

Muñoz Vicente 1991

Ángel Muñoz Vicente. "Intervención arqueológica en el acueducto romano de Cádiz: Los sectores de 'El Mimbral' (Jerez) y 'Tres Caminos' (Puerto Real)." *Anuario Arqueológico de Andalucía* 1989.III (1991), 98–103.

Murcia Viudas 1958

Andrés Murcia Viudas. *Aguas subterráneas. Prospección y alumbramiento para riegos*. Madrid: Ministerio de Agricultura, 1958.

Olcina Cantos 2012

Jorge Olcina Cantos. "De los mapas de zonas afectadas a las cartografías de riesgo de inundación en España." *Universidad de Alicante. Departamento de Análisis Geográfico Regional y Geografía Física* 32.1 (2012), 91–131.

Oliver Asín 1959

Jaime Oliver Asín. *Historia del nombre de Madrid*. Madrid: Consejo Superior de Investigaciones Científicas, 1959.

Onrubia Pintado et al. 2014

Jorge Onrubia Pintado, Yasmina E. Cáceres Gutiérrez, María del Cristo González Marrero, Jorge de Juan Ares, Víctor Manuel M. López-Menchero, Ángel Marchante-Ortega, Marta Moreno-García, Carmen Gloria Rodríguez Santana, Youssef Bokbot, and Fethi Amani. "Investigaciones arqueológicas en la región de Sus-Tekna (Marruecos). Informe preliminar de la campaña de resultados de 2014." *Informes y trabajos* 12 (2014), 315–344.

Pavón Maldonado 1990

Basilio Pavón Maldonado. *Tratado de arquitectura hispano-musulmana I: Agua. Aljibes, puentes, qanats, acueductos, jardines, ruedas hidráulicas, baños, corachas*. Madrid: Consejo Superior de Investigaciones Científicas, 1990.

J. Rodríguez and Gascó Pedraza 1996

Julio Rodríguez and Fermín Gascó Pedraza. *El archivo de Ocaña; Una parte de la historia a través de sus documentos*. Toledo: Excmo Ayuntamiento de Ocaña, 1996.

Solesio de la Presa 1975

María Teresa Solesio de la Presa. *Antiguos viajes de agua a Madrid*. Madrid: Instituto Torraja de la Construcción y del Cemento, 1975.

Troll and Braun 1974

Carl Troll and Cornell Braun. "Madrid. El abastecimiento de agua a la ciudad por medio de 'qanates' a lo largo de la historia." *Geográfica* 1–4 (1974), 235–314.

Ventura Villanueva 1993

Ángel Ventura Villanueva. *El abastecimiento de agua a la Córdoba romana I: El acueducto de Valdepuentes*. Córdoba: Servicio de Publicaciones, Universidad de Córdoba, 1993.

Ventura Villanueva 2002

Ángel Ventura Villanueva. "Los acueductos romanos de Córdoba y su rehabilitación omeya?" *Empuries* 53 (2002), 113–128.

Ventura Villanueva and Pizarro Berengena 2010

Ángel Ventura Villanueva and Guadalupe Pizarro Berengena. "El aqua augusta (acueducto de Valdepuentes) y el abastecimiento de agua a Colonia Patricia Corduba: Investigaciones recientes (2000–2010)." In *V Congreso de Obras Públicas Romanas*. Córdoba: Fundación de la ingeniería técnica de obras públicas, 2010, 177–203.

Wilson 2008

Andrew I. Wilson. "Hydraulic Engineering and Water Supply?" In *Engineering and technology in the Classical World*. Ed. by J. P. Oleson. Oxford: Oxford University Press, 2008, 285–319.

Wilson and Mattingly 2003

Andrew I. Wilson and David J. Mattingly. "Irrigation Technologies: Foggaras, Wells and Field Systems?" In *The Archaeology of Fazzan*. Vol. 1 Synthesis. Ed. by D. Mattingly. London: Society for Libyan Studies, 2003, 235–278.

Yanguas 1823

José María Yanguas. *Diccionario histórico-político de Tudela*. Zaragoza: Andrés Sebastián, 1823.

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Irrigation Communities and Agricultural Water Management in Andalusia. A Special Focus on the Vega of Vélez Blanco

Summary

A freely available data set about Andalusian irrigation communities was comprehensively analyzed and combined with a local time series of precipitation and temperature data and put into historical context. Andalusia's annual precipitation lies between 150 and 1000 mm*yr⁻¹. Due to the high seasonal and inter-annual variability of precipitation, irrigation measures are a necessity to enable intensive cultivation. The largely prevailing water scarcities are one likely reason for the evolution and continuation of water cooperations practicing irrigation strategies that have probably existed since Roman times, certainly since Islamic times. This study gives an overview of water management practices in Andalusia and highlights the Vega of Vélez Blanco (NE Andalusia), as a case study.

Keywords: water balance; Spanish water management history; water scarcity; groundwater and surface water sources; agricultural water consumption

Es wurde ein freier Datensatz zu Bewässerungsgemeinschaften in Andalusien mit lokalen Klimazeitreihen vergleichend analysiert und in einen historischen Kontext gesetzt. Die durchschnittlichen Niederschlagsmengen in Andalusien variieren zwischen 150 und 1000 mm*yr⁻¹. Aufgrund der hohen saisonalen und zwischenjährlichen Schwankungen von Niederschlagsmengen ermöglichen Bewässerungsstrategien intensive Landwirtschaft. Die in weiten Gebieten herrschende Wasserknappheit ist wahrscheinlich Grund für die Entwicklung und Fortführung von Bewässerungsstrategien. Diese Strukturen haben sich vermutlich während römischer und islamischer Zeit etabliert. Der Artikel gibt einen Überblick über das Wassermanagement in Andalusien und hebt die Vega von Vélez Blanco (Nordost-andalusien) als Fallbeispiel hervor.

Keywords: Wasserbalance; spanische Bewässerungsgeschichte; Wasserknappheit; Grundwasser- und Oberflächenwasser; landwirtschaftlicher Wasserbedarf

Meteorological data used in this article was provided by the Spanish State Agency for Me-

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teorology (AEMET). The study is part of the Cluster of Excellence Cluster 264 *Topoi – The Formation and Transformation of Space and Knowledge in Ancient Civilizations*.

I Introduction

Numerous studies exist on the long history of irrigation strategies used on the Iberian Peninsula, with its different historical influences from Roman, Moorish, Iberian, and other Mediterranean cultures and schemes.¹ Irrigation is a necessity to cope with water deficits and seasonal water scarcities for the agriculture on the Iberian Peninsula, and especially for its semi-arid south. Irrigation institutions and communities that have existed in wide areas of Spain since at least medieval times are an outstanding characteristic of the area. This applies especially to Andalusia, which was the heartland of the Almoravid Dynasty during medieval times. Granada was the capital of Al-Andalus, the area of the Iberian Peninsula governed under Muslim influence the longest, lasting until the Christian reconquest. Locally, these irrigation governance systems that were installed during medieval times, function in an only slightly altered form today. Prominent examples of traditional water management systems in southeastern Spain can be found in Valencia, Murcia, and Alicante.² Beyond this, more than 500 irrigated areas administrated by irrigation communities currently exist in Andalusia. In total, irrigated farmland generates about 50% of the annual agricultural income of Andalusia.³ Many of the irrigation communities share elements of the technical infrastructure of their water management systems, like tunnels for tapping groundwater or widely distributed channels of irrigation networks. Rotation based water allocation is a common feature. In some of these communities, water is even still traditionally auctioned, as happened in Valencia, for example; meaning that additional water rights can be bought from the irrigation community by its members during regular auctions.

In this study, Andalusian irrigation communities are compared based on the aggregation and reassessment of information about their size, number of irrigation water users productivity, water balance, and local climatic conditions. On this basis, the representativeness of a concrete case study will be evaluated, namely the irrigation community of Vélez Blanco.

1 Glick 1970; Ostrom 1990; Kress 1968; Fröhling 1965; Brunhes 1902.

2 Glick 1970; Ostrom 1990.

3 Andalucía 2013.

The community of Vélez Blanco, located in northeast Andalusia, will be presented in detail as an example of the preservation of governance structures and techniques of water management.

1.1 Geographic location of Andalusia

With an area of 87 597 km² and a population of 8.4 million people, Andalusia is the second largest and most populated autonomous region of Spain.⁴ Its landscape can be subdivided topographically into three main units: the Sierra Morena, the Guadalquivir Valley, and the Baetic System. The Sierra Morena, a low mountain range with elevations between 800–1000 m above sea level, separates Andalusia from the northern Castilian Meseta, in Spain's interior. The landscape of Andalusia is dominated in its central and western-parts by the fertile basin and alluvial plain of the Rio Guadalquivir. To the west, the Guadalquivir meets the Atlantic Ocean at the Gulf of Cádiz, where the river delta is characterized by fertile wetlands. The rough terrain of the Baetic Mountains shapes the south-east of Andalusia. With elevations above 3400 m above sea level in the area of the Sierra Nevada, this high mountain range forms a natural barrier between the Mediterranean coastline and the Andalusian hinterland (Fig. 1).

1.2 Climatic characteristics

The climate in most parts of Andalusia is Mediterranean and corresponds to a *Csa* climate, only in the southeast of Andalusia is the climate significantly drier, corresponding to a steppe climate.⁵ In general, the climate mostly consists of a pronounced dry season during summer months, while most of the rainfall events occur from autumn to spring. The annual precipitation is characterized by rainfall events that most often occur during the autumn months and to a lesser extent during winter and spring.⁶

Regional differences in the climate of Andalusia are predominantly controlled by the topography and distance from the coastline. As a consequence, the strong seasonality of the Mediterranean climate is overlapped regionally by maritime influences, due to the geographical position of being adjacent to the Mediterranean Sea in the south and the east, and the Atlantic Ocean in the west. This especially applies to the spatial and temporal distribution of rainfall: In Andalusia, high regional variations of annual precipitation occur, ranging between less than 150 mm in the area of Cabo de Gata in the southeast and more than 1000 mm in the Sierra de Grazalema in the western Baetic Mountain range, whereas annual precipitation in the area of Vélez Blanco locally

4 Andalusía 2018.

5 Köppen 1936: BSk climate, C32.

6 Geiger 1970, 154–157; Rodrigo et al. 2000, 1233–1234.



Fig. 1 Topographical map of southern Spain. The autonomous region of Andalusia is highlighted. Elevation data are based on SRTM 3 data. Major divides are marked by white lines.

averages 420 mm.⁷ Precipitation amounts also show a high seasonal and annual variability. In general, the occurrence of rainfall in Andalusia is controlled by two types of pressure cells, the Azores high and Atlantic lows with their related fronts.⁸ Particularly during the wet season from autumn to spring, precipitation of low intensity is mainly brought to western Andalusia by low pressure cells or rain bearing clouds from the Atlantic ocean.⁹ As shown by isotope analyses of Andalusian aquifers, groundwater recharge mainly comes from more intense winter precipitation originating from the Atlantic ocean.¹⁰ The steppe-like climate of south-east Andalusia is also characterized by wet seasons in autumn and spring, but with precipitation appearing reliably only in autumn. During this time, the precipitation maxima is caused by the Balearic low from the Mediterranean Sea, a thermal depression of stationary character that emerges in September due to the thermal difference between land and water masses.¹¹ The winter in this

7 Pita López 2003, 15–28.

8 Rodrigo et al. 2000, 1233–1234.

9 Schütt 2004; Sumner, Homar, and Ramis 2001, 220.

10 Julian et al. 1992.

11 Lautensach 1964, 700.

| | Cultivated Area | | Irrigation Farming | |
|-------------------|-----------------|------|--------------------|------|
| | [ha] | [%] | [ha] | [%] |
| Arable Crops | 1 564 387 | 49.1 | 322 620 | 20.6 |
| Olive Groves | 1 358 757 | 42.7 | 359 366 | 26.5 |
| Fruit Cultivation | 229 515 | 7.2 | 105 649 | 46.0 |
| Vineyards | 26 299 | 0.8 | 2837 | 10.8 |
| Other | 4609 | 0.2 | 2560 | 46.9 |

Tab. 1 Main agricultural cultivations of Andalusia, Spain. The category of 'arable crops' comprises the cultivation of vegetables and cereals, Andalucía 2013.

region is usually marked by a dry phase.¹² In this area, dryness is mainly caused by the Baetic Mountains which function as a barrier to precipitation coming from the west.¹³

1.3 Aspects of agricultural production in Andalusia

Despite the fact that most areas in Andalusia struggle with water scarcity, agricultural production has a long history and is an important economic sector. More than 50 % of the region's surface is used as farmland, of which arable crops and olive groves are the main cultivation forms, while fruit farming and vineyards are – today – of minor importance. In general, agricultural cultivation can be subdivided into dry and irrigation farming, with irrigation farming practiced on approximately 25 % of the agricultural land (Tab. 1). Due to the severe dry season from June to August, irrigation farming is a frequently used tool to enable cash crop farming.

1.4 The Vega of Vélez Blanco

In the village of Vélez Blanco, eponymous for the adjoining Vega, irrigation water is still obtained by public sale at auctions that take place twice a week during summer months. Due to its special character of governance, the Vega of Vélez Blanco is described separately in this study. The remarkable – and in Andalusia, today, singular – water governance system in the Vega of Vélez Blanco was already the object of various publications.¹⁴

The Vega of Vélez Blanco is located in northeast Andalusia, downslope from the town of Vélez Blanco, a small town in the easternmost part of the autonomous region of Andalusia (Fig. 2). At an altitude of 1070 m above sea level, the town is embedded in the

12 Geiger 1970, 154–157.

13 Andalucía 2013.

14 Roth, Beckers, et al. 2018; Navarro Sánchez 2010;

Schütt 2001; Tyrakowski 2001; Navarro López et al. 2012; Real Orden 1903.

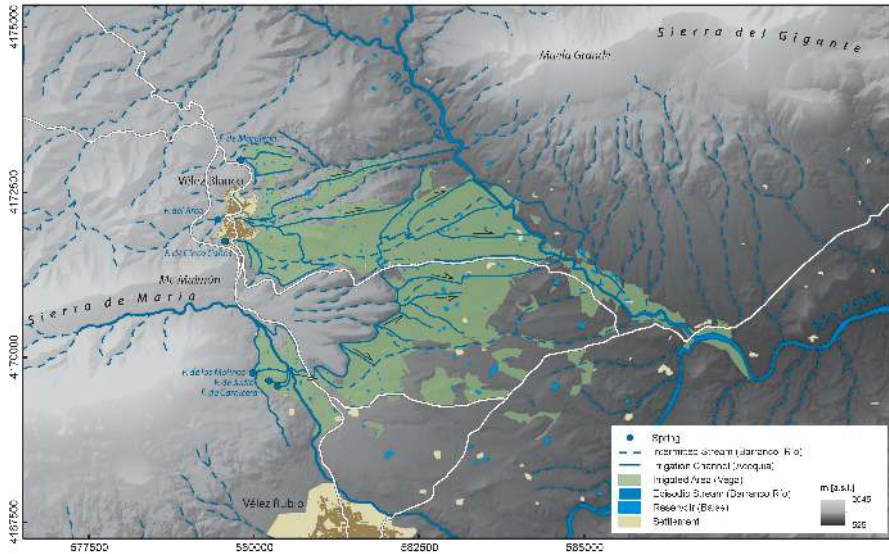


Fig. 2 Location of the Vega of Vélez Blanco. The depiction of water management infrastructure is simplified and illustrated by solid blue lines (irrigation channels) and light blue polygons (reservoirs). Elevation data are based on Lidar data (5 m resolution), Información Geográfica (CNIG) 2018.

mountainous region of the Sierra de Maria. This mountain range is primarily composed of Jurassic limestone, and is part of the southern foothills of the Baetic Mountains.¹⁵ The springs located above the town have their source at the eastern slopes of the Mount Maimón and ensure a perennial water supply to the town and adjacent agricultural areas. The springs are fed by an extensive aquifer situated in the karstic limestone formations of the Sierra de Maria. The environs of Vélez Blanco are characterized by terraced slopes where intensive irrigation farming is practiced; this area is also known as the Vega of Vélez Blanco. Within the irrigated area, traditional cultivation such as olive and almond groves can be found, as well as vegetable gardens and orchards. In the lower parts of the Vega of Vélez Blanco, cultivation of intensive irrigated vegetables is also practiced.

15 Schütt 2001.

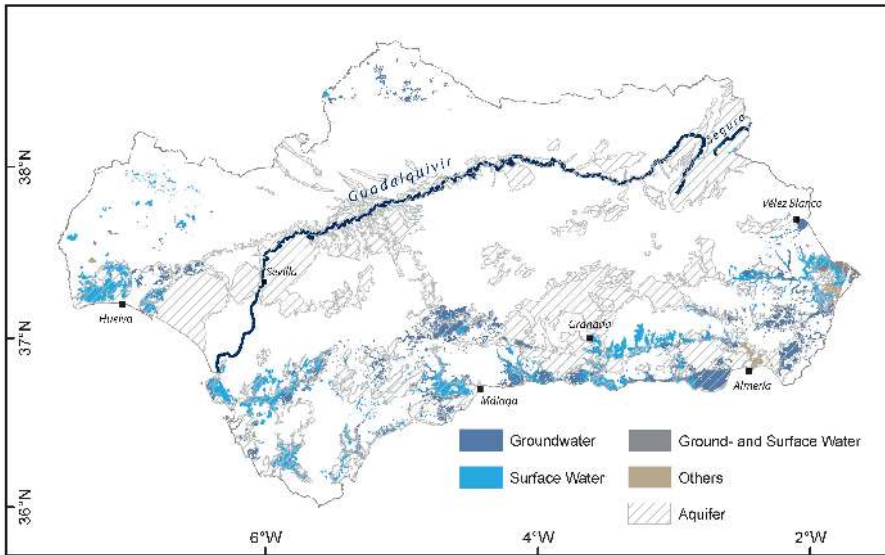


Fig. 3 Areas under irrigation in Andalusia, subdivided by the origin of the water. Locations of aquifers are indicated with grey stripes.

2 Components of Andalusia's water management history

2.1 Water utilization

Water scarcity is a serious problem in wide areas of Andalusia. The main water supply for irrigation farming originates from surface- and groundwater, with surface water supplied by streams, lakes, and reservoirs (Fig. 3).¹⁶ Irrigation water originating from desalination of seawater and water treatment is of minor importance.¹⁷ In addition to the physical availability of water, good technical and administrative management practices are required to achieve a sustainable distribution.

While surface water needs management techniques for its transportation, distribution, and storage, such as aqueducts, channels, and reservoirs, groundwater also needs technical facilities for its exploitation. In Spain, a traditional technique for groundwater exploitation is the so called *galería*.

This technique is similar to that of the *qanat* systems that probably originate from Persia.¹⁸ *Galerías* are frequently used to exploit water from an upslope aquifer by tapping

¹⁶ Andalucía 2018.

¹⁷ Andalucía 2018.

¹⁸ Mays 2010.

into the waterbody via a tunnel or conduit that leads the water to a foreland outflow facility, from where it is transferred into small artificial reservoirs (*span. balsa*) where it is temporarily stored.¹⁹ From there, the water is distributed by networks of channels to serve the fields below. Often these systems are traditionally managed by so called irrigation communities or irrigation associations (subsequently the term irrigation community will be used as an equal term for both irrigation community and irrigation association).

2.2 Historical development of the water management's legal framework and administration

In Spain, the first evidence of the implementation of water management structures dates to Roman times, though most of the present structures were established during the Muslim period (8th century BCE).²⁰ The Moors introduced the autonomous management of water allocation systems and improved water availability through technical advances during the medieval times.²¹ Since then, a variety of transformations in administrative organization, legal ownership, and local water law have taken place, but fundamentally, the Moorish structures still provide the basis for the current Spanish water management practices and structures.²² The first standardized guidelines for water regulation were adopted with the initial Water Act in 1866.²³ At this time, the first low degree state regulations on spatial organization and usage of water were introduced. Subsequently, a significant turn in the spatial organization of administrative water management units took place between the 1920s and 1960s, with the foundation of river basin authorities (*Confederaciones Hidrográficas*). From here on, the drainage basins of the main streams of Spain were treated as hydrological units, defined by their natural catchment area, instead of territories limited by political borders (Fig. 4).²⁴

The Water Act of 1985 has had the most significant influence on the current Spanish water management practices. Its implementation led to an almost completely revised organization of water property rights and administrative management structures. The new legislation declared all surface water, as well as renewable groundwater bodies, as public goods, except those where private ownership was adjudged by prior legislation.²⁵

The multiplicity of the water management regulations implemented over time have led to the high complexity of the present administrative water management structures in Spain (Fig. 5). Large scale systems that operate on basin levels are directly supervised

19 Beckers, Berking, and Schütt 2012/2013, 148–150;

Roth, Schütt, et al. 2001, 37–45.

20 Fröhling 1965, 25; Kress 1968, 131–134.

21 Boelens and Post Uiterweer 2013, 44–45.

22 Glick 1970.

23 Fornés et al. 2007, 676–677.

24 Sánchez-Martínez, Salas-Velasco, and Rodríguez-Ferrero 2012.

25 Sánchez-Martínez, Salas-Velasco, and Rodríguez-Ferrero 2012.



Fig. 4 A: Hydrological basin level administration units (Confederaciones Hidrográficas) of Spain; boundaries are defined by the major divides (black lines). The location of Vélez Blanco is indicated by the red point. The political border of the autonomous region of Andalusia is highlighted by the red line. 1 Islas Baleares, 2 Cuenca Mediterránea de Andalucía, 3 Cuenca Atlántica de Andalucía, 4 Cuenca Interna de Cataluña, 5 País Vasco, 6 Cantábrico, 7 Miño-Sil, 8 Galicia Costa. B: The overview map illustrates the political borders of the Spanish autonomous regions. The area of Andalusia is marked in red.

by the central government (central management), while systems of a smaller scale are usually administered by regional and local institutions or private associations (decentralized management). It is assumed that a number of these irrigation communities were founded at least during the Muslim period. Today, only a few of these sub-systems still exist with their historical administration structures, while most of them have been transformed by external influences.

At present, a total of 586 irrigated regions exist in Andalusia, administered by so called irrigation communities (*Comunidades de Regantes*). Most of the irrigation communities are private and show a wide variety in size, water availability, and crops cultivated.²⁶ Additionally, the management of the irrigation communities varies. In principle, they can be distinguished by their characteristics in terms of the legal relationships between the land, owner, and water law. According to Butzer et al.,²⁷ two basic types of linkages between landownership and water law exist historically: On the one hand, there is the Syrian system, where land property is inseparable from irrigation rights, implying that each land plot is legally entitled to an amount of (irrigation) water proportional to the area. On the other hand, the Yemenite system separates the ownership of water and land, so that they can both be sold independently.

Furthermore, the irrigation communities can also be differentiated by the local organizational systems of water sharing. A frequently used method is water allocation by

26 Consejería de Agricultura 2018.

27 Butzer et al. 1985, 490.

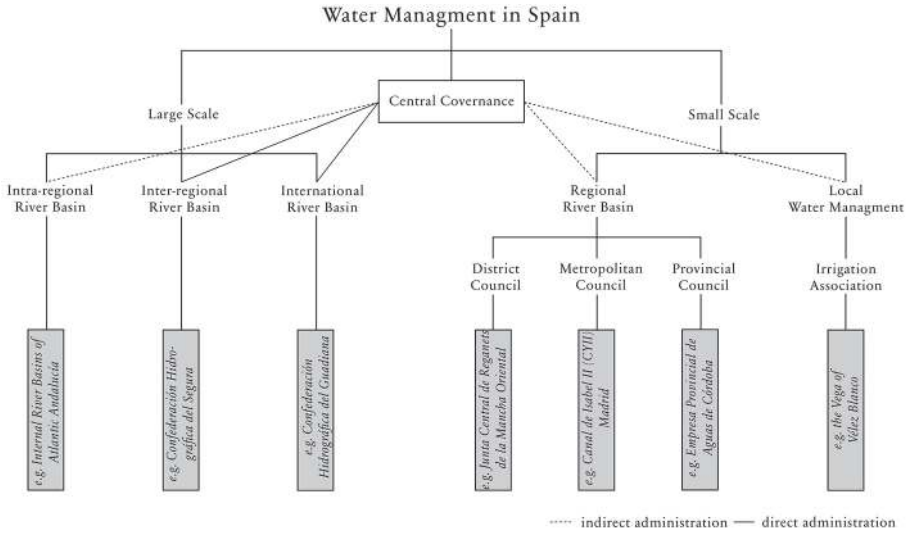


Fig. 5 Exemplary organization of the water management in Spain.

rotation, where each eligible user is entitled to receive irrigation water in a fixed turn of time units or volume.²⁸ Another type, is water allocation on demand, where landowners need to apply for irrigation water. The auctioning of water was a common method in the past, but is rarely found nowadays.²⁹ Prominent examples in south-eastern Spain, where water was auctioned in the past, are the irrigated areas of Elche, Alicante, and Lorca,³⁰ though most of the irrigation communities abandoned the auction-based system.

2.3 The water management system of the Vega of Vélez Blanco

With regard to its location, the Vega of Vélez Blanco (Fig. 6) represents a good example of the modern reorganization of the traditional administration. While politically the town of Vélez Blanco is part of Andalusia, its hydrological administration is the responsibility of the *Confederación Hidrográfica del Segura*, that is situated in the autonomous region of Murcia. Since the local springs are traditionally managed by the local irrigation community, however, the national water management has just a marginal influence on this system.³¹

Based on knowledge about similarly structured systems in the area of south-eastern Spain, it is assumed that the local water management structures in the Vega of Vélez

28 Glick 1970.

29 Geiger 1970, 144–146.

30 Brunhes 1902; Geiger 1970, 144–146; Ostrom 1990,

69–81.

31 Navarro Sánchez 2010, 341–354.



Fig. 6 View into the Vega of Vélez Blanco (line of sight, westerly direction). The mountain Muela Grande can be seen in the background.

Blanco can at least be dated to the Muslim period.³² Its uninterrupted irrigation history enables the investigation of an irrigation community that has been only marginally affected by large-scale restructuring plans and external institutions. Even today, the local water allocation is organized in a mixed system that consists of irrigation rotations and water auctions.³³ Within this system, each farmer with legal water rights has a fixed amount of irrigation time that is assigned to the land owned or held; landownership and irrigation rights are originally bound to each other.³⁴ Likewise, the irrigation community is part of the rotation system, so they also get water out of the rotations. This surplus is periodically sold during public auctions, where everybody who is connected to the channel network of the Vega of Vélez Blanco is allowed to buy a fixed amount of irrigation water.³⁵ Especially during dry periods in the summer months, additional irrigation water is frequently needed to gain good harvests and in some years, to avoid crop failure.

3 Materials and Archives

To determine the characteristics of the average Andalusian irrigation community, the data set *Inventario de Regadíos 2008* was used. It also includes the irrigation community of Vélez Blanco, for which several values are highlighted for comparison. The selection of numeric attributes enabled the evaluation of local hydrological and economic features within the irrigated areas.

32 Roth, Beckers, et al. 2018, 59–73.

33 Navarro Sánchez 2010, 341–344.

34 Roth, Beckers, et al. 2018, 59–73.

35 Tyrakowski 2001, 97–116.

3.1 Archives

The data set *Inventario de Regadíos 2008* is a state inventory of the irrigated areas in Andalusia. It is generated by the *Confederación Hidrográfica del Guadalquivir* as part of the national hydrological plan, and includes detailed information on a total of 979 irrigation areas supplied by fresh water that mainly originates from ground or surface waters. Additional water sources, such as desalinated seawater and treated wastewater are of minor importance. Data about local irrigation communities relevant for this study were extracted from this inventory; subsequently, only data on areas supplied by ground or surface water remained. The variables used for statistical analyses are briefly introduced in Tab. 2. They were chosen as representative characteristics for comparison.

The detailed information on cultivation and handling of the irrigated areas is based on interviews with local landowners and staff members of irrigation communities.³⁶

3.2 Data preparation

The data are not normally distributed; hence all data sets were statistically edited by determining extreme values. Extreme values were calculated based on the individual interquartile range of each factor. The minimum value in Tab. 2 represents the 0.25 quartile while the maximum value marks the 0.75 quartile; extreme values that exceed the statistical boundaries defined by the interquartile range are not equal to bias within the data set. Therefore, these adjusted data were interpreted carefully. In general, all values show a high degree of dispersion. To determine measures of central tendencies, basic statistics were calculated for the processed data. Mean values extracted from the data set represent the properties of the average Andalusian irrigation community.

3.3 Water balance

Data on local water consumption and demand allow the analysis of local water balances. By plotting the parameters of consumption and demand, the individual water balance of an irrigation community is visualized. Local water consumption is calculated using information about locally cultivated goods and their respective water demand, hence water demand is estimated internally within the data set.

³⁶ Consejería de Agricultura 2018; only values given for the *Comunidad de Regantes de las Aguas del Maimón*

de la Villa de Vélez Blanco were selected as characteristic for the Vega of Vélez Blanco.

3.4 Irrigation volume

The local irrigation volumes were calculated by the quotient of water prices per area ($\text{€}\cdot\text{ha}^{-1}$) and water costs per volume ($\text{€}\cdot\text{m}^{-3}$). The local average volume of irrigation water was determined in cubic meters per hectare ($\text{m}^3\cdot\text{ha}^{-1}$). This value allows the classification of irrigated areas in terms of its irrigation intensity. As the calculated irrigation volume is similar to the value of local water consumption, these values were applied to verify the data set.

3.5 Precipitation and temperature

The annual precipitation for each irrigation community was extracted from the global Worldclim precipitation data set with a spatial resolution of 1 km^2 . The Worldclim 30 arc-seconds dataset is generated by the interpolation of climate information from a large number of weather stations with a temporal resolution for the precipitation records of at least 30 years (1960–1990).³⁷ This data set is known to give reliable results and is widely used in the scientific community.³⁸

A dataset of daily precipitation measurements (1969–2014) from the weather station in Vélez Blanco was used to illustrate the seasonal variations of precipitation; for monthly data, the daily precipitation measurements were summed up.³⁹ Temperature measurements from the weather station in María, situated about 6 km west of Vélez Blanco, were used to represent the seasonal variation of the monthly mean temperature.⁴⁰ Mean values were calculated based on daily minimum and maximum temperature data.

Based on these data sets, mean values were calculated and boxplot diagrams for each month were created to outline the variation of the amount of monthly precipitation and the mean temperature during the hydrological year (Nov. 1st–Oct. 31st). Moreover, data about cycles of irrigation, blossoming, and harvesting of olives were extracted from the literature to exemplarily show the importance of precipitation variability for plant growth.

37 WorldClim – Global Climate Data 2018.

38 Hijmans et al. 2005; Avellan, Zabel, and Mauser 2012.

39 AEMET 2014.

40 AEMET 2014.

| | Irrigation Communities Andalusia (n=301) | | | | Vega of Vélez Blanco |
|--------------------------------------------------|------------------------------------------|--------------------|------|-------|----------------------|
| | Mean (AIC) | Standard Deviation | Min. | Max. | |
| Property Size per Farmer [ha] | 2.76 | 12.52 | 0.04 | 15.13 | 2.76 |
| Irrigators per ha | 2.50 | 3.03 | 0.01 | 28.03 | 0.36 |
| Water Consumption [m^3ha^{-1}] | 3732.8 | 457.88 | 2953 | 4500 | 3000 |
| Water Demand [m^3ha^{-1}] | 3517.4 | 521.63 | 2732 | 4620 | 2682 |
| Water Balance [m^3ha^{-1}] | 215.4 | | | | 318 |
| Irrigation Volume [m^3ha^{-1}] | 3723.0 | 450.07 | 2953 | 4500 | 3000 |
| Production [m^3ha^{-1}] | 3711.2 | 444.01 | 2965 | 4505 | 3217 |
| Annual Precipitation [mm] | 450.43 | 139.55 | 224 | 870 | 403 |

Tab. 2 Results of the statistical analysis of the Inventario de Regadíos of 2008. Since all data show high standard deviation, mean values should be handled with care. AIC: Average Irrigation Community. Data: Consejería de Agricultura 2018.

4 Results

4.1 Characteristics of Andalusian irrigation communities

In Andalusian irrigation communities, land property size per farmer averages 2.76 ha and is, in general, irrigated annually by 3700 m^3 water per hectare (m^3ha^{-1}). The estimated water surplus of approximately 215 m^3ha^{-1} indicates that the average irrigation community has a positive water balance. In total, annual mean productivity rates of agricultural cultivation of more than 3700 m^3ha^{-1} are achieved by irrigation farming (Tab. 2).

The direct comparison of the Vega of Vélez Blanco with the average Andalusian irrigation community shows that the number of irrigation water users per ha in the Vega of Vélez Blanco is higher than in the average Andalusian irrigation community, while the average property size per farmer is more or less identical in both groups (Tab. 2). In contrast, the average amounts of annual water consumed and demanded, as well as those of productivity and irrigation volume, are lower in the Vega of Vélez Blanco than in the average Andalusian irrigation community.

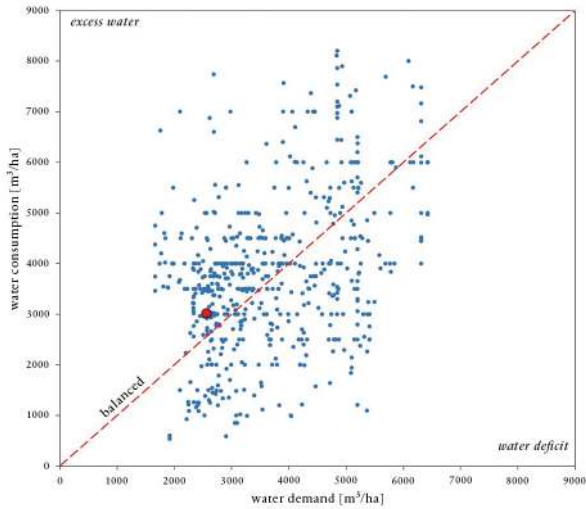


Fig. 7 Correlation of water consumption and water demand in irrigated areas managed by an irrigation community. The red line indicates the theoretically balanced water budget equilibrium. The red point marks the Vega of Vélez Blanco.

4.2 Water balance

The data show that 58.7 % of irrigated areas managed by irrigation communities in Andalusia have water excess, while 41.3 % struggle with water deficits (Fig. 7); as a consequence, nearly half of the irrigated areas in Andalusia suffer from a considerable water deficit, where the water demand for irrigation farming cannot be covered by local water resources. With an average annual water consumption of $3000 \text{ m}^3 \cdot \text{ha}^{-1}$ and a demand of $2682 \text{ m}^3 \cdot \text{ha}^{-1}$ the Vega of Vélez Blanco has a well-balanced water budget with a small amount of excess water.

4.3 Irrigation volume and precipitation amounts

The most intense irrigation is practiced in areas used for vegetable cropping or citrus fruit plantations; in these areas, annual irrigation capacity averages $400 \text{ mm} \cdot \text{ha}^{-1}$ and can reach up to $800 \text{ mm} \cdot \text{ha}^{-1}$ ⁴¹. Olive groves require less irrigation water volume, with an average amount of $290 \text{ mm} \cdot \text{ha}^{-1}$ and maximum amounts of $780 \text{ mm} \cdot \text{ha}^{-1}$ of irrigation water.

The annual precipitation amounts in the analyzed regions range between $230\text{--}795 \text{ mm} \cdot \text{yr}^{-1}$ (Fig. 8). Citrus fruits are planted in regions with annual precipitation amounting to up to $690 \text{ mm} \cdot \text{yr}^{-1}$, while most plantations operate in areas with annual rainfall amounts of $300\text{--}460 \text{ mm} \cdot \text{yr}^{-1}$. Subtropical fruits are cultivated in re-

41 Consejería de Agricultura 2018.

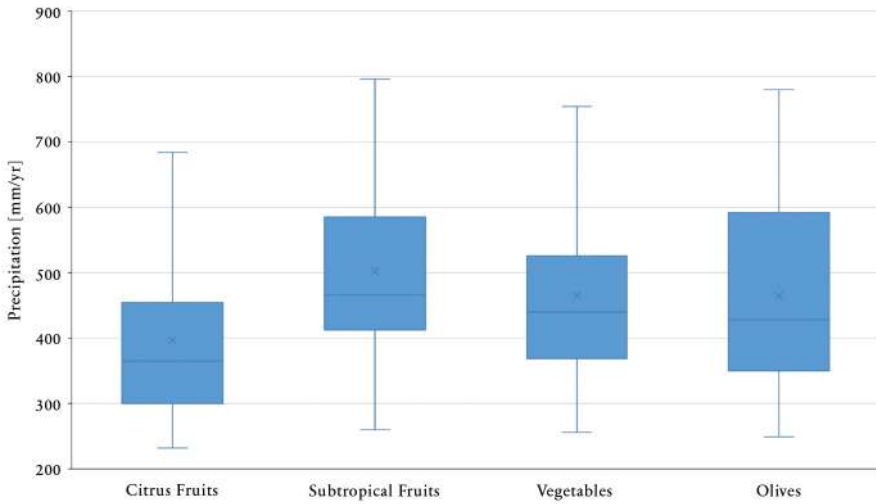


Fig. 8 Boxplot diagrams of areal precipitation ranges for irrigated areas and their respective main crops.

gions with up to $800 \text{ mm} \cdot \text{yr}^{-1}$ annual precipitation, where most areas receive about $410\text{--}590 \text{ mm} \cdot \text{yr}^{-1}$ of annual precipitation. The precipitation range of regions where vegetables and olives are cultivated correspond to those of the subtropical fruits, with olives showing the widest range of annual precipitation, spanning between 350 and $590 \text{ mm} \cdot \text{yr}^{-1}$. For the data analyzed, all means were higher than the median. Summarizing, the box-plot in Fig. 8 clearly shows that the amount of annual precipitation is not the controlling factor for cropping.

More important for the selection of a crop type for a region is the relation of the respective flowering period and growing season to the annual cycle of precipitation and prevailing temperatures at a location. The demand for water for the plants usually increases during these phenological growth stages. Also, seasonal variations in temperature have a major influence on the growth of certain plants; this especially applies to plants that are vulnerable to temperatures below the freezing point.

4.4 Precipitation and temperature variability in Vélez Blanco

In Vélez Blanco, autumn is characterized by having the highest variation in monthly amounts of precipitation, with means of about 50 mm per month and extreme values of more than 240 mm (1969–2014, Fig. 9). During this time of the year, mean temperatures rapidly fall from about 17°C in September to less than 8°C in November. The months of September and November also show the lowest range of mean temperatures.

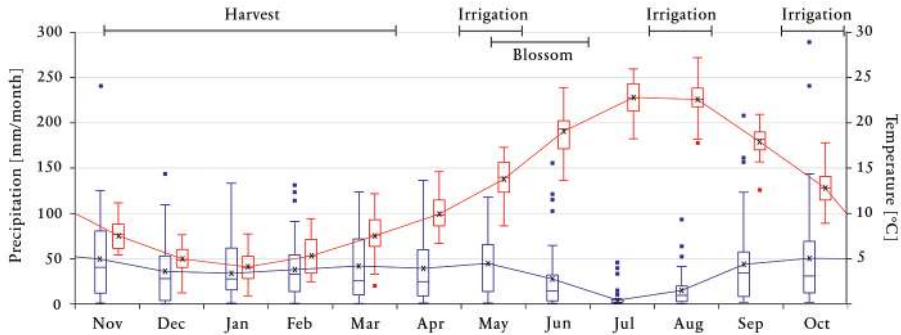


Fig. 9 Boxplot diagram of the monthly precipitation and mean temperature values (precipitation data recorded at the weather station in Vélez Blanco; temperature data recorded at the weather station in María) for a period of 45 years (1969–2014). The data is arranged in the sequence of the hydrological year (Nov. 1st–Oct. 31st). The blue boxplots and line represent the monthly mean precipitation rates, while the red boxplots and line illustrate the monthly mean temperature. Blue and red squares mark extreme values of monthly precipitation sums and mean temperature rates. The general annual cycle of irrigation, blossoming, and harvesting of olives is based on data from the FAO, FAO 2015b; AEMET 2014.

A significant low in average precipitation volume (less than 5 mm on average) marks the summer month of July, while the highest temperatures are reached in August. June and August show low precipitation amounts, averaging less than 25 mm. Winter and Spring are characterized by constant mean precipitation amounts of about 40–45 mm, where the highest variation can be observed in January and April (1969–2014). The winter months are dominated by the lowest monthly mean temperature, which show a moderate range. Highest variations in mean temperature can mainly be observed in the transition zone of the seasons.

The comparison of precipitation and temperature data from Vélez Blanco with annual general cycles for the cultivation of olives shows that the major irrigation period in August coincides with aridity and high mean temperature that marks the summer months from June to August. The low precipitation probability during this time overlaps with the flowering period of the olive trees. In contrast, the water demand of olive plantations during the start of the blossoming period in May is likely to be covered by precipitation, while additional irrigation is only required during dry springs. The same holds true for the ripening process of the olive fruits in autumn.

5 Discussion

The data set of irrigated areas in Andalusia was already used in several studies.⁴² These studies share a tentative handling of the data, since much of the information provided is aggregated indirectly from interviews and remote sensing analyses. Nevertheless, this archive contains comprehensive information about irrigation communities in Andalusia that is currently openly accessible.⁴³

5.1 Organization of irrigation communities in Andalusia

A literature review revealed that the degree of complexity of the administration of irrigated areas mainly depends on the number of farmers that rely on surface or groundwater.⁴⁴ Especially irrigated areas that are supplied by surface water, often need a high degree of administration, with decentralized cooperation, since these sources often supply several irrigated areas within a river's course, such as the Guadalquivir. In contrast, areas supplied by groundwater are usually small in size and, therefore, need a relatively low degree of administration. Butzer et al. defines three basic scales to classify the management of irrigated areas.⁴⁵ The smallest one is *micro-scale* irrigation, with a size of less than 1 ha. Here, an individual farmer or a few farmers use water from one small spring or a cistern. *Meso-scale* irrigation areas include one single or several cooperating irrigation communities that are supplied by water from at least one spring. On average, these systems contain up to several hundred farmers that together usually irrigate less than 100 ha. The largest unit are the *macro-scale* irrigation areas, which comprise several irrigation communities; up to several hundred cultivators can be included in these systems. The area under irrigation normally exceeds 50 km² and, therefore, necessitates a highly complex channel network for the water distribution, as well as a sophisticated government structure.

Based on the numeric characteristics of the Vega of Vélez Blanco and the definitions by Butzer et al. the Vega of Vélez Blanco can be classified as a meso-scale irrigation area.⁴⁶ This is also the classification for the average Andalusian irrigation community.

5.2 Vélez Blanco within the Andalusian irrigation communities

The comparison of the irrigation area of Vélez Blanco with the average Andalusian irrigation community reveals that the Vega of Vélez Blanco is a good representation of the

42 Rodríguez-Díaz et al. 2008; Solbes 2003; Salmoral et al. 2011.

43 Solbes 2003.

44 S. Garrido 2014; Butzer et al. 1985, 485–493; Hunt

1988; Lopez-Gunn 2003.

45 Butzer et al. 1985, 485–493.

46 Butzer et al. 1985, 485–493.

average Andalusian irrigation community. The only feature that distinguishes the Vega of Vélez Blanco from other Andalusian irrigation areas is the tradition of auctioning irrigation water during the summer months. The prevailing mixed system of irrigation rotations and water auctions has lasted centuries in approximately the same administrative form that is still in place today, while other irrigation communities of Andalusia abandoned this type of organization.⁴⁷ A well-known example is the *Huerta de Lorca*, located in western Murcia, where water auctions were abolished in 1961.⁴⁸

Since water is an important resource for the development of local economic and social structures, transformations in water availability or its quality can influence these developments.⁴⁹ As shown by Boelens and Uiterweer,⁵⁰ a change in political or economic conditions, for example, the governmental reorganization of administrative structures, can trigger transformations of organizational water management systems.⁵¹ In the most recent water management history of Spain, large scale water allocation programs led to a completely revised organization of local and regional water management systems. These restructuring plans have deconstructed self-governance systems in many regions that had previously worked in a self-organized way for centuries.⁵² Substantial imbalances in regional water supply were the initial reason for this reorganization. According to the analyzed inventory, more than half of the irrigated areas of Andalusia show a positive water balance, whereas water demand exceeds the natural availability in 41.3 % of the areas.⁵³

5.3 Water balance

Water consumption and demand in the Vega of Vélez Blanco is approximately balanced. Thus, on average, the given water resources are sufficient to supply the cultivated crops. This general statement does not include seasonality and inter-annual variations. An extended dry season, as well as a drought or a sequence of years with below average annual rainfall, can lead to an increased water demand and, thus, to a shift towards an unbalanced water regime.

The main crop cultivated in Andalusia are olive groves. In total, they cover more than 40 % of the irrigated land of the autonomous region.⁵⁴ Olives require water, especially during their growth periods in May, August, and October in order to obtain good harvests.⁵⁵ To produce a harvest, the minimum amount of water required during

47 Roth, Beckers, et al. 2018.

48 Geiger 1970, 144–146.

49 Custodio et al. 2016, 314.

50 Boelens and Post Uiterweer 2013.

51 Boelens and Post Uiterweer 2013, 53–57.

52 Boelens and Post Uiterweer 2013, 53–57.

53 Fröhling 1965, 17–23; Geiger 1970, 144–153; Saurí and Moral 2001.

54 Andalucía 2013.

55 Galán et al. 2008, 100–104.

this time totals 200 mm, while the highest crop yields are achieved with 600–800 mm of water during that time; as in most cases, these water amounts are not provided by precipitation, irrigation is required.⁵⁶ Most importantly, irrigation is required about two to three weeks prior to the flowering period of the olive trees.⁵⁷ Olive groves in irrigated areas of Andalusia that are administrated by an irrigation community receive 230–795 mm of annual precipitation, which should be adequate to receive low to sufficient yields without irrigation. However, due to the seasonal and inter-annual variations in precipitation, irrigation is frequently required to improve harvests or secure crops. Especially during the main growing seasons in the summer months, irrigation is often used to bridge the dry season to improve the crop yields.

Vegetables and cereal fields cover nearly half of the cultivated surface area of Andalusia.⁵⁸ Based on data found in the literature, vegetable crops such as tomatoes, peppers, cabbage, and onions need on average 350–900 mm of annual precipitation to achieve adequate crop yields.⁵⁹ Within the irrigated areas of Andalusia, these agricultural products are usually cultivated in regions where annual precipitation ranges from 250–760 mm. Here, likewise, annual sums of precipitation provide no reliable information about the natural water supply of the cultivated crops during the growth season. The cultivation of most vegetables in Andalusia needs intensive irrigation.

Agricultural production in the Vega of Vélez Blanco is dominated by olive and almond groves. A small area of intensively irrigated vegetables can also be found in the lower part of the Vega of Vélez Blanco. These vegetable gardens are mainly for private consumption.

As literature sources and the case study from Vélez Blanco show, for most of the cultivated goods represented in this study, the main periods of growth coincide with the dryness and high temperatures of the summer months. Additionally, cold winters with temperatures below freezing, as well as hot summers with extended dry periods can result in crop failures. An example is provided with the olive tree; long lasting periods of frost with temperatures of -10°C and below lead to poor harvests and even to crop failure.⁶⁰ Furthermore, various plants cultivated in Andalusia are very sensitive to fluctuations in temperature. As a consequence, especially in the driest parts of Andalusia, irrigation is necessary to ensure good harvests for agricultural goods such as olives.

One of the challenges concerning irrigation farming is the cultivators' profit orientation. Frequently, cash crop farming is practiced in areas where climate conditions barely suite the natural needs of the cultivated crops during their growth periods and, hence,

56 FAO 2015b.

57 Caliendo and Boari 1992, 24–27.

58 Andalucía 2013.

59 FAO 2015e; FAO 2015d; FAO 2015a; FAO 2015c.

60 Steduto et al. 2012, 303–308.

high yields can only be achieved by intensive irrigation. Especially in areas where irrigation is supplied by groundwater, the higher water demand for irrigation often results in an increased exploitation of groundwater.⁶¹ In fact, the extraction of groundwater with deep wells has increased dramatically since the 1950s, leading to an uncontrolled overexploitation of groundwater bodies,⁶² triggered by private farmers, as well as by large companies. Consequently, human-induced intensification of the already existing natural water scarcity is increasingly becoming a serious problem in large areas.⁶³

6 Conclusions

The comprehensive analysis of the state inventory *Inventario de Regadíos*, in combination with a literature review, enables new insights into Andalusian irrigation communities and reveals some of the challenges they face.

From this we conclude, that:

(i) An average Andalusian irrigation community is characterized by a property size of roughly 3 ha per farmer, which is fed by about 3700 m³*ha⁻¹ of irrigation water.

(ii) 41 % of the irrigation communities suffer water deficits concerning their respective crops, while nearly 60 % of the irrigation communities have an excess of water in regards to their irrigation demands for cultivation.

(iii) The high seasonal and spatial variability of precipitation in Andalusia means that, in many regions, it is necessary to irrigate crops to safeguard harvests and avoid crop loss.

(iv) The outstanding feature that distinguishes the Vega of Vélez Blanco from other irrigated areas is the tradition of auctioning irrigation water.

61 Custodio et al. 2016; Salmoral et al. 2011.

62 Geiger 1970, 148.

63 A. Garrido et al. 2009, 57–58.

Bibliography

AEMET 2014

AEMET. *Agencia Estatal de Meteorología – AEMET. Gobierno de España*. 2014. URL: <http://www.aemet.es/es/portada> (visited on 23/05/2018).

Andalucía 2018

Junta de Andalucía. *Andalucía*. URL: <http://www.juntadeandalucia.es/andalucia.html> (visited on 23/05/2018).

Andalucía 2013

Junta de Andalucía. *Instituto de Estadística y Cartografía de Andalucía. Censo Agrario 2009. Resultados de Andalucía*. 2013. URL: <http://www.juntadeandalucia.es/institutodeestadisticaycartografia/iea/consultasActividad.jsp?CodOper=703&sub=45376> (visited on 23/05/2018).

Avellan, Zabel, and Mauser 2012

Tamara Avellan, Florian Zabel, and Wolfram Mauser. “The Influence of Input Data Quality in Determining Areas Suitable for Crop Growth at the Global Scale – A Comparative Analysis of two Soil and Climate Datasets: Influence of Input Data on Crop Suitability”. *Soil Use and Management* 28.2 (2012), 249–265.

Beckers, Berking, and Schütt 2012/2013

Brian Beckers, Jonas Berking, and Brigitta Schütt. “Ancient Water Harvesting Methods in the Drylands of the Mediterranean and Western Asia”. *eTopoi. Journal for Ancient Studies* 2 (2012/2013), 145–164.

Boelens and Post Uiterweer 2013

Rutgerd Boelens and Nynke C. Post Uiterweer. “Hydraulic Heroes: The Ironies of Utopian Hydraulism and Its Politics of Autonomy in the Guadalhorce Valley, Spain”. *Journal of Historical Geography* 41 (2013), 44–58.

Brunhes 1902

Jean Brunhes. *L'Irrigation. Ses conditions géographiques, ses modes et son organisation – dans la Péninsule Ibérique et dans L'Afrique du Nord*. Paris: C. Naud, 1902.

Butzer et al. 1985

Karl W. Butzer, Juan F. Mateu, Elisabeth K. Butzer, and Pavel Kraus. “Irrigation Agrosystems in Eastern Spain: Roman or Islamic Origins?” *Annals of the Association of American Geographers* 75.4 (1985), 479–509.

Caliandro and Boari 1992

Angelo Caliandro and Francesca Boari. “Supplementary Irrigation in Arid and Semiarid Regions”. *International Conference on Supplementary Irrigation and Drought Water Management* 1 (1992), 24–27.

Consejería de Agricultura 2018

Junta de Andalucía Consejería de Agricultura Pesca y Desarrollo Rural. *Junta de Andalucía – Inventario de regadíos 2008*. URL: <http://www.juntadeandalucia.es/organismos/agriculturapescaeydesarrollorural/areas/infraestructuras-agrarias/regadios/paginas/sig-regadios-evolucion.html> (visited on 23/05/2018).

Custodio et al. 2016

Emilio Custodio, José Miguel Andreu-Rodes, Ramón Aragón, Teodoro Estrela, Javier Ferrer, José Luis García-Aróstegui, Marisol Manzano, Luis Rodríguez-Hernández, Andrés Sahuquillo, and Alberto del Villar. “Groundwater Intensive Use and Mining in South-Eastern Peninsular Spain: Hydrogeological, Economic and Social Aspects”. *Science of the Total Environment* 559 (2016), 302–316.

FAO 2015a

Food and Agriculture Organization of the United Nations FAO. *Crop Water Information: Cabbage*. 2015. URL: <http://www.fao.org/land-water/databases-and-software/crop-information/cabbage/en/#c236407> (visited on 23/05/2018).

FAO 2015b

Food and Agriculture Organization of the United Nations FAO. *Crop Water Information: Olive*. 2015. URL: <http://www.fao.org/land-water/databases-and-software/crop-information/olive/en/#c236114> (visited on 23/05/2018).

FAO 2015c

Food and Agriculture Organization of the United Nations FAO. *Crop Water Information: Onion*. 2015. URL: <http://www.fao.org/land-water/databases-and-software/crop-information/onion/en/#c236423> (visited on 23/05/2018).

FAO 2015d

Food and Agriculture Organization of the United Nations FAO. *Crop Water Information: Pepper*. 2015. URL: <http://www.fao.org/land-water/databases-and-software/crop-information/pepper/en/> (visited on 23/05/2018).

FAO 2015e

Food and Agriculture Organization of the United Nations FAO. *Crop Water Information: Tomato*. 2015. URL: <http://www.fao.org/land-water/databases-and-software/crop-information/tomato/en/> (visited on 23/05/2018).

Fornés et al. 2007

Juan María Fornés, África de la Hera, Ramón Llamas, and Pedro Martínez-Santos. "Legal Aspects of Groundwater Ownership in Spain". *Water International* 32.4 (2007), 676–684.

Fröhling 1965

Margaret Fröhling. *Die Bewässerungslandschaften an der spanischen Mittelmeerküste*. Westfälische Geographische Studien 17. Münster: Im Selbstverlag des Instituts für Geographie und Länderkunde und der Geographischen Kommission für Westfalen, 1965.

Galán et al. 2008

Carmen Galán, H. García-Mozo, Luis Vázquez, Consuelo Díaz de la Guardia, and Eugenio Domínguez-Vilches. "Modeling Olive Crop Yield in Andalusia, Spain". *Agronomy Journal* 100.1 (2008), 98–104.

A. Garrido et al. 2009

Alberto Garrido, Maite M. Aldaya, Ramón M. Llamas, Consuelo Varela-Ortega, Paula Novo, and Roberto Rodríguez Casado. "Water Footprint and Virtual Water Trade in Spain". In *Water Policy in Spain*. Boca Raton: CRC Press, 2009, 49–59.

S. Garrido 2014

Samuel Garrido. "Water Management, Spanish Irrigation Communities and Colonial Engineers". *Journal of Agrarian Change* 14.3 (2014), 400–418.

Geiger 1970

Folkwin Geiger. *Die Aridität in Südostspanien – Ursachen und Auswirkungen im Landschaftsbild*. Stuttgarter Geographische Studien 77. Stuttgart, 1970.

Glick 1970

Thomas F. Glick. *Irrigation and Society in Medieval Valencia*. Cambridge, MA: Harvard University Press, 1970.

Gobierno de España 2016

Ministerio de Agricultura Gobierno de España Alimentación y Medio Ambiente. *SIA – Sistema Integrado de Información del Agua*. 2016. URL: <https://servicio.mapama.gob.es/sia/consultas/servlet/consultas.GlobalFilter?tipo=masiva&sid=generate> (visited on 23/05/2018).

Hijmans et al. 2005

Robert J. Hijmans, Susan E. Cameron, Juan L. Parra, Peter G. Jones, and Andy Jarvis. "Very High Resolution Interpolated Climate Surfaces for Global Land Areas". *International Journal of Climatology* 25.15 (2005), 1965–1978. DOI: 10.1002/joc.1276.

Hunt 1988

Robert C. Hunt. "Size and the Structure of Authority in Canal Irrigation Systems". *Journal of Anthropological Research* 44.4 (1988), 335–355.

Información Geográfica (CNIG) 2018

Centro Nacional de Información Geográfica (CNIG). *Centro de Descargas del CNIG (IGN) - MDT05/MDT05-LIDAR*. URL: <http://centrodedescargas.cnig.es/CentroDescargas/catalogo.do#selectedSerie> (visited on 02/01/2018).

Jarvis et al. 2008

Andy Jarvis, Hannes Isaak Reuter, Andy Nelson, and Edward Guevara. *Hole-Filled Seamless SRTM data V4*. International Centre for Tropical Agriculture (CIAT). 2008. URL: <http://srtm.csi.cgiar.org/> (visited on 23/05/2018).

Julian et al. 1992

J. Cruz-San Julian, L. Araguas, K. Rozanski, J. Benavente, J. Cardenal, M. C. Hidalgo, S. Garcia-Lopez, J. C. Martinez-Garrido, F. Moral, and M. Olias. "Sources of Precipitation over South-Eastern Spain and Groundwater Recharge. An Isotopic Study". *Tellus B* 44.3 (1992), 226–236.

Köppen 1936

Wladimir Köppen. "Das geographische System der Klimate". In *Handbuch der Klimatologie Bd. 1*. Ed. by W. Köppen and R. Geiger. Berlin: Verlag von Gebrüder Borntraeger, 1936, 1–44.

Kress 1968

Hans-Joachim Kress. *Die islamische Kulturepoche auf der iberischen Halbinsel*. Heft 43. Marburger Geographische Schriften. Marburg/Lahn: Im Selbstverlag des Geographischen Institutes der Universität Marburg, 1968.

Lautensach 1964

Hermann Lautensach. *Iberische Halbinsel*. Munich: Keyserische Verlagsbuchhandlung, 1964.

Lopez-Gunn 2003

Elena Lopez-Gunn. "The Role of Collective Action in Water Governance: A Comparative Study of Groundwater User Associations in La Mancha Aquifers in Spain". *Water International* 28.3 (2003), 367–378.

Mays 2010

Larry W. Mays. "A Brief History of Water Technology During Antiquity: Before the Romans". In *Ancient Water Technologies*. Ed. by L. Mays. Dordrecht: Springer Netherlands, 2010, 1–28.

Ministerio de Agricultura 2016

Gobierno de España Ministerio de Agricultura Alimentación y Medio Ambiente. *Sistema Integrado de Información del Agua*. 2016. URL: <http://www.mapama.gob.es/es/agua/temas/planificacion-hidrologica/sia-/infovisor.aspx> (visited on 26/06/2018).

Navarro López et al. 2012

Encarnación María Navarro López, Ángel Custodio Navarro Sánchez, Dietmar Roth, and Sandra Schimansky. *Vélez Blanco – Medio Natural, Historia y Patrimonio Cultural*. Pueblos de Almería 3. Almería: Instituto de Estudios Almerienses, 2012.

Navarro Sánchez 2010

Ángel Custodio Navarro Sánchez. "Una joya del derecho consuetudinario y de la hidráulica tradicional de la cuenca del Segura". *Revista Cangilón* 33 (2010), 340–382.

Ostrom 1990

Elinor Ostrom. *Governing the Commons – The Evolution of Institutions for Collective Action*. 1st ed. Cambridge: Cambridge University Press, 1990.

Pita López 2003

María Fernanda Pita López. "El clima de Andalucía". In *Geografía de Andalucía*. Barcelona, 2003, 137–174.

Real Orden 1903

Real Orden de 18 de Enero de 1902. *Reglamentos para el sindicato y jurado de riegos de las aguas del Maimón de la villa de Vélez Blanco*. Madrid, 1903.

Rodrigo et al. 2000

Fernando S. Rodrigo, María-Jesus Esteban-Parra, D. Pozo-Vázquez, and Y. Castro-Díez. "Rainfall Variability in Southern Spain on Decadal to Centennial Time Scales". *International Journal of Climatology* 20.7 (2000), 721–732.

Rodríguez-Díaz et al. 2008

J. A. Rodríguez-Díaz, E. Camacho-Poyato, R. López-Luque, and L. Pérez-Urrestarazu. "Benchmarking and Multivariate Data Analysis Techniques for Improving the Efficiency of Irrigation Districts: An Application in Spain". *Agricultural Systems* 96.1–3 (2008), 250–259.

Roth, Beckers, et al. 2018

Dietmar Roth, Brian Beckers, Jonas Berking, Sarah Isselhorst, and Brigitta Schütt. "A Short History of the Water and Society in the Region of Vélez Blanco, East Andalusia". *Water History* 8 (2018), 59–73.

Roth, Schütt, et al. 2001

Dietmar Roth, Brigitta Schütt, Helena Burg, and Magnus Herrmann. "Las galerías con lumbreras (qanat): Obras maestras de ingeniería rural amenazadas." *Revista Velezana* 20 (2001), 53–64.

Salmoral et al. 2011

G. Salmoral, M. M. Aldaya, D. Chico, A. Garrido, and R. Llamas. "The Water Footprint of Olives and Olive Oil in Spain." *Spanish Journal of Agricultural Research* 9.4 (2011), 1089–1104. URL: <http://revistas.inia.es/index.php/sjar/article/view/2430> (visited on 23/05/2018).

Sánchez-Martínez, Salas-Velasco, and Rodríguez-Ferrero 2012

María-Teresa Sánchez-Martínez, Manuel Salas-Velasco, and Noelina Rodríguez-Ferrero. "Who Manages Spain's Water Resources? The Political and Administrative Division of Water Management." *International Journal of Water Resources Development* 28.1 (2012), 27–42.

Saurí and Moral 2001

David Saurí and Leandro del Moral. "Recent Developments in Spanish Water Policy. Alternatives and Conflicts at the end of the Hydraulic Age." *Geoforum* 32.3 (2001), 351–362.

Schütt 2001

Brigitta Schütt. "Der Naturraum der Region Los Vélez und angrenzender Gebiete." In *Los Vélez – Ein landeskundlicher Reiseführer für eine Region in Südost-Spanien*. Heft 24. Trier Geographische Studien. Ed. by Dietmar Roth, Brigitta Schütt, and Roland Baumhauer. Trier: Selbstverlag der Geographischen Gesellschaft Trier in Zusammenarbeit mit dem Fachbereich VI Geographie/Geowissenschaften der Universität Trier, 2001, 13–34.

Schütt 2004

Brigitta Schütt. *Zum holozänen Klimawandel der zentralen Iberischen Halbinsel*. Vol. 20. Borntreager, 2004.

Solbes 2003

Rosa Vives Solbes. "Economic and Social Profitability of Water Use for Irrigation in Andalucía." *Water International* 28.3 (2003), 326–333.

Steduto et al. 2012

Pasquale Steduto, Theodore C. Hsiao, Elias Ferreres, and Dirk Raes. *Crop Yield Response to Water*. FAO Irrigation and Drainage Paper 66. Rome: FAO Publications, 2012.

Sumner, Homar, and Ramis 2001

G. Sumner, Victor Homar, and Climent Ramis. "Precipitation Seasonality in Eastern and Southern Coastal Spain." *International Journal of Climatology* 21.2 (2001), 219–247.

Tyrakowski 2001

Konrad Tyrakowski. "Kulturelle Aspekte des geographischen Inventars der Region Los Vélez." In *Los Vélez – Ein landeskundlicher Reiseführer für eine Region in Südost-Spanien*. Ed. by Dietmar Roth, Brigitta Schütt, and Roland Baumhauer. Heft 24. Trier Geographische Studien. Selbstverlag der Geographischen Gesellschaft Trier in Zusammenarbeit mit dem Fachbereich VI Geographie/Geowissenschaften der Universität Trier, 2001, 97–116.

WorldClim – Global Climate Data 2018

WorldClim – Global Climate Data. *WorldClim 1: Current Conditions (1960–1990) | WorldClim – Global Climate Data*. URL: <http://www.worldclim.org/current> (visited on 25/05/2018).

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Monika Trümper

Swimming Pools and Water Management in the Eastern Mediterranean World of the 4th to 1st Century BC

Summary

While it is debated in scholarship whether the Greeks conceptualized swimming as a sport and leisure activity, the archaeological evidence of swimming pools in the Eastern Mediterranean from the 4th to 1st century BC speaks for the existence of such a concept. This paper argues that challenges of water management are a major reason why the Greeks did not systematically build swimming pools as an urban standard for the physical education and pleasure of broader parts of the population. By examining 13 pools, it is shown that their water management required specific topographical conditions, notably, a location close to a river or a spring, and the appropriate socio-economic conditions, notably, patrons with sufficient financial means, access to technological know-how, and cultural appreciation of swimming.

Keywords: swimming pools; athletics; water management; Panhellenic sanctuaries; Hellenistic palaces

In der Forschung ist umstritten, ob die Griechen Schwimmen als Sport- und Freizeitaktivität konzipierten. Die archäologischen Befunde von Schwimmbecken im östlichen Mittelmeer aus dem 4.–1. Jh. v. Chr. belegen aber eindeutig, dass ein solches Konzept existierte. Dieser Beitrag zeigt, dass die erheblichen Anforderungen an das Wassermanagement vermutlich der wichtigste Grund waren, warum die Griechen nicht systematisch eigene Schwimmbecken als urbanen Standard für Sport und Vergnügen der breiten Bevölkerung bereitstellen konnten. Mit der Untersuchung von 13 Schwimmbecken wird dargelegt, dass ihr Wassermanagement besondere Bedingungen erforderte: die Nähe zu Flüssen und Quellen, wohlhabende Bauherren, Zugang zu technologischem Knowhow und eine kulturelle Wertschätzung des Schwimmens.

Keywords: Schwimmbecken; Sport; Wassermanagement; panhellenistische Heiligtümer; hellenistische Paläste

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First of all, I would like to thank the conference organizers for inviting me to this very stimulating conference. Earlier versions of this paper were presented at the Annual Meeting of the Archaeological Institute of America in 2012 and the conference *Cura Aquarum* in Greece, held in Athens in 2015, and I am much indebted to the audiences for the discussions and advice they shared.

There is a strong notion in scholarship that Greeks would not have known and enjoyed swimming as a leisure and athletic-competitive activity, although Greece was surrounded by the sea and provided abundant natural waters.¹ While there is archaeological evidence, namely images of people swimming and remains of pools, that challenges this notion, it is by no means abundant. Furthermore, this evidence suggests that swimming from about the 6th to the 1st century BC was a privilege of the urban elite and royal households. Since swimming is today a prime athletic activity and one of the most popular sports, one wonders why the Greeks, with their strong focus on athletic-military training and shaping the body, would not have embraced swimming more systematically for training the youth.

Efficient systematic swim training and swim competitions need, ideally, relatively safe and reliable settings, notably, waters without strong currents, waves, winds, unpredictable depths, and other obstacles. Such conditions are best met by purposely-built swimming pools that require not only an appropriate setting (indoors or outdoors) and certain efforts to be made for their construction, but, above all, constant maintenance. Most challenging is the water management, particularly providing a steady supply of water, but also maintaining the quality and purity of the water and its drainage. This paper argues that the challenges of water management are a major, if not the main reason why the Greeks did not systematically build swimming pools as an urban standard for the physical education and pleasure of broader parts of the population. By examining 13 selected pools from six sites in the Eastern Mediterranean from the 4th to 1st centuries BC in a chronological order, it is shown that the water management of these pools required specific topographical conditions, notably, a location close to a river or spring, and socio-economic conditions, notably, patrons with sufficient financial means, access to technological knowhow, and cultural appreciation of swimming as an athletic and leisure activity. The selected pools are located in, or closely connected to, four Panhellenic sanctuaries in Olympia, Isthmia, Nemea, and Delphi, as well as two royal palace

¹ Most strongly Auberger 1996, but also Elitzur 2008; Handy 2008.

areas in Aï Khanoum and Jericho.² Only when cities were increasingly provided with aqueducts from the late 1st century BC onwards, did cold water pools become more common, and even standard within public baths.

Due to the restrictions of space, the focus in the following is entirely on water management of swimming pools, whereas other key features such as the size and design, architectural-urban context, dates, possible functions, users, and socio-cultural significance of the pools cannot be discussed in detail. Since there is no comprehensive study of ancient swimming pools, let alone their water management, and since most pools have not been sufficiently explored and some are no longer visible today, this paper can only offer preliminary considerations and not final answers to all of the questions.³

1 Olympia

The Panhellenic sanctuary of Zeus was probably the first to be provided with a pool, most likely in the first half of the 4th century BC. This pool is located in the area between the sanctuary proper (Altis) and the Kladeos River, which was used to accommodate visitors in temporary structures and was gradually provided with permanent buildings for the convenience of visitors in the 4th century BC (Fig. 1). Based on the remains of waterproof pebble cement floors discovered at two different levels, the pool is reconstructed as an open-air facility with a rectangular shape, at a size of 24×16 m at the bottom and a maximum depth of 1.60 m, as well as including five steps (0.32 m deep and high) and a paved walkway of about 2.50 m width on all four sides (Fig. 2).⁴ Thus, the maximum capacity would have been about 614 000 liters.

Remains of a large drainage channel (0.50 m wide, 0.75 m high) were found under the later Roman Kladeos Baths, at a distance of about 5 m from the bottom of the pool

2 More pools are known from Late Classical and Hellenistic sites in the Eastern Mediterranean that cannot be discussed here: Pella, Palace, peristyle-complex V, pool 7.5×5 m, 1.65 m deep, end of 4th/early 3rd century BC (Chrysostomou 1996, 114–119); Samos, *Gymnasion*, central courtyard with *stoai*, pool 15.70 by 14.80 m, 1.26–1.66 m deep, mid-3rd century BC (Martini 1984, 23–25); pools of the late 1st c BC and early 1st c AD are also excluded, among them pools in the palaces of Herod the Great (Netzer 1986; Netzer 2001a; Netzer 2001b); and a pool in the area of the *gymnasion* of Corinth (10.32×11 –12 m, at least 1.58 m deep; 1st century

AD; Wiseman 1972, 18–22).

3 11 of the 13 pools discussed here became only known after René Ginouvès had published his study on the Greek bathing culture; Ginouvès 1962. There is also no monograph on the much more numerous swimming pools of the Roman Imperial period; however, for a summary of their water management, see Garbrecht and Manderscheid 1994, 21–23, 59–60, 70–76.

4 Schleif 1943, 17–18; Kunze and Schleif 1944, 40–46, 80–96; Mallwitz 1958, 23–24. – In more detail for this pool, Trümper 2017.

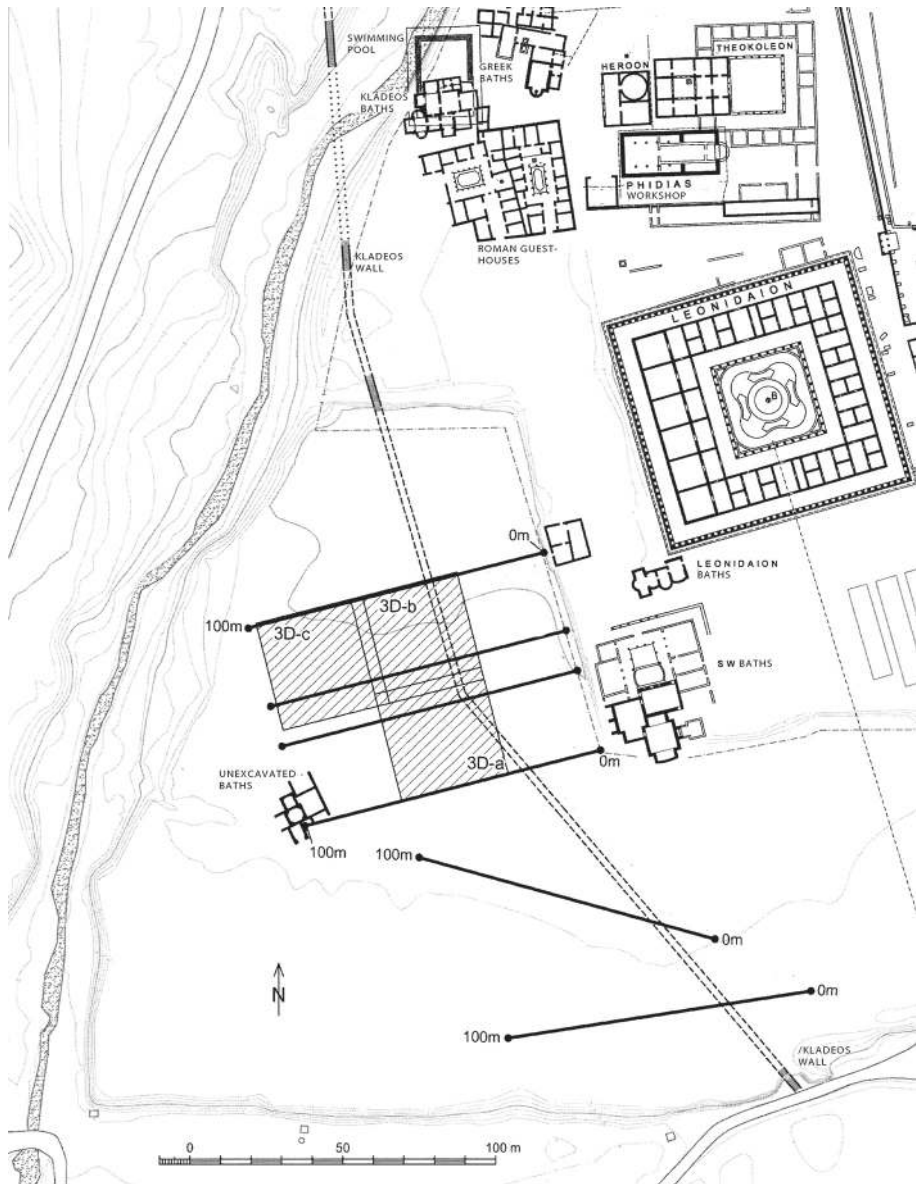


Fig. 1 Olympia, Sanctuary of Zeus, plan of the western section.

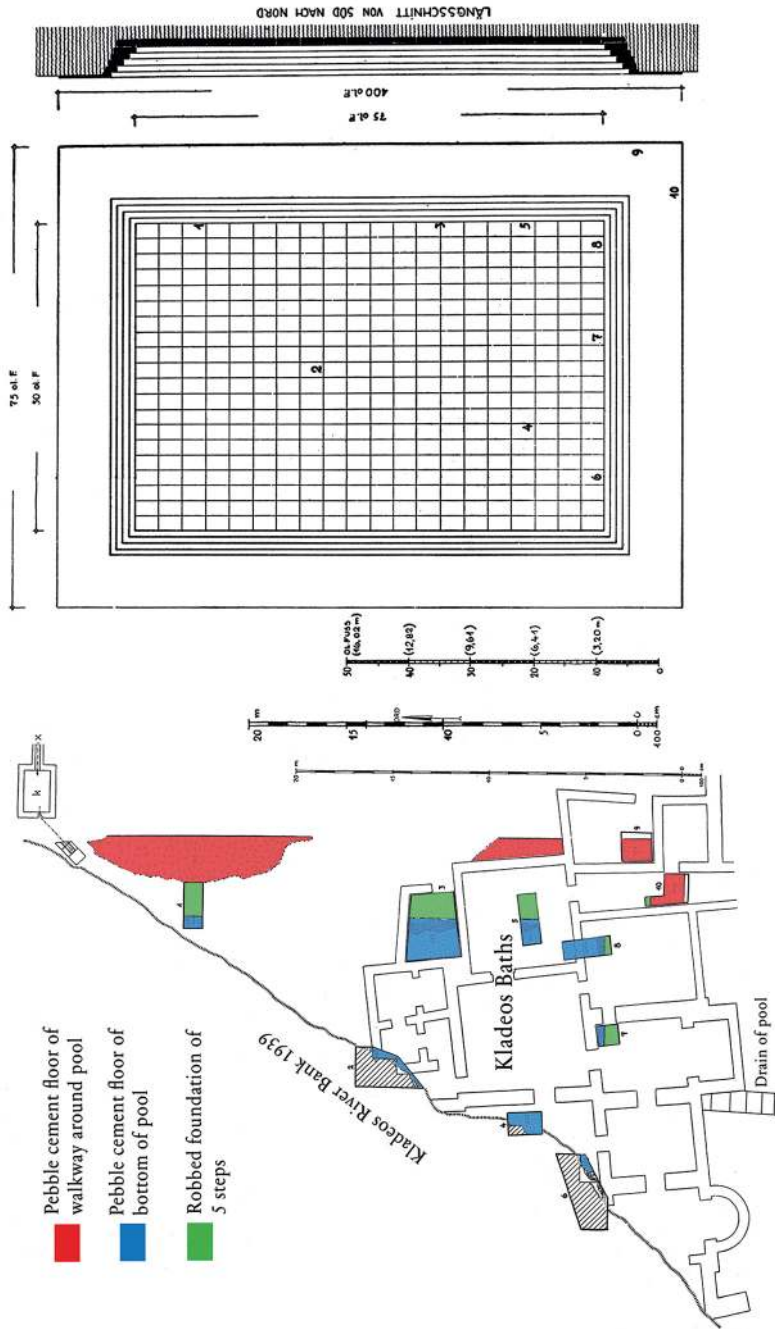


Fig. 2 Olympia, Sanctuary of Zeus, reconstruction of the swimming pool.

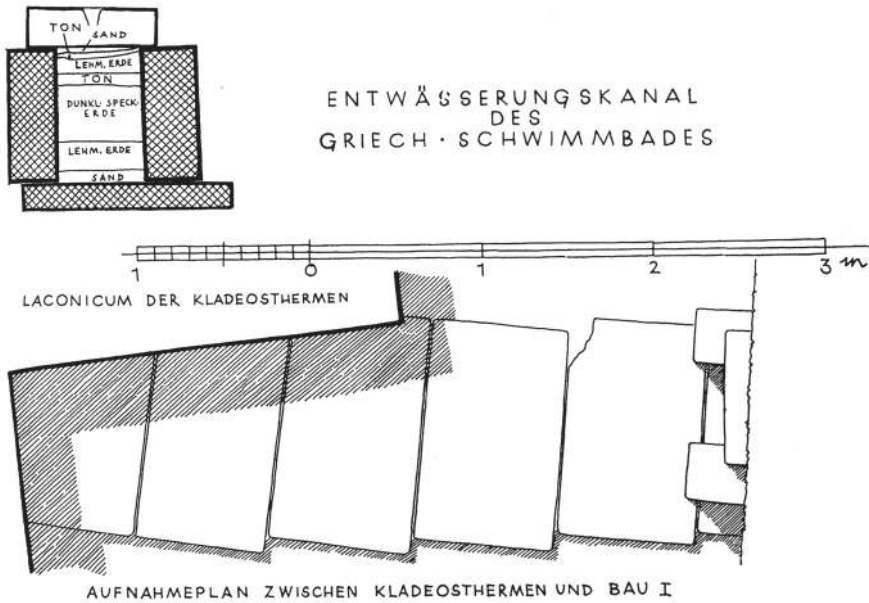


Fig. 3 Olympia, Sanctuary of Zeus, drainage channel of the swimming pool.

and, thus, without any direct connection with the remains of the pool (Fig. 3).⁵ Alfred Mallwitz assumed that this channel led from the bottom of the pool, through its steps, to the adjacent Kladeos River, and that drainage to the south, instead of more directly to the west, would have been chosen in order to avoid backwater during the rain-laden winter months.⁶ While it is questionable that the pool would have been used in the winter, they may still have tried to keep it as clean as possible, to avoid flooding year-round. Where exactly the drainage channel would have traversed the embankment wall of the Kladeos and reached the Kladeos, remains unknown.⁷

Reconstruction of the crucial water supply is problematic. Close to the reconstructed northeast corner of the pool, a basin (K) was found, whose size and depth are

5 Cf. Kunze and Schleif 1944, pl. 15 and Mallwitz 1958, pl. 2, who does not indicate any elevations for this channel; pl. 3 shows the pool in a section of trench 3 that was carried out in the Roman guest-houses with an elevation of -500, in a distance of about 15.25 m from the bottom of the pool. Mallwitz 1958, 23, claimed that he had seen the beginning of the drainage channel of the pool in the northwest corner of the Tepidarium of the Kladeos Baths, but this is questionable; see in detail Trümper

2017, 223 n. 23.

6 Mallwitz 1958, 23–24: on his reconstructed plan, pl. 4, the channel leads slightly to the southeast, but the remains as shown on pl. 2 suggest that it ran straight to the south.

7 Recent research on this embankment wall did not yield any evidence of this channel: Kyrieleis and Herrmann 2003, 43–45; Herrmann et al. 2013, esp. 401.

nowhere mentioned.⁸ This was presumably fed by the open channel X that, according to Hans Schleif, was constructed later than the pool itself.⁹ A channel leads from the basin to the southwest, widening from 10 to 28 cm, but after 3 m runs against a square block (60 × 60 cm), which is located in the northeast corner of the reconstructed paved walkway of the pool. While Schleif used these structures mainly for a reconstruction of the pool, their function was not discussed. A basin with an inlet, but no obvious outlet is hard to explain. If the basin had a connection to the pool, which seems most likely, if currently unprovable,¹⁰ it could have served as a settling basin from where cleaned water would have been led into the pool. In this case, it remains to be assessed in more detail how exactly this shallow open channel would have been supplied and whether it could have sufficed to fill the entire pool. If these structures did not belong to the pool, from the beginning or at a later period, water supply must have been granted altogether differently: the easiest option seems to be a channel from the Kladeos River to the northern border of the pool, of which no evidence for this has ever been found, however. This channels would have also had to cross the Kladeos embankment wall; the latter was located 27 m from the pool. The supply channel would have had to start at a sufficient distance upstream, in order to provide an appropriate slope down to the pool.¹¹

Whether water would have flowed continuously from the river to the pool and back into the river, depending on the season and water level of the river, must remain open, but seems an attractive possibility.

8 While the size can be taken from the plans, ca. 2.2 × 1.40 m, the depth must remain unknown.

9 Kunze and Schleif 1944, 43–44. The water management of the entire sanctuary has not been studied comprehensively; recent excavations to the northwest of the Philippeion yielded remains of five successive water supply systems that were dated from the 5th to the 2nd century BC; it is unclear, however, whether any of these and which would have supplied the basin k; Kyrieleis and Herrmann 2013, 20–25.

10 See in detail Trümper 2017, 229 n. 30.

11 There is no agreement in literature, when exactly the Kladeos ran where in relation to the embankment wall: Knauss 2004, 67 fig. 10, suggests that the

river ran to the west of the wall, once the wall had been built; Herrmann et al. 2013, 400, argue, based on recent excavations, that the Kladeos partially returned to its old riverbed to the east of the northern part of the wall, but it would have been diverted back to the west of the wall further south, e.g. at the height of the workshop of Pheidias. In this case, the Kladeos could have run immediately to the west of the pool, without any embankment wall between pool and river. Since the precise chronology of these changes remains unknown, however, they currently cannot be assessed with view to the (changing?) water supply of the pool. Cf. also Mallwitz 1981, 370–382; Matzanas 2012.

2 Isthmia

The Panhellenic sanctuary of Poseidon was provided with a pool around the mid-4th century BC, when the sanctuary saw a major remodeling and monumentalization.¹² Located about 100 m to the north of the temple and next to the theater, the pool can be reconstructed from substantial remains of different waterproof pavements and walls found under a Roman bath building from the 2nd century AD (Fig. 4). The open-air pool measured 30 × 30 m and was about 1.2 m deep, thus providing a capacity of 1 080 000 liters (Fig. 5).¹³ At least in the east, it was flanked by a paved walkway of 2.1 m in width and an adjacent wall; this pavement included a water line with seven oval basins that may have served as foot washbasins for swimmers or as drainage basins for a roofed structure.

Two drains leading from the center of the north wall of the pool to the north (and probably northeast) were found. One of them was safely connected to an outlet at the bottom of the pool that had a diameter of 0.12–0.18 m, which was presumably fitted with a bronze pipe, and led to a well-made drainage channel of 0.51–0.56 m in width.¹⁴ Of the other drain, only a channel to the north of the pool survives, which was made of large blocks and covered with waterproof cement, and reused in the later Roman bath.¹⁵ It cannot be determined whether both drains were used at the same time, presumably for granting smooth evacuation of large amounts of water, or whether they were built and operated consecutively. Immediately north of the pool, the water line branched to the east and west, but it is unclear where exactly the branches ended in the use period of the pool. They most likely emptied conveniently into the adjacent ravine, like other drains coming from the sanctuary.¹⁶

In contrast, no evidence of the central water inlet and supply has been securely identified. Possible remains of a channel to the southwest of the pool suggest, however, that water was supplied somewhere from this direction.¹⁷ Water sources seem to concentrate in this area, in the ancient and modern periods, because there is still a functioning spring, a large ravine (the ‘Northwest Gully’), and a network of channels and reservoirs from the Greek and Roman periods to the sanctuary. While the narrow water channels and the large reservoir found in the area of the temple do not

12 Gregory 1995, 303–312; Reinhard 2005, 9–10.

13 The pool is actually 1.40 m deep, but provided with curving cap stones, which indicated the height of the water.

14 Gregory 1995, 308.

15 The size of this drainage channel is not indicated in

Gregory 1995.

16 Gregory 1993, 9–10.

17 Gregory 1995, 308 mentions a small trench, RB 76–22, to the southwest of room XIV of the Roman bath building, in which a cutting in hardpan with several stones in situ were found.

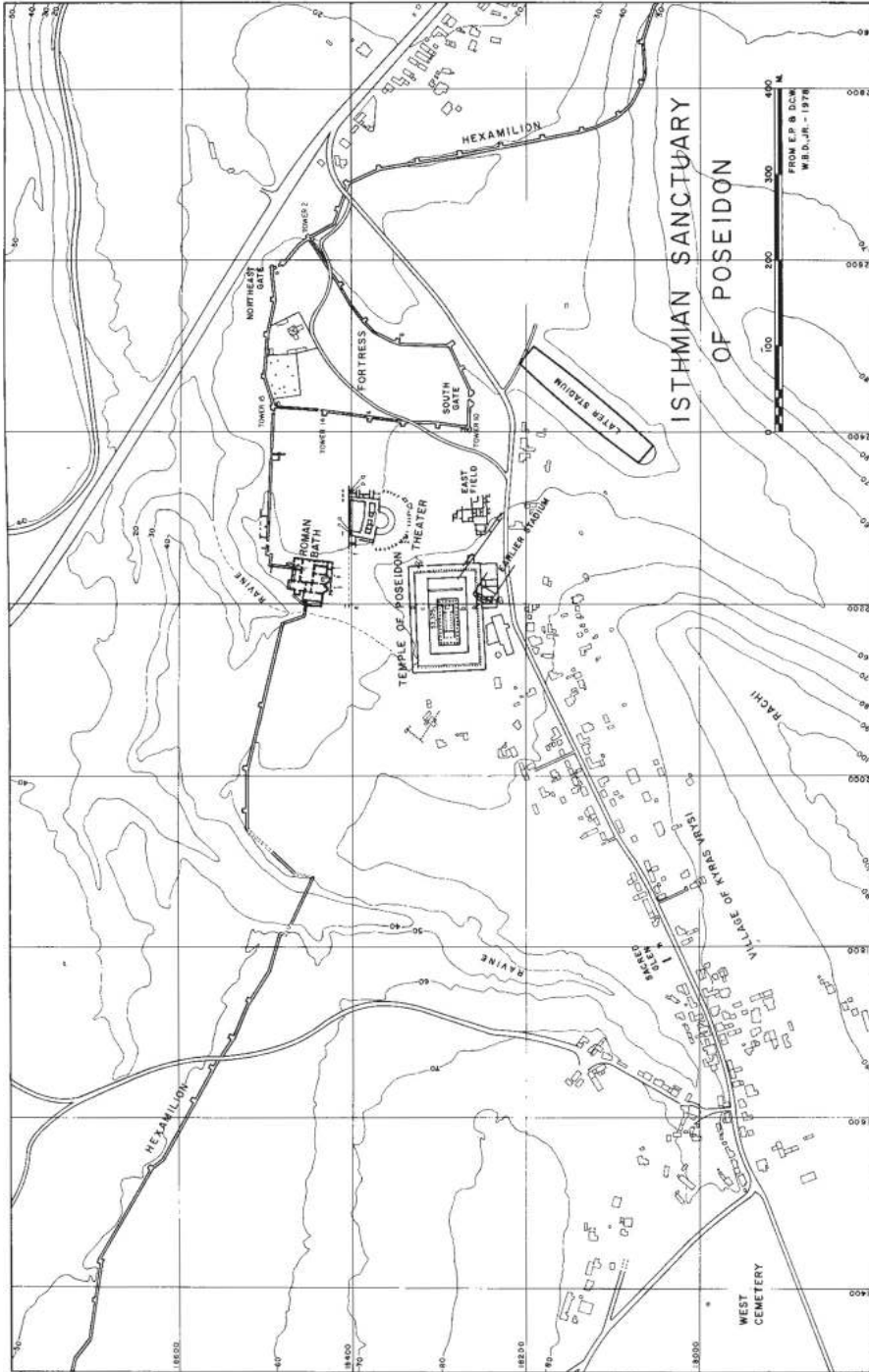


Fig. 4 Isthmia, Sanctuary of Poseidon, plan.

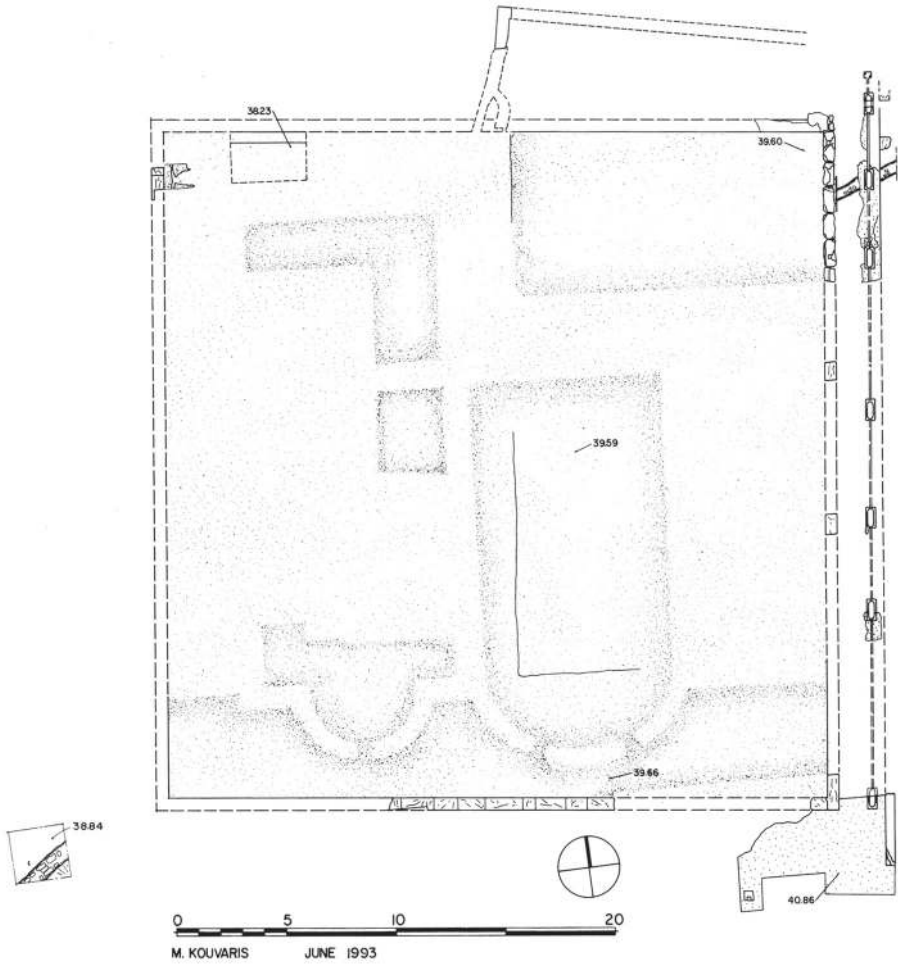


Fig. 5 Isthmia, Sanctuary of Poseidon, reconstruction of the swimming pool.

seem sufficient to supply the large pool,¹⁸ a system of large rock-cut tunnels (0.80 m wide, 2 m high) found close to the western ravine seems more appropriate for this purpose (Figs. 6 and 7). These have barely been explored, however, and their date, exact

18 Broneer 1973, 24–27: channels I–III (for example, channel I is 0.14 m wide at the bottom and 0.07 m deep); the largest reservoir, the northwest reservoir,

had only a capacity of 110 m³, and water was drawn by hand via three manholes.



Fig. 6 Isthmia, Sanctuary of Poseidon, rock-cut water tunnel at the eastern border of the ravine ('North-west Gully').



Fig. 7 Isthmia, Sanctuary of Poseidon, rock-cut water tunnel at the eastern border of the ravine ('North-west Gully').

course, and function cannot safely be determined.¹⁹ It is unknown whether this large pool could have been supplied continuously with fresh water, but the potential double drainage system may reflect a high use of water.²⁰

¹⁹ Jenkins and Megaw 1931–1932, 85–89, have briefly explored these features; they found the rock-cut tunnels covered with excellently preserved cement and filled with debris that included sherds from the Geometric to Roman periods. They argue that the cement would indicate a date in the 6th or 5th century BC. The tunnels ran into a barely preserved cistern. The opening of the main tunnel was found about 8–10 m below the top of the ravine (in the early 1930s), but earthquakes seem to have considerably altered the landscape in the area of the sanctuary of Poseidon over the centuries; Gregory 1993, 9. – Similar rock-cut tunnel systems for water supply, built from the Archaic period onwards, are known from

other sites, among them nearby Corinth, Megara, Nemea, and Samos; for Corinth, Hill 1964; Landon 2003; Robinson 2011, 11–17; for Megara, Avgerinou 2015; for Nemea, see below; and for Samos, Kienast 1995.

²⁰ Recent research in the area of the Roman bath has yielded evidence that has cautiously been identified as remains of a bath building with a *hypocaust* system in the north, a large complex of stoas (*gymnasion?*) in the east, and another stoa (*palaistra?*) in the south. While these remains date to the Roman Imperial period, there are some indications of earlier phases, not yet fully explored, however (Frey and Gregory 2016), ongoing research in these areas may

3 Nemea

The Panhellenic sanctuary of Zeus was provided with a separate bath complex when the Nemean games were revived and the sanctuary experienced a building boom in the years of ca. 330 to 270 BC. The completely roofed bathing facility was located to the south of the temple, between a guesthouse (Xenon) and the Nemea River (Fig. 8). It included a central pool flanked by two rooms, each with four tubs on high feet for washing with cold water. Measuring 8.20 by 3.90 m at the bottom, the pool was at most 1.30 m deep and accessible by a monumental staircase with four steps that stretched across the entire northern side of the pool. Its maximum capacity has been calculated at 43.56 m³ (Figs. 9, 10).²¹

The pool was drained through a small hole at the bottom of the northwest corner into a shallow open U-shaped tile channel; this channel ran hidden under the lowest entrance step of the pool and collected water from both tub rooms and the pool, exiting through the west wall of the West Tub Room. All water from the bath complex was drained into a rubble-lined drain, which was covered with reused starting blocks of an early stadium.²²

Reconstructing the water supply is again more challenging, although there are substantial remains of the supply system. Both the tubs and the pool were fed with water from a system of reservoirs along and outside the southern wall of the building, which in turn, was most likely fed by a spring located 650 m to the east of the bath building. While no continuous channel from the spring to the bath complex was found, several sections were explored that may have belonged to different phases:

1. At the spring, a rock-cut tunnel (1.97 m high, 0.48 m wide, preserved for a length of about 16.40 m);
2. About 100 m west of the spring, a series of blocks that originally formed a rather monumental triangular shaped closed channel and that show heavy lime encrustations;²³

shed more light on the water supply, context, and function of the pool.

21 Miller 1992.

22 Miller 1992, 212–213; no measures for the outlet hole are given; the tiles of the channel had an interior width of 0.08 m at the small end, and an interior height of 0.14 m at the small end and 0.21 m at the large end. Miller 1992, 216 had still assumed that water was drained into the adjacent Nemea River. In Miller 2004, 67 and Miller 2015, 279–280,

the river is identified as a wide, deep, artificially made drainage channel that was only created at the end of the 4th century AD in order to convert the once swampy valley into arable land.

23 Miller 1992, 225–227: the blocks are about 0.29 m thick, 0.89–0.9 m high, and 1.02 m long. Since the technique of these reused blocks is strongly reminiscent of that on blocks of the Temple of Zeus, the aqueduct would be too late for the bath building.

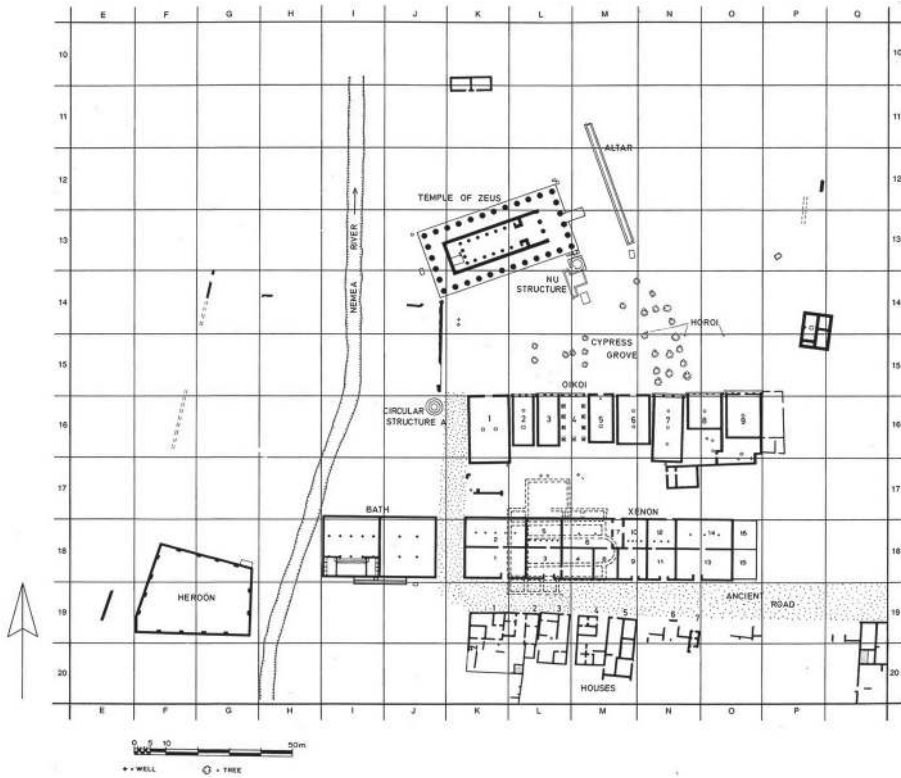


Fig. 8 Nemea, Sanctuary of Zeus, plan.

3. A covered small aqueduct line found to the south of the Xenon; this channel was traced for about 80 m, was made with shallow U-shaped terracotta tiles at the bottom, and may have supplied the reservoir system of the bath complex, even if no immediate connection between these structures was found. For this stretch, Stephen Miller calculated a steady slope of 0.9 m over every 100 m of distance traversed;²⁴
4. An aqueduct located directly south of, and largely parallel to, the reservoirs of the bath complex, which is constructed of small stones and tile fragments. Since it was cut by the reservoirs, it may originally have supplied the bath building with water.²⁵

24 Miller 1992, 227, 300: the U-shaped tiles are 0.107 m wide and 0.201 m high; the area was covered with Corinthian cover tiles, Lakonian ridge cover tiles, and broken Corinthian pan tiles.

25 Miller 1992, 231: followed for about 19 m, 0.1 m

wide and 0.3 m deep. It is lined with hydraulic cement and notable for its lack of heavy lime accretions; its bottom is with 332.839 partially on a lower level than that of the reservoirs with 332.740 to 332.995; cf. Miller 1992, Fig. 259*.

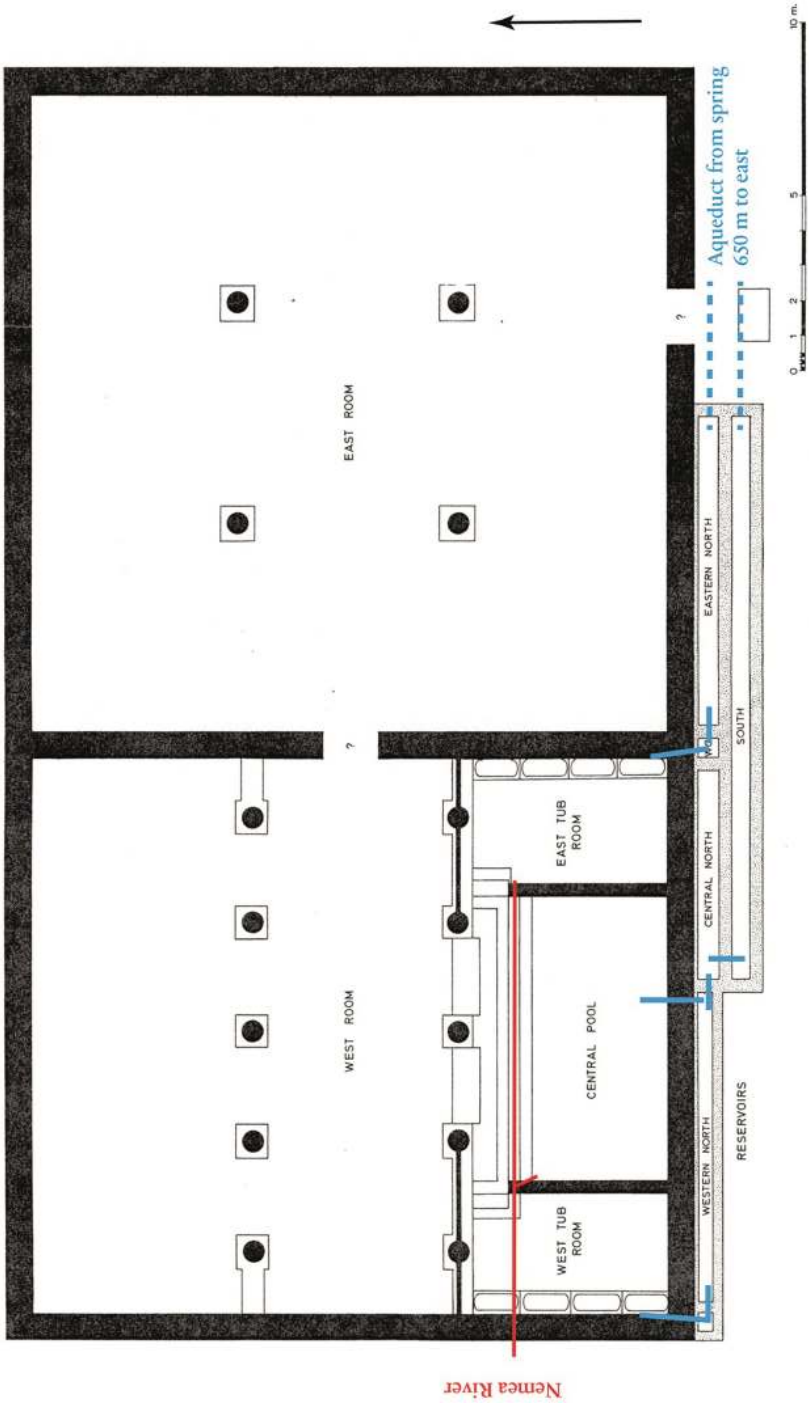


Fig. 9 Nemea, Sanctuary of Zeus, reconstructed plan of the bath building with water management (blue: supply – red: drain).

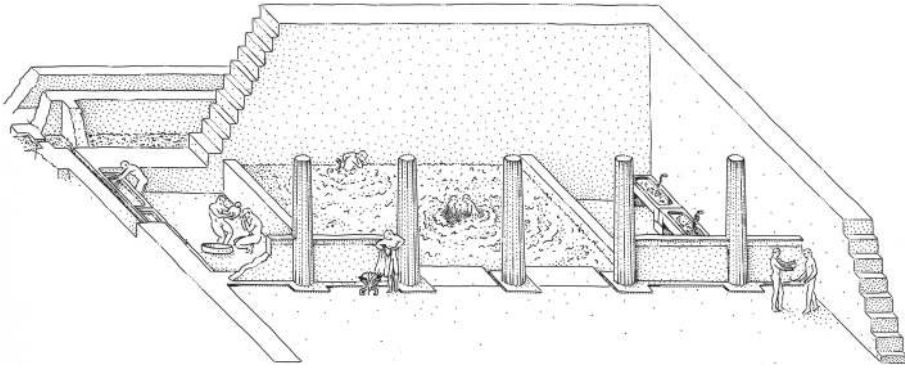


Fig. 10 Nemea, Sanctuary of Zeus, reconstruction of the bathing rooms.

Therefore, the intricate system of four reservoirs seems to belong to a later phase of the building when water supply was improved: either in order to better feed the existing pool and tubs, or to feed the newly built pool and tubs that replaced some unknown, presumably simpler bathing installations.²⁶ It is not at all clear, however, why the reservoir system was established and how exactly it worked. There were presumably two connections between the aqueduct and the reservoir system: one to the eastern north reservoir that was connected with the ‘water closet’ to its west and fed the East Tub Room.²⁷ The other must have filled the south reservoir, which supplied the central north reservoir, from where water ran into the western north reservoir; the latter fed both the pool, most likely with a pipe of less than 0.1 m diameter from its eastern end, and probably also the West Tub Room via a water closet system from its western end. Since the capacity of these three interconnected reservoirs has been calculated to be 12.34 m³, it would have required 3.5 fillings of all three reservoirs to fill the pool. Thus, one wonders whether the reservoirs did not primarily function as settling basins, rather than storage facilities, at least with the view of supplying the pool.²⁸

Miller assumed that the bath building was operated and supplied with water at intervals, and not continuously throughout the day.²⁹ Alternatively, the aqueduct could

26 Miller 1992, 237–239.

27 Miller 1992, 219, does actually not discuss at all how this reservoir was supplied, but states that the eastern north reservoir and the closet “served the hydraulic needs of the East Tub Room exclusively”; since the water closet is only connected with this reservoir and since the south reservoir with its slope from east to west has an outlet at the very western end, it seems most likely that the eastern north reservoir and the south reservoir were not

connected.

28 Note, however, that the aqueduct was presumably fully covered and the pool was also roofed, whereas the reservoirs were left open.

29 Miller 1992, 216–220; Miller 2004, 120–122, reconstructs a kind of flushing system for the tub rooms which would not have received constantly flowing water, but would have been filled periodically; one closet filling would have sufficed to fill all four tubs

have provided a steadily running supply for the bath building where the tub rooms were fed intermittently, via the closet system, and the pool permanently, serving as a kind of ‘flow-through’ pool. Outlet and inlet were correspondingly small in this pool, suggesting a modest, if possibly still permanent flow or trickle of water.

If the bath building was not supplied continuously with water, however, the aqueduct must have been shut off regularly somewhere between the spring and the bath complex, and it must have led water to other destinations, probably on a more permanent basis. One such destination could have been a large tripartite reservoir (112.72 m³ capacity) which has recently been discovered to the west of the bath complex. Miller suggested that excess water of the aqueduct was channeled to this large reservoir once the needs of the bath were satisfied. The elevation of the inlet and outlet of the bath complex and the inlet of the large reservoir show that the reservoir could only have been supplied with fresh water from the aqueduct, which must have been split at the height of the bath complex to feed both the bath and the reservoir.³⁰ Since the reservoir was only constructed in the late 4th or early 3rd century BC, it could have been conceived when the water supply of the bath was remodeled and improved; some contemporaneously established intricate system may have regulated distribution of spring water to the small bath reservoirs and the large reservoir. The latter presumably served to supply horses that ran in the nearby Hippodrome;³¹ therefore, in theory, it could also have received wastewater from the bath. The drain from the bath lies on a slightly lower level (0.07 m), however, than the inlet of the large reservoir, and could hardly have led water over a distance of about 80 m from the bath to the reservoir. Thus, it must remain open for now, where exactly the wastewater from the bath was drained to.

3.1 Delphi

The *gymnasion* complex at Delphi was located in close vicinity to the Panhellenic sanctuary of Apollo. Its *palaistra* was built in the third quarter of the 4th century BC and later enlarged, probably in the second quarter of the 3rd century BC, to include race tracks (*xystos* and *paradromis*) and a separate bathing complex (*loutron*) (Fig. 11). The different components of the *gymnasion* were organized on two long, north-south oriented terraces,

once. The pool would have been drained and re-filled perhaps only once per day. Miller 2004, 122: “the pool was probably completely filled and emptied at relatively lengthy intervals.” Cf. also Manderscheid 2000, 483–484.

30 Miller 2004, 134; Miller 2015, 335–344; the inlet of this reservoir is at 331.65; the bottom of the west-

ern north reservoir of the bath is at 332.740; the drainage outlet of the bath complex (in the north-western corner of the West Tub Room) is, according to Miller 1992, 216 note 611, at 331.582.

31 As suggested by Miller 2004, 92–93, fig. 60, 135; Miller 2015, 344–348.

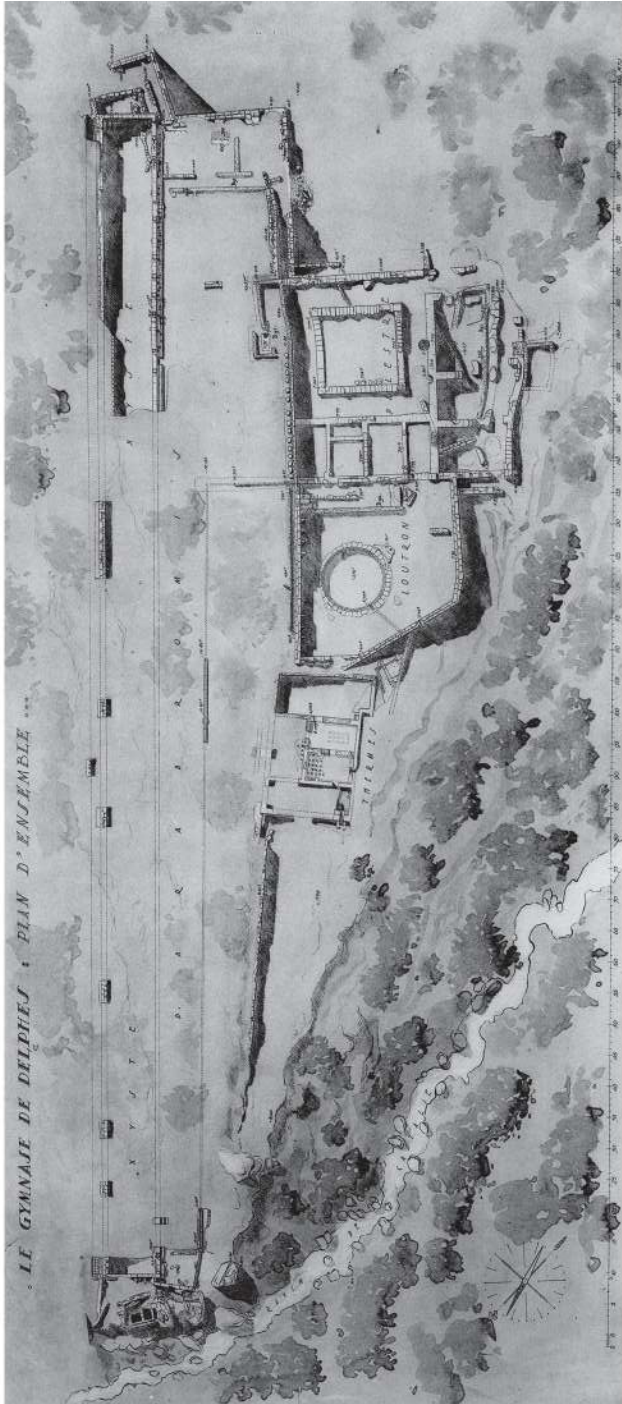


Fig. 11 Delphi, *Gymnasium*, state plan.

the bathing complex and *palaistra* on the lower terrace being complemented by the race tracks on the upper terrace. The *loutron* occupied an open-air paved terrain to the north of the *palaistra* and included ten basins for cold water ablutions along its eastern wall, and a centrally placed round pool (Fig. 12). The pool may even have been mentioned in an inscription that refers to a *kolymbethra*.³² The latter has a diameter of 8.6 m at the bottom and 9.7 m at the top and originally had a depth of 1.9 m, being provided with four steps all around. Thus, its maximum capacity was about 98 000 liters.

The pool was drained through an outlet that was installed at the bottom of its northwestern wall and had a diameter of 0.16 m. This was connected to a built covered drainage channel (0.69 m high, 0.5 m wide) that ran to the northwest with a steep decline and emptied into the adjacent Castilian ravine.³³

The pool was fed presumably by running water from the nearby Castilian spring that first supplied a channel system on the upper terrace (Fig. 13); an open channel made of limestone blocks (interior width of 0.95 m and depth of 0.115 m) and provided with settling basins was found in the middle of the terrace, running in a north-south direction parallel to the *xystos* and *paradromis*. While the beginning of this channel has been excavated at the northern end of the *paradromis*, it is unclear how this channel received water from the ravine below. Published plans show a system of terrace walls and two reservoirs in the embankment between the ravine and the *paradromis* that could have served to supply the channel, with possible temporary storage facilities.³⁴ On the terrace, the channel descends with a steady slope.³⁵ This channel, or a branch extending from it, must have turned west, roughly at the height of the pool, and descended quite steeply in order to feed a covered channel that ran behind the east wall of the *loutron*; the connecting channel ended in a settling basin from which water must have flown to the north and south.³⁶

32 Jannoray 1953, 53–63; Wacker 1996, 195–207. – For the inscription, accounts written under the archon Dion II (247–246 BC), see Pouilloux 1977.

33 Jannoray 1953, 62.

34 Jannoray 1953 does not discuss these structures, but his state plans, pl. I and III (here Figs. 11, 13), clearly show them. The channel starts at an elevation of 12,027, the bottom of the two interconnected reservoirs seems to have been at 12,70, and their top borders at 13,51. The elevation of the ravine is not indicated, but it seems to be significantly lower than that of the reservoirs; thus, a channel must have led from some point upstream down to the reservoirs.

35 Jannoray 1953, pl. I: from 12,027 in the north to 10,85 at the height of the northeast corner of the *loutron* terrace. When Pentazos and Trouki 1994, 433–434, reexcavated part of the upper terrace they

did not find any evidence that would safely date this channel to the 3rd century BC, however; their investigations showed that the terrace was used until late antiquity and that some of the water management structures (esp. terracotta pipes) certainly belonged to late phases of use.

36 Jannoray 1953, pl. I: this connecting channel had to descend from 10,85 down to 9,84. Jannoray 1953, 63, assumed that a terracotta pipe running from the open channel west to the southeast corner of the *loutron* would have supplied the *loutron* channel; recent excavations showed, however, that this terracotta pipe, made of reused elements, went to the northeast corner of the *palaistra* and served as a drain; Pentazos and Trouki 1994, 428–433, also found the location of the original supply channel

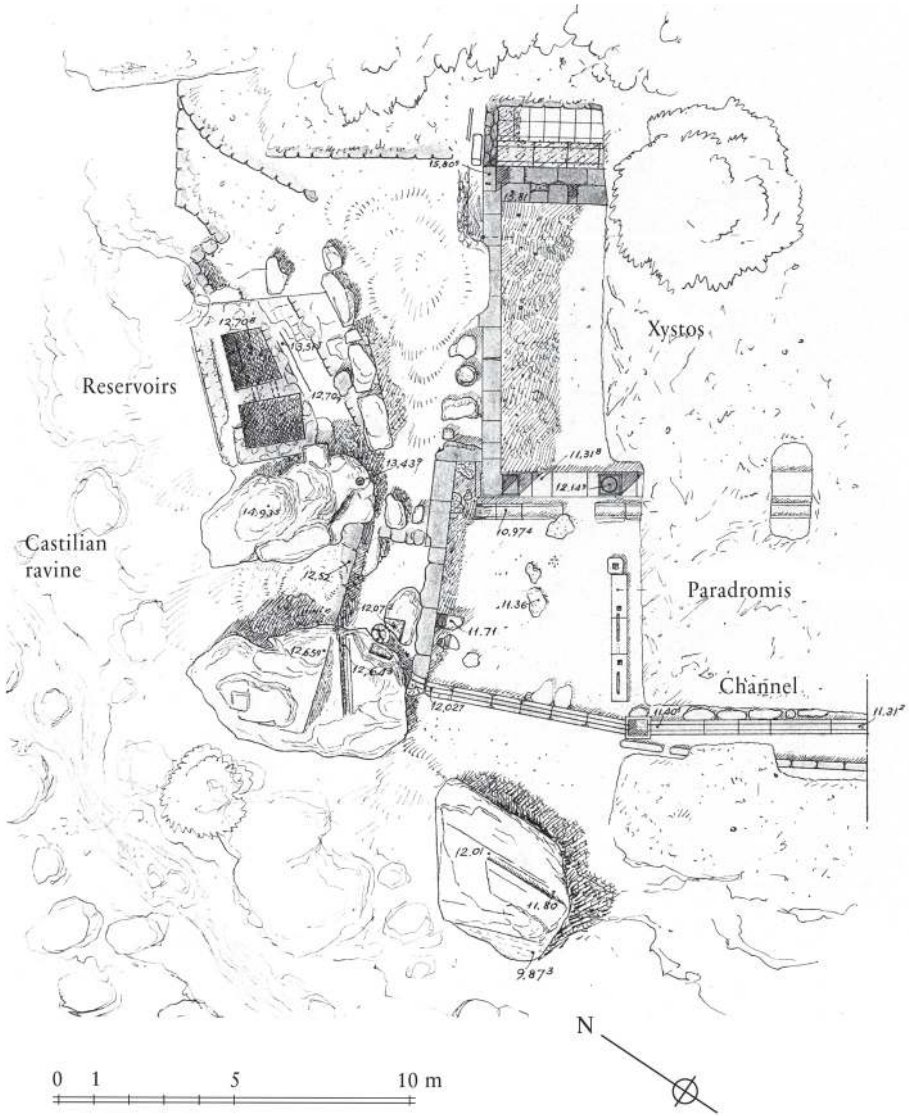


Fig. 13 Delphi, *Gymnasion*, state plan of the northern upper terrace.

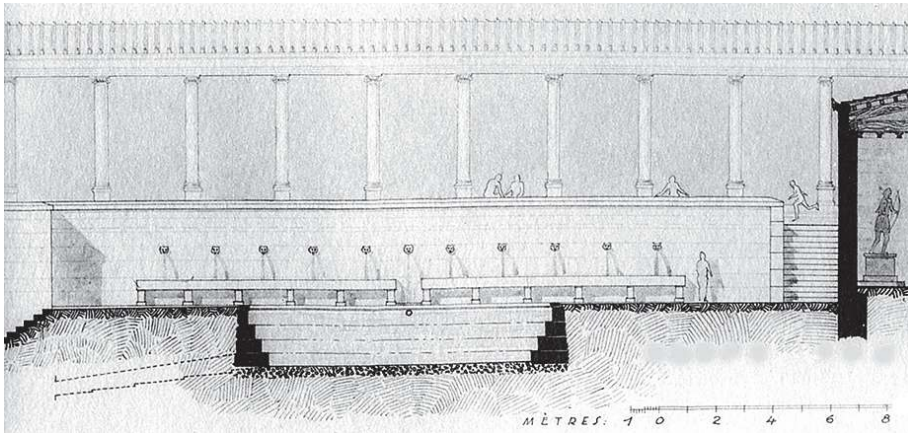


Fig. 14 Delphi, *Gymnasion*, reconstruction of the *loutron*.

The *loutron* channel supplied 11 water spouts that fed the ten above-mentioned basins, and presumably the pool. It must be emphasized, however, that no traces remained of the necessary connecting (open or closed?) channel between the central water spout, which was larger than the ten flanking spouts, and the pool; the precise location and size of the inlet of the pool remain unknown.³⁷ While obvious care was taken to supply the basins with relatively clean water, this was maybe not the case for the pool. Since no channel was found that would have drained waste and spilled water from the basins, Jannoray assumed that this water was led to the pool, via the central connecting channel between the central water spout and the pool; the basins would have been interconnected, water flowing from the northernmost and southernmost basins to the center (Fig. 14). Thus, the pool would have received more water, but presumably partially wastewater. The whole argumentation is flawed, however, because Jannoray misinterpreted the only evidence for his reconstruction, the only relatively well-preserved basin.³⁸ This basin has a groove or overflow channel on its left short border and a drainage hole in its left front corner; today, the right border is not sufficiently preserved to exclude the existence of a groove.³⁹ In any case, the hole in the bottom clearly suggests that water was drained onto the floor, at least at certain intervals, and not (solely) via the lateral grooves into a channel.

with its settling basin; this is not shown on the plan of their trenches on the upper terrace, 429 Fig. 5, however, which also does not include any elevations.

37 Jannoray 1953, pl. XI, 2 (here Fig. 14), reconstructs a small circular inlet (pipe?) at the top of the highest

step.

38 This basin has a length of 1.82 m and, according to Jannoray 1953, 39, would have an overflow outlet at the top right border; Jannoray 1953, 59 n. 1, argued that this basin could only have been set up as the fifth basin from north (with the direction of flow

In sum, it seems most likely that water from the basins simply ran over the paved floor of the terrace and via two outlets in its northwest terrace wall into the Castilian ravine. The pool could have been protected from this run-off water if its upper fourth step was slightly raised above the pavement of the open terrace; since the pavement of the open area and the highest step are not preserved in situ, however, their relationship cannot be safely determined.

While the supply from the Castilian spring, in theory, could have been shut off and the *loutron* fed only at intervals, when needed, water could also have run permanently, adding fresh and cold water to the 'flow-through' pool.

4 Aï Khanoum

The palace complex of Aï Khanoum in Bactria was located on a terrace next to the large Oxus River (Fig. 15). It was provided with a pool shortly before the destruction of the city in 145 BC. Located between the palace in the south and a complex identified as a *gymnasion* in the north, the pool was built in a large open-air courtyard⁴⁰ that was possibly planted with trees and most likely surrounded by a precinct wall on all sides (Figs. 16, 17). The pool is reconstructed from remains of its pebble pavement with a size of 41.5 × 44 m and a maximum depth of 2.1 m in the center; the pavement sloped slightly from all sides to the center. No evidence of access facilities (ramp or stairs), of a paved area around the pool, or of water management was found in the cross-shaped large trench that revealed the center of the pool and scanty remains of its borders (Fig. 16).

It is assumed that drainage would have been unnecessary because the pavement of the pool, made of two thick layers of pebbles, was most likely not entirely waterproof but would have allowed for seeping. It is unclear, however, how this would have worked and how quickly water would have disappeared: if too quickly, this would have required a significant steady inflow of water in order to keep a certain level in the pool, and, if not quickly enough, it may have hindered the regular exchange of water and caused flooding. In theory, water could have been drained to the west or southwest, into the nearby Oxus River, but two facts challenge this idea. First, the drain would have had to cross the precinct wall of the pool area, as well as the fortification along the Oxus River.

from the north to the center), next to the central outlet, or as the tenth basin from north (with direction of the flow from the center to the south); it would have been too short, however, to have served as the tenth and last basin in the row.

39 With a single groove, this basin could have been the tenth basin from the north (with direction of the

flow from the south to the center), or the fifth basin from the north (with the direction of the flow from the center to the north).

40 Veuve 1987, 39–41, 97, 103–106 Taf. IV, VI: precinct with a north-south extension of 152.8 m and an unknown east-west extension (at least 88 m).

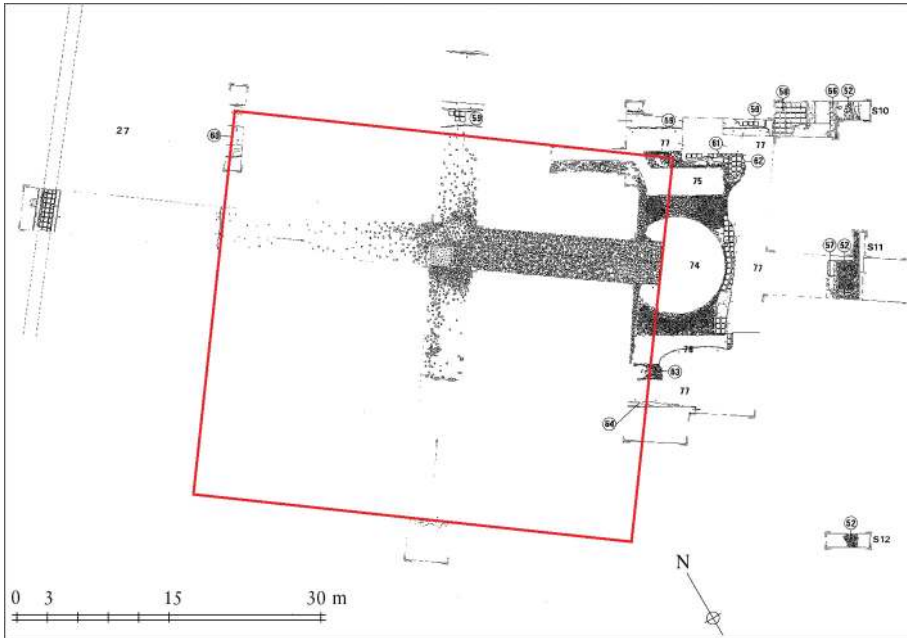


Fig. 16 Ai Khanoum, Pool area, state plan.

palace area is built on a terrace about 20 m above the river.⁴¹ The water supply of the city and the palace area has not been studied comprehensively, but it is generally stated that the city was supplied by a network of open-air channels,⁴² and it is emphasized that water-supply and water-drainage networks were highly developed.⁴³ The high number of bathing installations in the palace area and in private houses confirms that water must have been available in significant abundance.⁴⁴ A main channel brought water into the city from the north, flowing between the main north-south street and the foot of the eastern acropolis hill (upper city); but whether this channel also supplied the palace

41 This is clearly visible in the sections at the area of the fountain house and fortification, located to the north of the *palaistra*; Leriche 1986, pl. 8 fig. 11; cf. also the plan in Veuve 1987, pl. 2 with levels: the pool area is almost 10 m (+436.7) above the lowest point of the embankment (+427.8); no levels are indicated for the Oxus and its immediate border. A fountain house that was built between the Oxus River and the fortification, to the north of the *palais*-*tra*, was supplied by its own spring from the east;

Leriche 1986, 32–41. Cf. also the recent 3D reconstruction of the city, Martínez-Sève 2014, 271 fig. 3.

42 Bernard 1981, 110: “l’approvisionnement en eau étant normalement assuré, comme partout en Asie Centrale, par des canaux à ciel ouvert, branchés sur le système d’irrigation de la plaine.”; cf. also Francfort et al. 2014, 21, 64, 84, 96.

43 Martínez-Sève 2014, 273–274, 279.

44 Bernard 1981, 118.

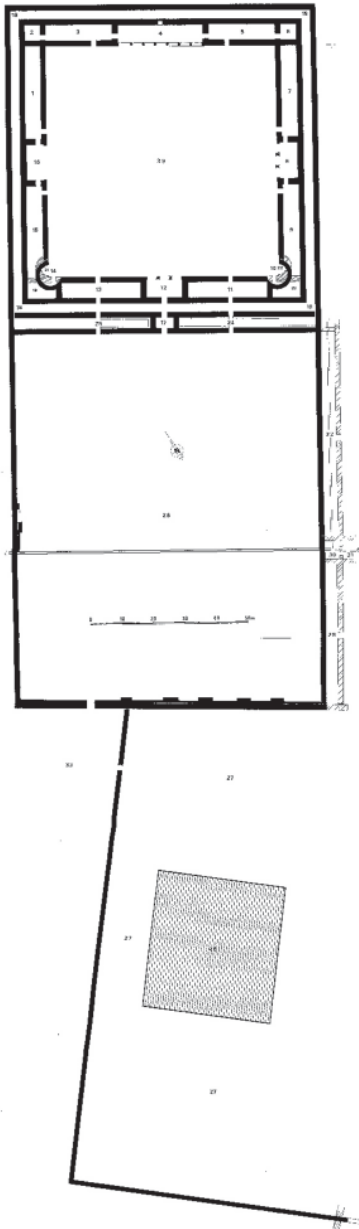


Fig. 17 Ai Khanoum, Reconstructed plan of the *gymnasion* and pool area.

and pool area, currently cannot be determined.⁴⁵

It cannot be safely determined whether this pool ever functioned, and how precisely. It must be emphasized that its identification as a pool has been challenged, in favor of a park for horses with a drinking trough.⁴⁶

5 Jericho

The Hasmonean royal family seems to have been very interested in installing swimming pools. Between 125 and 63 BC they built a large palace complex at Jericho that included eight large open-air pools (Fig. 18). Jericho is located in a desert area with an arid climate that was mild and agreeable in winter. The palace complex itself was laid out between a Wadi, Wadi Qelt, and the royal estate, an irrigated terrain of 45 ha surface that was surrounded by a wall and used to grow date palms and balsam shrubs. While Ehud Netzer reconstructed the development of the Hasmonean Palace complex in seven phases, swimming pools were only installed in phases 2–6.⁴⁷ Almost all of these pools were used contemporaneously until the destruction of the palace complex by an earthquake in 31 BC, and four of them were even reused by Herod the Great in his second palace at the site, built after 31 BC. The eight pools are very similar in design and function: they are rectangular and fall into two different size groups, namely 8 × 8 m and 13 × 18–20 m; they are 3–3.8 m deep, have benches built along the top of the side walls and a staircase leading to the bottom of the pool in one corner. Their capacity ranged from about 220 000 liters to 819 000 liters. All pools were open air, surrounded by paved areas and gardens with various banqueting facilities, and presumably also by high walls that granted privacy.⁴⁸

The drainage system of the pools is known in a general outline, even if its full functioning and final destination cannot always be clearly determined. The pools were commonly provided with outlets at the top of the side walls, a position that is common for overflow drainage.⁴⁹ For example, two narrow open channels emerge from the southwest corner of pool A(C)94, one coming presumably from the pool itself, and the other from the outer edge, although no immediate connection was found in either case

45 Martinez-Sève 2014, 269 Fig. 2; the 3D model developed by G. Lecuyot and O. Ishizawa, <https://www.youtube.com/watch?v=oyap-dAjj6M> (visited on 25/05/2018), does not include a clearly visible network of channels in the city.

46 Francfort et al. 2014, 63: “une vaste enceinte abritait une ‘piscine’, à ciel ouvert, espace que l’on a plutôt identifié à un parc à chevaux avec abreuvoir.”

47 Netzer 2001a, 1–7.

48 Netzer 1986; Netzer 2001b; Netzer 2001a. – Stacey 2006 challenged the function of the pools as recreational facilities and identified them as fishponds; Regev 2013, 246 n. 85, refers to an unpublished reply by Netzer who emphasized the lavish character of the garden areas with pools. Netzer’s interpretation is followed here.

49 Netzer 1986, 7.

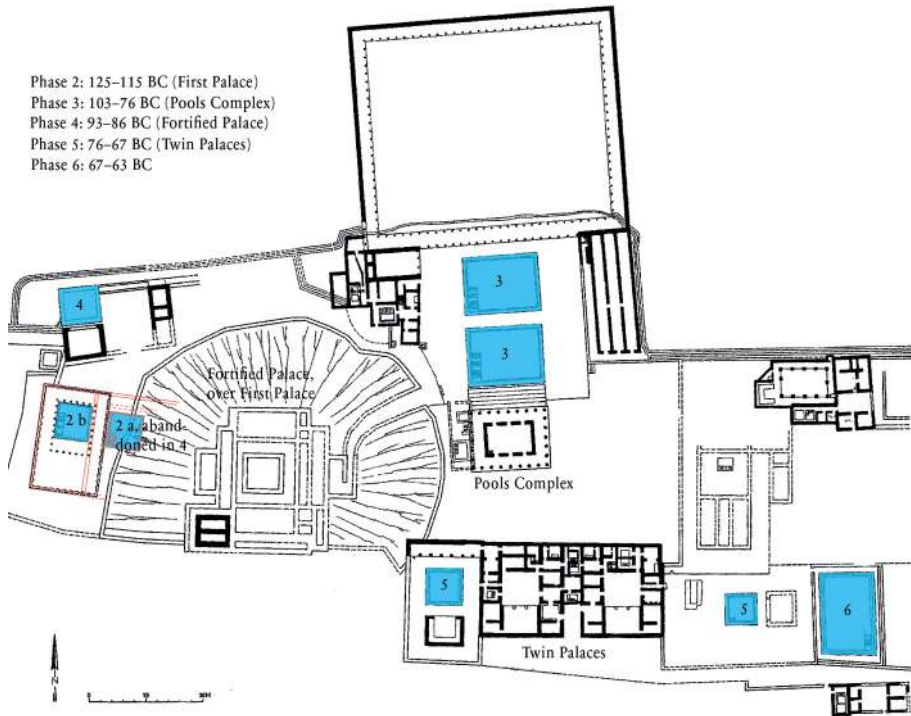


Fig. 18 Jericho, Hasmonean winter palaces with pools.

(Fig. 19). With elevations at 102.88 and 102.84, the bottom of these channels is located far above the bottom of the pool at 99.45 and even above the level of the bench of the pool with 102.71. The channels merged before passing through the precinct wall of the pool area; although the channel was not found to the west of this wall, it is assumed that it would have continued further west and irrigated the fields of the adjacent royal estate.⁵⁰ Similarly, none of the other many pools of the palace that are identified as ritual baths and reservoirs included drainage holes at their bottom; they were presumably either bailed out by hand with the help of buckets and jars, or also included pipes and channels at their upper border that drained overflow water.⁵¹

50 Netzer 2001a, 60 fig. 88: While no measures (width, depth) of these channels are given in the text, the state plan and published photos suggest that these were no more than 0.1–0.2 m wide, shallow, and found without cover. Similarly for the adjacent pool AC44, the bottom of the narrow shallow drainage channel was found 102.68 close to the southwestern

edge of the pool, 8 cm above the bench, and could be followed for 20 m, sloping down to 102.31 at a point when it apparently continued underground; this channel became broader and deeper towards its western end and was found partially covered with simple slabs (Netzer 2001a, 60).

51 Netzer 2001a, 119, 122, 131, 153, 157, 160, 167, 194.

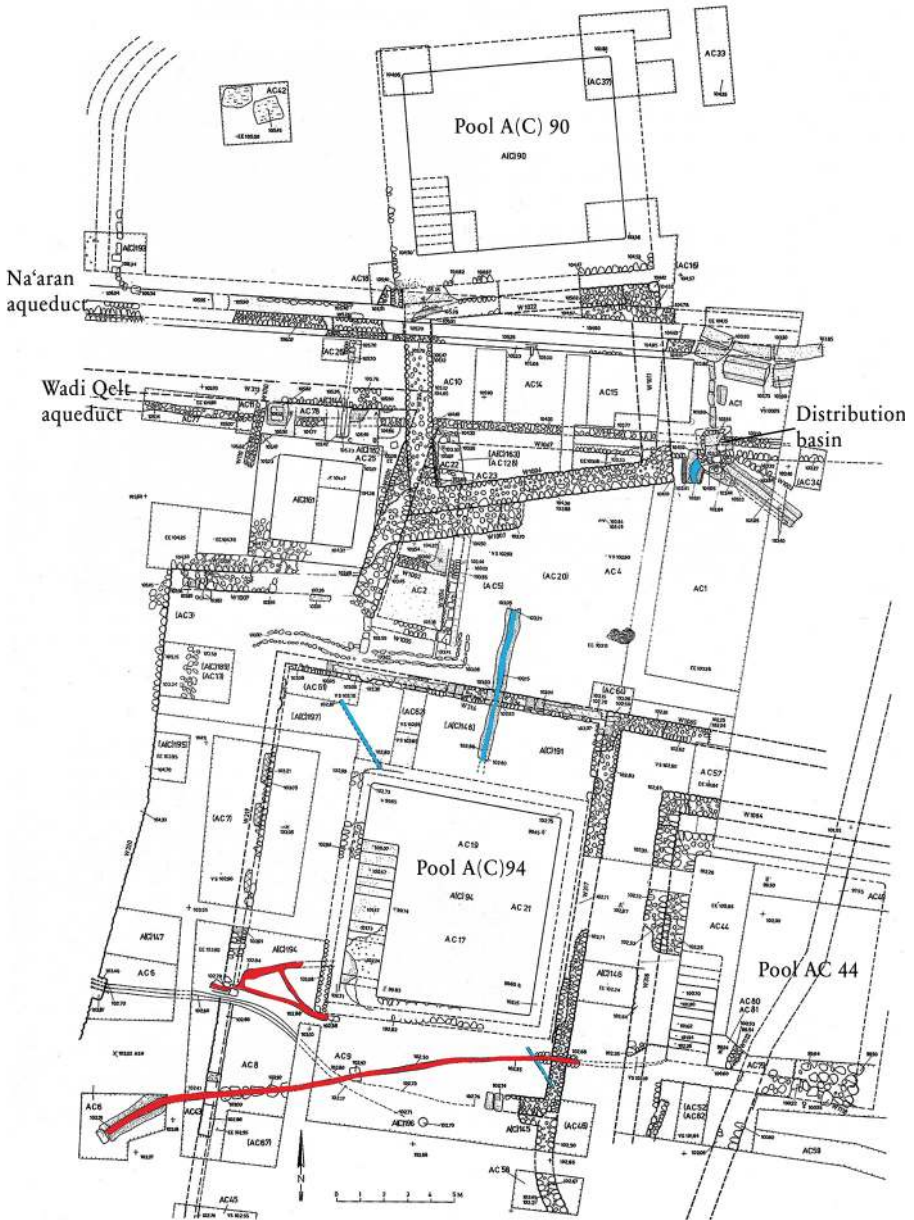


Fig. 19 Jericho, Hasmonean winter palaces: state plan of area AC, water management (blue: supply – red: drain).

The water supply of the royal estate and palace area has been comprehensively studied.⁵² Two main phases can be distinguished: When John Hyrcanus I built the royal estate and palace with the first two swimming pools around 125 BC, they were supplied by three springs in the Wadi Qelt, whose water was combined in one large open aqueduct channel. From this channel, a terracotta pipe with a diameter of 12 cm, buried 40 cm under the ancient surface, branched off to supply the palace, and probably also the first two pools. At the end of the 2nd century BC, the successor, Alexander Jannaeus, enlarged the estate and palace, building the two largest swimming pools (Pools Complex) and improving the water supply: water from three more springs, which were partially located much farther away in the Na'aran Valley and provided more water more reliably year-round, was channeled to the palace area.⁵³ While the Wadi Qelt aqueduct mainly supplied the royal estate, the Na'aran aqueduct fed first and foremost the palace and an adjacent industrial complex. The latter ran right through the palace area from west to east, but its course was changed several times in the Hasmonean Era.⁵⁴ While many remains of hydraulic installations were found in the palace area, connections between the different elements were often missing, so that coherent supply and drainage circulation patterns could rarely be reconstructed. Furthermore, in correspondence with the aqueducts, the sophisticated water management in the palace area itself saw many changes that also regarded the various pools.⁵⁵

For example, pool A(C)94, one of the earliest in the palace area, provides evidence of three different supply systems that belonged to at least two different phases (Fig. 19): 1. a terracotta pipe leading water from a roof in the east to the southeastern corner of the pool, but no inlet was found there;⁵⁶ 2. a terracotta pipe was found in the northern wall of the pool, close to the northwest corner; it could be followed for 3.3 m to the northwest, and originally most likely branched off of the Wadi Qelt aqueduct;⁵⁷ 3. this pipe was cut when the Na'aran aqueduct was built, which fed, among others, a distribution basin to the northeast of the pool. One of the three channels emerging from this

52 Garbrecht and Netzer 1991.

53 The farthest spring, Ein Auja, was located 11 km northwest of Jericho; Garbrecht and Netzer 1991, pl. 5. 1; the aqueduct was at least 18.73 km long; the aqueduct coming from the Wadi Qelt was around 8 km long.

54 While the aqueduct originally ran as a covered channel between the two large swimming pools of the Pools Complex, it was later relocated several times, bypassing the Pools Complex (Netzer 2001a, 92–100, plans 17–22).

55 Netzer 1986, 3; Netzer 2001a. – The many changes cannot be discussed in detail here for all eight swim-

ming pools. In addition, there are many other pools and basins in the palace area, identified as reservoirs, distribution basins, and ritual baths, which cannot be taken into account here.

56 Netzer 2001a, 60, plan 13: no elevation and no date are indicated for this pipe.

57 Netzer 2001a, 57, plan 13: this pipe slopes from 102.87 to 102.80 and must have ended at the very top of the pool; the bench below the inlet is at 102.73. The top of the Wadi Qelt aqueduct (underground pipe set into casing made of fieldstones) is at 104.77–105.14 to the northwest of the pool.

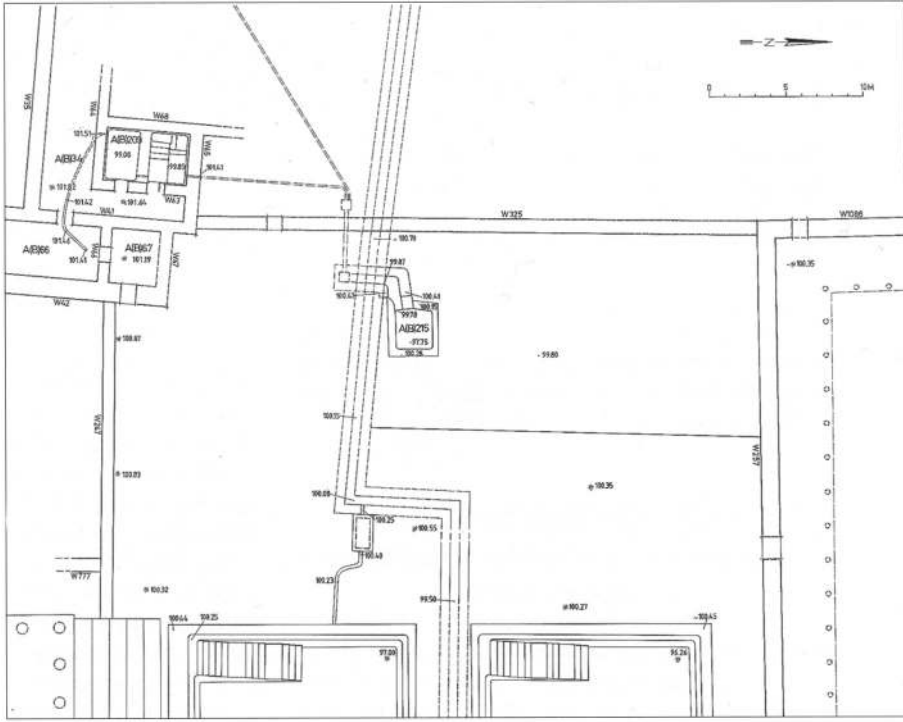


Fig. 20 Jericho, Hasmonean winter palaces: reconstructed plan of phase 3 of the Pools Complex.

basin supplied the pool; while part of this open channel was found to the north of the center of the pool, its connection with the pool did not survive.⁵⁸

The development of the water supply is even more complicated for the Pools Complex with its two large swimming pools. Apparently, the builders of the first Na'aran Aqueduct miscalculated the slope required for supplying both pools directly from the main branch that ran between both pools (Figs. 20–22).⁵⁹ Therefore, a separate channel with some distributive installation was built further west at a higher level, which presumably fed the south pool that, in turn, supplied the north pool via a connecting pipe. At a later point, the north pool was supplied with its own channel that branched off of the Na'aran Aqueduct. In a third phase, when the course of the Na'aran Aqueduct was significantly changed to bypass the Pools Complex, a separate settling basin was built to

58 Netzer 2001a, 54–55, 57, plan 13: bottom of Na'aran channel at 104.40; bottom of distribution basin at 103.54; bottom of the channel to the north of the pool at 102.80.

59 Netzer 2001a, 79: The aqueduct should have been about 0.60 m higher than actually built, which is a significant miscalculation.

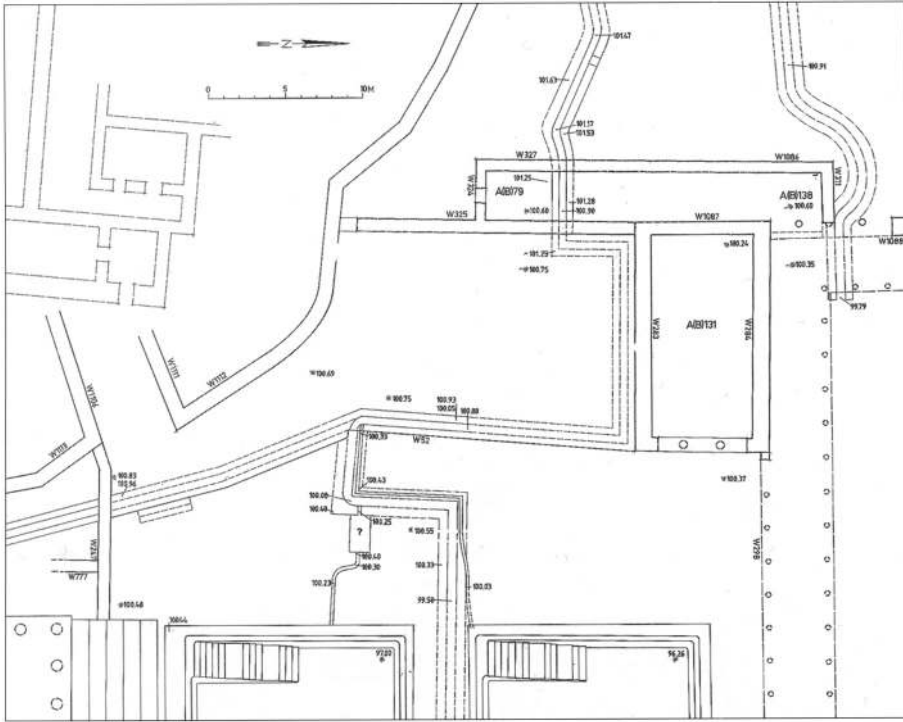


Fig. 21 Jericho, Hasmonean winter palaces: reconstructed plan of phase 5 of the Pools Complex.

the west of the pools that supplied both pools via two channels.⁶⁰ Due to substantial remodeling of the Pools Complex under Herod the Great, no original inlet to either pool and no connecting pipe between the pools were preserved. It must be emphasized, however, that the frequent changes in the water management of the Pools Complex clearly reflect the concern to grant, maintain, and improve the functioning of the pools.⁶¹

It is assumed that water was running constantly in the aqueducts and that the pools were supplied permanently, serving as flow-through pools on the way to the final destination, the gardens and cultivated fields. Cleaning these pools must have been challenging or impossible, however, because they could never be conveniently fully emptied, except by hand or by letting the water fully evaporate and dry out.

That these pools were really used for swimming and all kinds of entertainment, however, and not just as reservoirs, is confirmed by Flavius Josephus, who describes a

60 Netzer 2001a, 74–84, plans 14, 17–21.

61 For the water management of the other pools,

AC44, A(C)90, AE103, A(L)255, A(L)330; Netzer 2001a, 50–216.

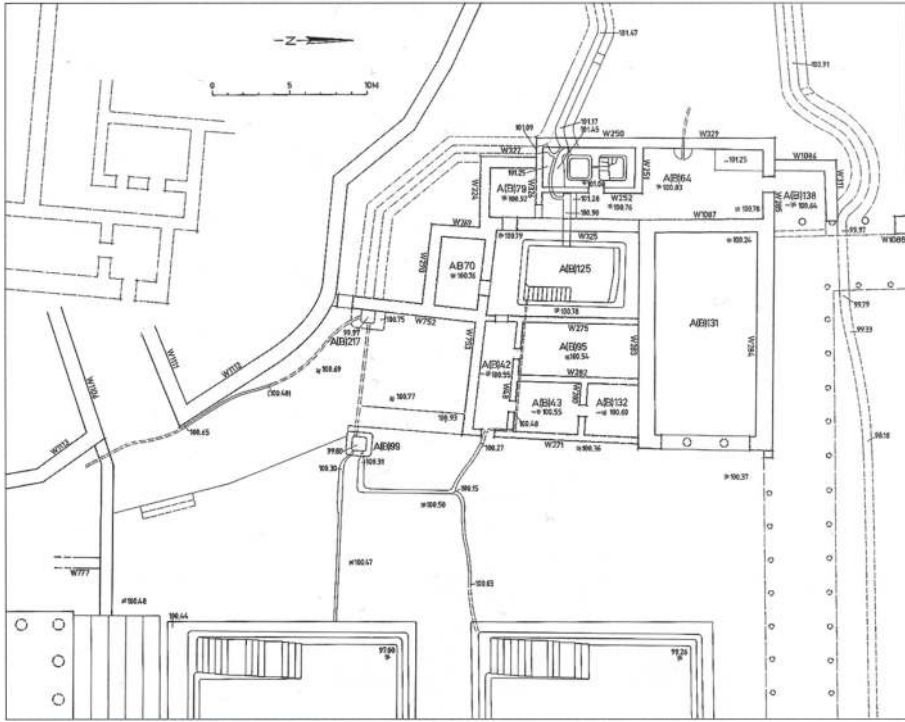


Fig. 22 Jericho, Hasmonean winter palaces: reconstructed plan of phase 6 of the Pools Complex.

political murder in the mid-30s BC that took place in one of the palace’s several large pools (*kolybethrai*).⁶²

5.1 Conclusion

For none of the 13 swimming pools discussed here, can the water management be fully reconstructed in all of its different aspects. There is evidence, however, that all pools were used and must have functioned, except for the example of Ai Khanoum.⁶³ Combining the data from various pools, the following picture emerges.

- Construction, topography: Swimming pools were commonly dug into the ground and lined with walls and some waterproof material. In two sites, evidence was found

62 Flavius Josephus, *Jewish Antiquities* 15.3.3.

63 Evidence includes a renewal of cement on floors and walls, and changes of the water management, not mentioned in detail here for the pools; in contrast,

calcareous concretions are not specifically mentioned for any of the pools. – For the questionable identification of the pool in Ai Khanoum, see Francfort et al. 2014. 63.

that the flanking walls were built as freestanding walls.⁶⁴ In all of the other cases, the area outside the pool walls was not sufficiently excavated in order to determine the construction technique and process. Where known, the top of the pools was commonly more or less at the level of the surrounding area; while this facilitated access, simply stepping down from walking level into the pool, it must have had consequences for the water management and water quality. From a practical point of view, ideal operation would have been to have inlets coming in at the top of the pool and outlets going out at the bottom; thus, drainage channels would have been on a significantly lower level than supply channels. How these differences in levels were negotiated, can only be assessed for the pools in Nemea and Delphi. The complex in Delphi, with its placement on terraces, provided the most convenient setting for water management. In Nemea, and presumably the other cases that do not provide evidence of extensive terracing or sloping terrain, slopes of supply and drainage channels must have been carefully calculated.⁶⁵ Certainly not by chance, the most ambitious, particularly deep pools were certainly (Jericho), or presumably (Aï Khanoum), not provided with drainage channels at their bottoms.

- Water supply: The supply sources for the pools include nearby rivers in Delphi, and possibly also in Olympia and Isthmia. Spring water was tapped with a short aqueduct in Nemea (650 m) and by much more ambitious aqueducts in Jericho (8 and 18 km). The pool of Aï Khanoum may have been fed by a channel system of unknown provenance and length. How precisely water flow was regulated and controlled from the source to the inlet of the pool cannot be fully reconstructed for any of the pools. The evidence in Delphi, Nemea, and Jericho⁶⁶ suggests that there were intermediating structures between the source and the pool, namely basins and reservoirs. Their precise function – settling, storage, distribution, pressure compensation – is not clear, however, and certainly depended upon their size and location. For example, the features in Jericho are all far too small in comparison to the pools to have served any kind of significant storage function. Distribution and settling seem more likely functions, the latter in order to keep channels unclogged and clean,

64 Jericho, Pools Complex: walls tapering from 1.50 at the bottom to 1.20 at the top (Netzer 2001a, 73–74 fig. 104); Jericho, pool A(L)255: walls widening from 1.00 at the bottom to 1.20 at the top (Netzer 2001a, 198); Nemea, pool: the lateral walls served as partition walls between the tub rooms and the pool and were built up to a height of about 1.3 m. Aï Khanoum, pool: the relationship between the top level of the walls and the walking level of the

surrounding area is unknown.

65 In Nemea, some artificial terracing was required for the construction of the bath complex: Since the terrain sloped down to the west, it had to be raised about 2 m with debris from the destruction of the early temple of Zeus; Miller 2004, 124; Miller 2015, 302, 324–326.

66 Possibly also Olympia, if the basin k was ever connected with the pool.

rather than the large open-air pools. While there is no evidence for sophisticated metal valve systems similar to those that regulated flows in water pipe systems and baths of the Roman Imperial period, sluice systems could have been installed: this is possible in cases where supply channels branched off from rivers (Delphi) or central aqueducts (Jericho), or some distribution system (basin, reservoir) was constructed between the source and different users (Jericho, Olympia?, Isthmia?, and Nemea?).

- Inlets: The little surviving evidence suggests that inlets were rather small in size and possibly preferably round. So far, not a single rectangular inlet has been found. Special configurations of the inlet, notably water spouts and pipes projecting into the pool that would have provided special visual and acoustic murmuring and rippling effects, cannot be safely reconstructed. With the exception of one terracotta pipe,⁶⁷ no ceramic or metal appliances were found in situ. The *loutron* in Delphi was supplied with 11 decorative water spouts, of which imprints survive on the eastern terrace wall; but for the pool itself, no trace of a spout was found. The pool in Nemea may have been supplied by a lead pipe, but no evidence of any water spout survives and the inlet was not located centrally in the south wall of the pool.⁶⁸ Water spouts would have made incoming water clearly noticeable and possibly even suggested the notion of constantly running water.⁶⁹ Other special water effects like water cascading down over steps or water falls, known from baths of the Roman Imperial period, were certainly lacking in the swimming pools under discussion.
- Drainage, destination of wastewater: Water was certainly (Delphi) or most likely (Olympia, Isthmia) drained to adjacent or nearby rivers. In Aï Khanoum, water seems to have seeped away into the ground at an unknown speed. In contrast, wastewater from the pools in Jericho was obviously reused for the irrigation of the gardens of the palace and agricultural fields of the royal estate. Similarly, wastewater from the pool in Nemea may have fed a nearby reservoir used for supplying horses.
- Outlet, drainage channel: The size of the outlet holes and drainage channels is potentially important for calculating the flow of water. The known outlet holes (Isthmia, Delphi, and Nemea) are small, with diameters of 0.12 to 0.16 m. The drainage channels of three pools were significantly larger, however, with widths of about 0.5 m and depths of about 0.7 m (Olympia, Isthmia, and Delphi). In contrast, the

67 Jericho, Pool A(C)94; Netzer 2001a, 57.

68 While there is evidence that the outlet holes of the tubs were lined with lead, no traces of water spouts survive (Miller 1992, 207 n. 598; 213 n. 605).

69 For the multifaceted connotations of water spouts that splashed water permanently into pools of Roman Imperial baths, Garbrecht and Manderscheid 1994, 71.

small pool and the flanking tub rooms in Nemea, as well as the pools in Jericho, were drained with remarkably small and shallow channels.

Jannoray assumed that the outlet in Delphi was small in order to prevent water from draining too fast and to maintain a constant level of presumably permanently running water in the pool. This does not explain, however, the significant size of drainage channels and the possible double drainage system in Isthmia. Most relevant for granting constant levels of running water is the close correlation between the size of the inlet and that of the outlet. These seem to roughly match in Nemea and in some examples in Jericho, but cannot be assessed for the other pools.

The position of drainage outlets differs significantly, with a preference for the bottom in most sites (Olympia, Isthmia, Delphi, and Nemea) and the unusual location at the top in the pools of Jericho. Since both positions would have granted a continuous flow through of water with matching inlets and outlets, the main difference regards maintenance and the quality of the water. Pools with drainage at the bottom could be conveniently emptied and cleaned, whereas the pools in Jericho would have required emptying by hand, which is hardly feasible for pools with fillings of up to 820 000 liters of water. Providing inlets and outlets at different levels may have facilitated complete, efficient exchange of the water. Modern swimming pools, in which water is circulated and cleaned with the help of electrical pumps, are commonly built with inlets at the top and the main drain at the bottom in order to grant complete circulation and filtering of the water. While in these pools the pump sucks in the water, in the ancient pools the floors needed to slope consistently to the point of the outlet. Such a continuously sloping floor is indeed evidenced by the pools in Olympia, Nemea, and Delphi, and must also have been present in the pool of Isthmia.

- Quantity and quality of water: The crucial question of whether water was constantly running through the pools, day and night and in all seasons alike, cannot be safely answered for any of the pools. The availability of water may have changed in different seasons, and none of the pools are located in a climate where swimming in cold water would have been particularly agreeable year-round.⁷⁰ Constantly running water is neither compelling nor excluded for any of the pools, with the possible exception of the example in Aï Khanoum, whose ‘outlet’ was possibly not blocked, but the inlets and outlets, supply and drainage, could have been blocked in all cases,

70 Note, however, that the Hasmonean Palaces at Jericho are commonly identified as winter palaces. Aristobulos III was murdered in one of the pools in 36 or 35 BC, shortly after Sukkot, the Feast of Taberna-

cles celebrated between the end of September and the end of October. The nature of this place, however, was hotter than usual (Flavius Josephus, *Jewish Antiquities* 15.3.3).

even if no evidence survives of the practice. None of the pools provided an outlet at the bottom and an overflow outlet higher up in the wall, which, according to Günther Garbrecht and Hubertus Manderscheid, would have clearly suggested permanently running water.⁷¹

The quality of water must have depended upon exchange rates. Furthermore, all open-air pools (all except for the pool in Nemea) were also filled with rain water, which was most relevant in the rainy winter months, and were susceptible to flooding, evaporation, and pollution. While the areas around the pools seem, in general, to have been paved, it is unclear whether pavements were laid out in such a way that dirty run-off water would not have flown into the pools. Some pools had decorative curbed borders (Isthmia and Delphi), but with the curb inside the pool; thus, the borders were not necessarily raised above the level of the paved areas in order to prevent the contamination of the pool water.

- Patronage: All pools were ambitious costly enterprises, in terms of construction, operation, and maintenance. Differences in water management, particularly with a view to the water supply may reflect certain technological developments between the 4th and 1st centuries BC, but also, if not primarily, reflect the interests and socio-economic power of their patrons. The largest pool of the examples discussed here was built in the palace complex of Aï Khanoum, which is known for its impressive monumental building projects and corresponding royal pretensions; even if this never served as swimming pool, but was a watering horses of the royal stables,⁷² it would still have been an awe-inspiring water installation. A similar, if not even more daring conspicuous consumption of water can be reconstructed for the palaces of the Hasmoneans, which transported water from considerable distances to feed its many pools in an arid climate. Impressive water works were regularly praised as a hallmark and major achievement of powerful rulers in ancient literature. The range of works is broad, but large reservoirs and pools played a particularly important role. For example, the Emmenides in Agrigento were intimately connected with an artificially made *kolybethra* that was built in the city after the victory of Himera in 480 BC, and that has been identified as a public reservoir for water supply and various pleasures.⁷³ Another impressive case is the immense artificial basin that the emperor Augustus built in 2 BC on the right side of the Tiber

71 Garbrecht and Manderscheid 1994, 72. – A hole in the third step of the pool in Delphi is identified as a late addition, and not as an original overflow drainage hole; Jannoray 1953, 62 n. 2.

72 See above, n. 46. – The ‘idiosyncrasies’ of this pool in comparison with the other pools discussed here

challenges indeed its identification as a purpose-built swimming pool.

73 Bouffier 2000: with a perimeter of 12501.250 m and a depth of 9 m this reservoir had a capacity of ca. 12 000 m³ or 12 000 000 liters.

River in Rome for a Naumachia, the spectacle of a sea battle; this basin was supplied by its own aqueduct and served to demonstrate Roman sea power and engineering skills.⁷⁴ The swimming pools of the royal families in Ai Khanoum and Jericho can certainly be counted among the monumental hydraulic masterworks of powerful rulers.

The Patrons and the significance of the other pools discussed here are more difficult to assess, but it is certainly not by chance that they adorned the major Panhellenic sanctuaries. The pools in Olympia and Isthmia were the earliest of the examples discussed here, and may well have served as prominent models and benchmarks. In Delphi, the *gymnasion* and its swimming pool were included in accounts of the Amphictyonic League from the mid-3rd century BC, which enumerated expenses for preparing the important festival of the Pythia. While the Amphictyonic League that controlled the sanctuary of Apollo may not necessarily have been responsible for constructing the swimming pool, they were at least interested in granting its proper functionality for Apollo's main festival.⁷⁵ Thus, one may conclude that swimming pools as an extravagant novelty and technological masterpiece conveyed the importance and prestige of the sanctuaries, no less than those in royal palaces.

Most of the pools discussed here were no longer used by the end of the 1st century BC.⁷⁶ While the royal pools went out of use when the palaces were destroyed, abandonment of the sanctuary pools (esp. Olympia and Isthmia) may have been motivated by challenges of water management, as well as the changing fashions of bathing culture. The idea of swimming pools did not die with these pools, however, instead, cold water pools of different sizes became an integral part of public bath buildings from the 1st century AD onwards, when water management could be efficiently, reliably, and abundantly provided via aqueducts. This is vividly illustrated by the swimming pool in Delphi: this was the only one of the examples discussed here that was obviously used continuously until late antiquity, and it only seems to have survived because it could

74 Sueton, *Augustus* 23; Cariou 2009; Baltrusch 2016: this reservoir had an extension of 1800 × 1200 Roman feet, ca. 533 × 355 m, thus a perimeter of 1776 m, whereas the depth is not known.

75 Pouilloux 1977; the nature of the works (repairs, cleaning and the like) performed for the pool is unknown, however, because the inscribed *stèle* is broken right at the point where the *kolymbethra* is mentioned.

76 The pool in Isthmia was abandoned in 146 BC, but probably reused from AD 50 until the Hadrianic period, when it was replaced by a Roman-style bath building. For the pool in Olympia, an aban-

donment around 100 BC is commonly identified, but without conclusive evidence; later abandonment cannot be excluded, but the pool was replaced by AD 100 by a Roman-style bath building. The pool in Nemea was most likely abandoned when the sanctuary declined after 270 BC. The pool of Ai Khanoum was abandoned when the city and palace were destroyed in about 145 BC. The pools in Jericho were only partially reused after an earthquake in 31 BC in the palaces of Herod the Great, but Herod's palaces were, in turn, destroyed by an earthquake in AD 48, at the latest.

conveniently be integrated into a new fashionable bath building in the Roman Imperial period, now serving as the canonical frigidarium pool. This smooth transition was certainly facilitated, if not inspired by, the well-designed water management of this pool.⁷⁷ In contrast, the much larger pools in Olympia and Isthmia were completely overbuilt with modern bath buildings in the same period.

77 The bath complex of the Roman Imperial period is barely discussed by Jannoray 1953, 78–79, who assumed, however, that it was supplied in a similar

way as the *loutron* of the 3rd century BC, by channels coming from the Castilian Ravine.

Bibliography

Auberger 1996

Jannick Auberger. "Quand la nage devient natation..." *Latomus* 55 (1996), 48–62.

Avgerinou 2015

Panagiota Avgerinou. "The Water Management in Ancient Megara." Power Point Presentation. 2015. URL: https://www.academia.edu/6046045/Water_management (visited on 23/05/2018).

Baltrusch 2016

Ernst Baltrusch. "„Hier war doch eben noch Land“ – Nauchmachien in Rom". In *Seemacht, Seeherrschaft und die Antike*. Ed. by E. Baltrusch, H. Kopp, and C. Wendt. Stuttgart: Steiner, 2016, 289–302.

Bernard 1981

Paul Bernard. "Problèmes d'histoire coloniale grecque à travers l'urbanisme d'une cite hellénistique d'Asie Centrale". In *150 Jahre Deutsches Archäologisches Institut. 1829–1979*. Mainz: Philipp von Zabern, 1981, 108–120.

Bouffier 2000

Sophie Bouffier. "Quelles fonctions pour la kolymbethra d'Agrigente?" In *Cura aquarum in Sicilia*. Ed. by G. C.M. Jansen. Babesch Suppl. 6. Leiden: Stichting Babesch, 2000, 37–43.

Broneer 1973

Oscar Broneer. *Topography and Architecture*. Isthmia II. Princeton: American School of Classical Studies at Athens, 1973.

Cariou 2009

Gérald Cariou. *La naumachie: Morituri te salutant*. Paris: PUPS, 2009.

Chrysostomou 1996

Panagiotis Chrysostomou. "To anaktoro tes Pellas". *To archaiologiko ergo stē Makedonia kai stē Thrakē* 10 (1996), 105–142.

Elitzur 2008

Yoel Elitzur. "The Siloam Pool – 'Solomon's Pool' – Was a Swimming Pool". *Palestine Exploration Quarterly* 140.1 (2008), 17–25.

Francfort et al. 2014

Henri-Paul Francfort, Frantz Grenet, Guy Lecuyot, Bertille Lyonnet, Laurianne Martinez Sève, and Claude Rapin. *Il y a 50 ans... la découverte d'Ai Khanoum. 1964–1978, fouilles de la Délégation archéologique française en Afghanistan (DAFA)*. Paris: Boccard, 2014.

Frey and Gregory 2016

Jon M. Frey and Timothy Gregory. "Old Excavations, New Interpretations. The 2008–2013 Seasons of the Ohio State University Excavations at Isthmia". *Hesperia* 85 (2016), 437–490.

Garbrecht and Manderscheid 1994

Günther Garbrecht and Hubertus Manderscheid. *Die Wasserbewirtschaftung römischer Thermen. Archäologische und hydrotechnische Untersuchungen. Band A. Forschungsbericht*. Leichtweiß-Institut für Wasserbau der Technischen Universität Braunschweig, Mitteilungen 118 (A). Braunschweig: Leichtweiß-Institut, 1994.

Garbrecht and Netzer 1991

Günther Garbrecht and Ehud Netzer. *Wasserversorgung des geschichtlichen Jericho und seiner königlichen Anlagen*. Leichtweiß-Institut für Wasserbau der Technischen Universität Braunschweig, Mitteilungen 115. Braunschweig: Leichtweiß-Institut, 1991.

Ginouvès 1962

René Ginouvès. *Balaneutikè: recherches sur le bain dans l'antiquité grecque*. Bibliothèque des Écoles Françaises d'Athènes et de Rome 200. Paris: Boccard, 1962.

Gregory 1993

Timothy Gregory. *The Hexamilion and the Fortress*. Isthmia V. Princeton: American School of Classical Studies at Athens, 1993.

Gregory 1995

Timothy Gregory. "The Roman Bath at Isthmia: Preliminary Report 1972–1992". *Hesperia* 64 (1995), 279–313.

Handy 2008

Markus Handy. "Schwimmen bei den Römern". In *Antike Lebenswelten. Konstanz – Wandel – Wirkungsmacht. Festschrift für Ingomar Weiler zum 70. Geburtstag*. Ed. by P. Mauritsch, W. Petermandl, R. Rollinger, and Christoph Ulf. Wiesbaden: Harrassowitz, 2008, 101–111.

Herrmann et al. 2013

Klaus Herrmann, Stefan Hecht, Bernhard Eitel, and Gerd Schukraft. "Geophysikalische Untersuchungen an der Kladeosmauer". In *XIII. Bericht über die Ausgrabungen in Olympia 2000 bis 2005*. Ed. by H. Kyrieleis. Tübingen and Berlin: Wasmuth, 2013, 397–417.

Hill 1964

Bert Hodge Hill. *The Springs. Peirene, Sacred Spring, Glauke*. Corinth 1.6. Princeton: American School of Classical Studies at Athens, 1964.

Jannoray 1953

Jean Jannoray. *Le gymnase*. Fouilles de Delphes II. Paris: Boccard, 1953.

Jenkins and Megaw 1931–1932

R.J.H. Jenkins and H. Megaw. "Researches at Isthmia". *The Annual of the British School at Athens* 32 (1931–1932), 68–89.

Kienast 1995

Hermann J. Kienast. *Die Wasserleitung des Eupalinos auf Samos*. Samos XIX. Bonn: Habelt, 1995.

Knauss 2004

Jost Knauss. "Herakles in Olympia". In *Antikes Olympia: Ausgrabungen, Mythologie, Alltag der Spiele, Technologie*. Ed. by J. Knauss. Wertheim, Oberbayern: Verein zur Förderung der Aufarbeitung der Hellenischen Geschichte e. V., 2004, 41–72.

Kunze and Schleif 1944

Emil Kunze and Hans Schleif. *IV. Bericht über die Ausgrabungen in Olympia*. Berlin: De Gruyter, 1944.

Kyrieleis and Herrmann 2003

Helmut Kyrieleis and Klaus Herrmann. "Bericht über die Arbeiten in Olympia in den Jahren 1982 bis 1999". In *XII. Bericht über die Ausgrabungen in Olympia 1982 bis 1999*. Ed. by H. Kyrieleis. Berlin: De Gruyter, 2003, 1–65.

Kyrieleis and Herrmann 2013

Helmut Kyrieleis and Klaus Herrmann. "Bericht über die Arbeiten in Olympia in den Jahren 2000 bis 2005". In *XIII. Bericht über die Ausgrabungen in Olympia 2000 bis 2005*. Ed. by H. Kyrieleis. Tübingen and Berlin: Wasmuth, 2013, 1–50.

Landon 2003

Mark E. Landon. "Beyond Peirene. Toward a Broader View of Corinthian Water Supply". In *Corinth, the Centenary 1896–1996*. Ed. by C. K. Williams II and N. Bookidis. Princeton: American School of Classical Studies at Athens, 2003, 43–62.

Leriche 1986

Pierre Leriche. *Les remparts e les monuments associés*. Fouilles d'Aï Khanoum V. Paris: Boccard, 1986.

Mallwitz 1958

Alfred Mallwitz. "Das Gebiet südlich der Bäder am Kladeos". In *VI. Bericht über die Ausgrabungen in Olympia*. Ed. by E. Kunze. Berlin: De Gruyter, 1958, 12–41.

Mallwitz 1981

Alfred Mallwitz. *X. Bericht über die Ausgrabungen in Olympia*. Berlin: De Gruyter, 1981.

Manderscheid 2000

Hubertus Manderscheid. "The Water Management of Greek and Roman Baths". In *Handbook of Ancient Water Technology*. Ed. by Ö. Wikander. Leiden: Brill, 2000, 467–535.

Martinez-Sève 2014

Laurianne Martinez-Sève. "The Spatial Organization of Ai Khanoum, a Greek City in Afghanistan". *American Journal of Archaeology* 118 (2014), 267–283.

Martini 1984

Wolfram Martini. *Das Gymnasium von Samos*. Samos XIV. Bonn: Habelt, 1984.

Matzanas 2012

Christos Matzanas. "Die Kladeos-Ufermauer". In *Mythos Olympia. Kult und Spiele*. Ed. by W.-D. Heilmeyer, N. Kaltsas, H.-J. Gehrke, and S. Hatzigeorgidis. Berlin: Prestel, 2012, 238–239.

Miller 1992

Stephen G. Miller. "The Bath". In *Topographical and Architectural Studies: the Sacred Square, the Xenon, and the Bath*. Ed. by D. E. Birge, L. H. Kraynak, and S. G. Miller. Nemea I. Berkeley, Los Angeles and Oxford: University of California Press, 1992, 188–261.

Miller 2004

Stephen G. Miller. *Nemea. A Guide to the Site and Museum*. Athens: Archaeological Receipts Fund Directorate of Publications, 2004.

Miller 2015

Stephen G. Miller. "Excavations at Nemea, 1997–2001". *Hesperia* 84 (2015), 277–353.

Netzer 1986

Ehud Netzer. "The Swimming Pools of the Hasmonean Period at Jericho". *Leichtweis-Institut für Wasserbau der Technischen Universität Braunschweig Mitteilungen* 89 (1986), 1–12.

Netzer 2001a

Ehud Netzer. *Hasmonean and Herodian Palaces at Jericho. Final Reports of the 1973–1987 Excavations*. Vol. I: Stratigraphy and Architecture. Jerusalem: Israel Exploration Society, 2001.

Netzer 2001b

Ehud Netzer. *The Palaces of the Hasmonians and Herod the Great*. Mainz: Philipp von Zabern, 2001.

Pentazos and Trouki 1994

Évangélos Pentazos and Évangéλια Trouki. "Delphes. Gymnase". *Bulletin de correspondance hellénique* 118 (1994), 428–434.

Pouilloux 1977

Jean Pouilloux. "Travaux à Delphes à l'occasion des Pythia". In *Études delphiques*. Bulletin de correspondance hellénique Supplement IV. Athens: École française d'Athènes, 1977, 103–123.

Regev 2013

Eyal Regev. *The Hasmonians. Ideology, Archaeology, Identity*. Göttingen: Vandenhoeck & Ruprecht, 2013.

Reinhard 2005

Jayne Huntington Reinhard. *The Roman Bath at Isthmia: Decoration, Cult and Herodes Atticus*. Unpubl. PhD dissertation. Minneapolis: University of Minnesota Press, 2005.

Robinson 2011

Betsy Ann Robinson. *Histories of Peirene. A Corinthian Fountain in Three Millennia*. Princeton: American School of Classical Studies at Athens, 2011.

Schleif 1943

Hans Schleif. *Die neuen Ausgrabungen in Olympia und ihre bisherigen Ergebnisse für die antike Bau-forschung*. Berlin: Der Akademische Kulturaustausch und die Universität Berlin, 1943.

Stacey 2006

David Stacey. "Hedonists or Pragmatic Agriculturalists? Reassessing Hasmonean Jericho". *Levant. The Journal of the Council for British Research in the Levant* 38 (2006), 191–202.

Trümper 2017

Monika Trümper. "Greek Swimming Pools: Case-study Olympia". In *Cura aquarum in Greece*. Ed. by A. Androvitsanea and H. Fahlbusch. Clausthal Zellerfeld: Deutsche Wasserhistorische Gesellschaft, 2017, 215–249.

Veuve 1987

Serge Veuve. *Le gymnase*. Fouilles d'Ai Khanoum VI. Paris: Boccard, 1987.

Wacker 1996

Christian Wacker. *Das Gymnasion in Olympia*. Würzburger Forschungen zur Altertumskunde 2. Würzburg: Ergon-Verlag, 1996.

Wiseman 1972

James Wiseman. "The Gymnasium Area at Corinth 1969–1970". *Hesperia* 41 (1972), 1–42.

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1953, pl. II. 13 M. Trümper after Jannoray 1953, pl. III. 14 Jannoray 1953, pl. VI. 15 Veuve 1987, pl. I. 16 M. Trümper after Veuve 1987, pl. III. 17 Veuve 1987, pl. IV. 18 M. Trümper after Netzer 2001a, 6 fig. 8. 19 M. Trümper after Netzer 2001a, pl. 13. 20 Netzer 2001b, 93 plan 17. 21 Netzer 2001b, 96 plan 19. 22 Netzer 2001b, 7 plan 20.

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HYDROSYRA Project. Some Reflections about the Ancient Aqueduct of Galermi (Syracuse, Italy)

Summary

Since 2012, the Centre Camille Jullian team carries out an interdisciplinary study of the aqueduct Galermi, architectural work and hydraulic engineering of about 30 km long. This aqueduct, built between the 5th century BC and the Roman Empire, first supplied drinking water to Greek and/or Roman Syracuse. In the 16th–17th centuries, partial transformations have been done and changed the function of the channel, with the installation of flour mills. In the 19th century, the new Italian state gradually expropriated immediate neighbors who exploited abusively the aqueduct. It was then devoted only to irrigate the Syracusan territory according to a system of concessions that has almost remained unchanged since the 19th century. The paper will present this program and the last results that the team obtained in the last two years, particularly about intakes of water and underground galleries, and which chronology can be proposed.

Keywords: Aqueduct; Greek and Roman Antiquity; drinking water; Sicily

Seit 2012 führt das Zentrum von Camille-Jullian eine interdisziplinäre Studie zum Galermi-Aquädukt, seiner Architektur und hydraulischen Technik auf ungefähr 30 km Länge durch. Dieses Aquädukt, gebaut zwischen dem 5. Jahrhundert v. Chr. und dem römischen Reich, lieferte zunächst Trinkwasser zum griechischen bzw. römischen Syrakus. Vom 16. bis 17. Jahrhundert sind partielle Umwandlungen getätigt worden, die die Funktion des Kanals durch die Inbetriebnahme von Getreidemühlen änderten. Im 19. Jahrhundert dann eignete der neue italienische Staat stufenweise Anrainer, die das Aquädukt-Wasser illegal angezapft hatten. Das Wasser kam somit vollständig dem syrakusischen Gebiet zu und die entstandenen Konzessionen behalten bis heute ihre Gültigkeit. Der Aufsatz wird diese Geschichte und neueste Forschungen präsentieren, die sich in den letzten zwei Jahren besonders mit der Aufnahme unterirdischer Wassergalerien und der Erstellung einer Chronologie beschäftigt haben.

Keywords: Aquädukt; griechische und römische Antike; Trinkwasser; Sizilien

This work has been produced within the framework of the Unit of Excellence LabexMed – Social Sciences and Humanities at the heart of multidisciplinary research for the Mediterranean – which holds the following reference 10-LABX-0090. This work has benefited from a state grant administered by the Agence Nationale de la Recherche for the project Investissements d’Avenir A*MIDEX which holds the reference n° ANR-11-IDEX-0001-02. S. Bouffier is the scientific and administrative chief of the project, with the collaboration of Vincent Dumas, Marcello Turci, Philippe Lenhardt, Jean-Louis Paillet, Simona Laudani, Maria Trefilietti, Julien Curie, and Vincent Ollivier. Logistical and administrative support are provided by Genio Civile and Soprintendenza ai Beni Culturali e Ambientali di Siracusa.

Since 2012, the Centre Camille Jullian (Aix-Marseille University) has carried out an interdisciplinary study of the Galermi Aqueduct, a work of hydraulic engineering about 30 km long that is situated in the Province of Syracuse (Fig. 1).

This aqueduct, which was built between the 5th century BC and the Roman Empire, supplied drinking water to Greek and/or Roman Syracuse. In the 16th–17th centuries, partial transformations of the aqueduct were made, including the creation of new water intakes and the installation of flour mills, which changed the function of the aqueduct. In the 19th century, the Syracusan Senate recovered the control of the aqueduct from the aristocratic Gaetani-Specchi family; the new Italian State then gradually expropriated the immediate neighbors who had exploited the aqueduct abusively. They then devoted the aqueduct to irrigating the Syracusan territory according to a system of concessions that has remained almost unchanged since then (Fig. 2).

This shift promoted the implementation of an agrarian economy and a specific landscape: as it runs through an arid area, it has created a green zone of citrus fruits and plantations all along its sides because tanks and pipes have been installed on its course. From 1924 to 1967, it has also been used to operate one of the first hydroelectric firms in the region: Salonia e Carpenteri firm. Like other investors, these entrepreneurs bought land in 1923 to benefit from the close aqueduct and diverted its waters into a channel to run an electrical turbine. Technical responsibility for the aqueduct was given to Genio Civile under the supervision of the Syracuse Soprintendenza ai Beni Culturali. The aqueduct is still the center of the political and economic management of a Mediterranean country and the heart of debates about Sicilian and Mediterranean water policies. Comparative studies of other similar water transportation systems in the cities of Agrigento and Palermo, and in the countries of Spain and Portugal, highlight shifts in traditional practices. The project HYDROSYRA intends to explore the various facets of the aqueduct to

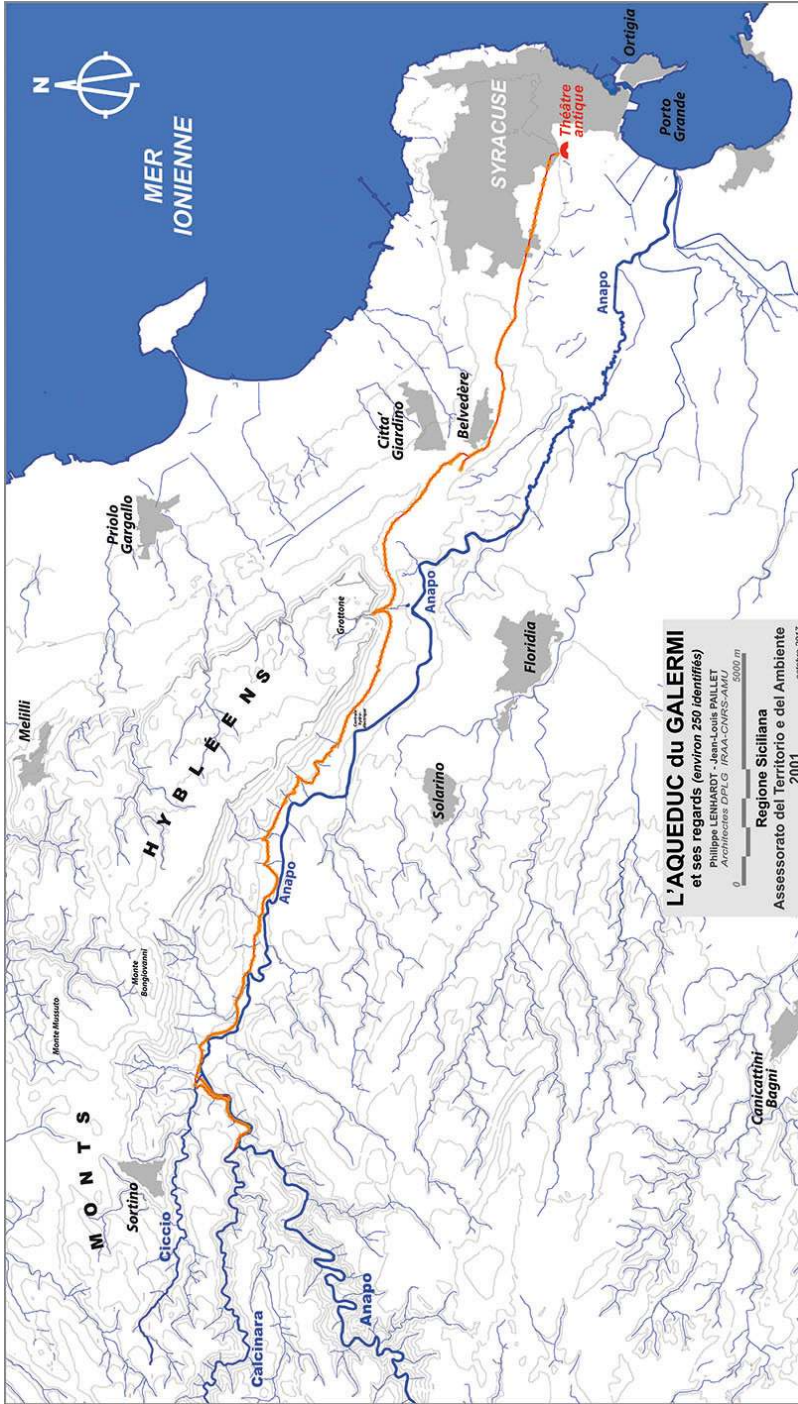


Fig. 1 Location of the Galermi Aqueduct (in orange colour on the map)



Fig. 2 The irrigation system: Fig. 2a: on the left, private reservoir for storing irrigation water. Fig. 2b on the right, Regulatory tank of irrigation, under the supervision of Genio Civile.

allow us to understand the control strategies implemented and the management of water resources of this territory in Sicily from a case study perspective. Inherently interdisciplinary, the project draws upon the expertise of several humanities and social science disciplines: geomorphological and paleo-environmentalism, archaeology, architecture, history, and anthropology.

After providing a general presentation of the aqueduct, this paper focuses on the knowledge that the team obtained regarding this ancient monument after field missions conducted between 2012 and 2016. We have been able to highlight the digging strategies of the engineers and the hydraulic technology in sectors that have been the least affected by recent repairs. Now it is possible to propose some dating to the different stages of use of the channel and underline its specificity.

I State of the art

I.1 Chronology of the aqueduct

One of the main problems being addressed is that the chronology of the aqueduct is challenging to determine. Actually, like all the hydraulic structures, it has been regularly cleaned from Antiquity to nowadays, and the sediments and traces of human frequentation and occupation have been removed during the cleaning phases; so it is difficult to accurately identify and date the different interventions.

For a long time, historiography knew several aqueducts in Syracuse and discussed

their chronology and sponsor¹. About the Galermi Aqueduct, the problem is more complex because the aqueduct has been used for more than 2000 years. The first unknown date is when the Syracusans excavated and created the structure, with scholars holding conflicting views. The other ones concern the different repairs of the monument. According to Julius Schubring, a German historian of the 19th century who wrote a number of papers about water management in the Sikeliot cities, the Galermi Aqueduct could have been established during two periods: before the tyrant Gelon, that is to say before 485 BC, or during the autocratic rule of Dionysius the Elder, between 405 and 367.² Francesco Saverio Cavallari and Adolf Holm set up the first scientific plans of the Syracusan aqueducts in 1883. They proposed to date these aqueducts before the Sicilian expedition in 415 BC.³ In Sophie Collin Bouffier's PhD about water in Greek Sicily⁴ and several papers she wrote,⁵ she discussed several dates of creation for the aqueduct: the contracting authority could be Dionysius the Elder between 405 and 367, Timoleon between 344 and 337, or Hiero the Second between 289 and 216. Collin Bouffier took no position on the dating, based upon the poverty of information available at the time her works were written. Some quick architectural studies have been carried out that have not resulted in anything novel in regard to the chronology of the aqueducts.⁶ Roger A. Wilson, at the congress of the Frontinus Gesellschaft *Cura aquarum in Sicily* in 1998, proposed dating the aqueducts to the Roman period.⁷ The latest investigations continue to highlight the questions surrounding the dating of the aqueducts.⁸

1.2 Ancient writers

The Syracusan aqueducts have been known since the 5th century BC, when Thucydides evoked the Athenian expedition in 415–413; he noted that the Athenians cut underground pipes that were established to provide the city with drinking water.⁹ Later texts

1 Collin Bouffier 2001.

2 Schubring 1865, 625–28.

3 Cavallari and Holm 1883, 106, note 1.

4 Collin Bouffier 1992.

5 Collin Bouffier 1987, 278–280; Collin Bouffier 2001; Collin Bouffier 2009, 73–74.

6 Crouch 1993.

7 Wilson 2000.

8 Sophie Bouffier, Julien Curie, Christophe Petit, and Cees Passchier. "Laqueduc grec du Galermi à Syracuse, Sicile." In *Les dépôts carbonatés en contexte archéologique. Une mémoire de la gestion de l'eau, Journées d'études géoarchéologiques 18–19 septembre 2014, Maison Archéologie et Ethnologie – René Ginouvès*. Ed. by J. Curie, C. Petit, and C. Passchier. Nan-

terre: Maison Archéologie et Ethnologie – René Ginouvès, forthcoming. Sophie Bouffier, Vincent Dumas, Philippe Lenhardt, and Jean-Louis Paillet. "Nouvelles recherches sur l'aqueduc du Galermi." In *Politiques et techniques hydrauliques en Méditerranée préromaine, HYDROMED Symposium II, Università di Palermo, décembre 2015*. Ed. by S. Bouffier, O. Belvedere, and S. Vassallo. Aix-en-Provence: PUP, forthcomingb.

9 Thuc. *The Peloponnesian War*, 6.100: "Meanwhile the Athenians destroyed their pipes which ran underground into the city and supplied it with drinking water." ("οἱ δὲ Ἀθηναῖοι τοὺς τε ὀχετοὺς αὐτῶν, οἱ ἐς τὴν πόλιν ὑπονομηδὸν ποτοῦ ὕδατος ἡγμένοι ἦσαν, διέφθειραν.") <http://www.perseus.tufts.edu/>

by Servius (from the 4th century AD) seem to refer to an aqueduct of the city, when he talks about a ditch that was dug by prisoners of war and filled with the water of a river. He noted that these prisoners were Athenian and Carthaginian captives after a defeat which is not dated.¹⁰ This ditch has been interpreted by Schubring as one of the Syracusan aqueducts: according to him, Servius was confused regarding the Athenian and Carthaginian prisoners, and these aqueducts had been dug after the battle of Himera in 480 BC, as was the case in Agrigento.¹¹

If we look at the historical context, aqueducts existed in several major Greek cities, in Sicily in Agrigento, as noted in Diodorus Siculus, and in Samos,¹² Athens,¹³ Corinth,¹⁴ and Megara,¹⁵ identified from archaeological ruins.¹⁶ The major cities of the Aegean world were equipped with water supply installations, fountains, and pipes of drinking water¹⁷ from the beginning of the 6th century BC (maybe even from the 7th century BC) until the Hellenistic period. Some of them were established under tyrannical regimes that, according to Aristotle,¹⁸ were intended to divert the people from their aspirations of freedom. In actuality, though, most of the Greek aqueducts were designed in cities that were experiencing an economic boom, during times that corresponded to development of the urban centers that improved the living conditions of the populations, in

hopper/text?doc=Thuc.+6.100&fromdoc=Perseus%3Atext%3A1999.01.0199 (visited on 25/05/2018).

- 10 Serv. *Aen.* 3.500: "At that time, the Syracusans, victors of the Athenians, took a huge number of prisoners at Syracuse, and made them increase the defence of the city by breaking the mountains. Then, as the walls had been extended, they also dug inside the rampart a ditch that was filled with the water of the river to reinforce the city. This ditch, that had been realized thanks to the punishment of the enemy for the damages they caused, they called it Thybris." ("Quodam tempore Syracusani, victores Atheniensium, ceperunt Syracusis ingentem hostium multitudinem et eam caesis montibus fecerunt addere munimenta civitati. Tunc auctis muris etiam fossa intrinsecus facta est, quae flumine admisso repleta munitiorem redderet civitatem. Hanc igitur fossam, per hostium poenam et iniuriam factam, Thybrin vocaverunt"). Serv. *Aen.* 8.330: "The poet called Tiberis Tybris compared with the Syracusan ditch that has been dug near the rampart of the city by Africans and Athenians because of the damages they caused" ("Tiberis Tybrin poetam dixisse ad similitudinem fossae Syracusanae quam fecerunt per iniuriam Afri et Athenienses iuxta civitatis murum.")
- 11 Diod. Sic. *Bibliotheca historica*, 11.25. "Most of them

[the Carthaginian captives] were handed over the state, and it was these men who quarried the stones of which not only the largest temples of the gods were constructed but also the underground conduits were built to lead off the waters from the city: these are so large that their construction is well worth seeing, although it is little thought of since they were built at slight expense. The builder in charge of these works, who bore the name of Phaeax, brought it about that, because of the fame of the construction, the underground conduits got the name "Phaeaces" from him. The Acragantini also built an expensive kolumbethra, seven stades in circumference and twenty cubits deep", 13.82.

- 12 Kienast 1995.
 13 Camp 1980; Tölle-Kastenbein 1994.
 14 Hill 1964; Robinson 2011.
 15 Panagiota Avgerinou. "Investigation of the Ancient Underground Aqueduct in Megara: Preliminary Results". In *Politiques et techniques hydrauliques en Méditerranée préromaine, HYDRQMED Symposium II, Università di Palermo, décembre 2015*. Ed. by S. Bouffier, O. Belvedere, and S. Vassallo. Aix-en-Provence: PUP, forthcoming.
 16 Arnone 1952.
 17 Tölle-Kastenbein 1990.
 18 Arist. *Po.* 1313a–b.

particular, improving public health. In Sicily, the victory of the tyrants, Gelon of Syracuse and Theron of Agrigento, over the Carthaginians at Himera in 480 BC fits into an era of urban upheaval that led them to the realization of large-scale hydraulic works, like aqueducts and the basin of Agrigento (the famous *kolymbethra*), as explained by the historian Diodorus Siculus.¹⁹

1.3 Fazello and other modern scholars

Since the 16th century, scholars and travelers in Sicily have confirmed the existence of aqueducts that they have described in a way that is more or less succinct and realistic. The most complete and detailed list of Syracusan works was been compiled by Tomaso Fazello in 1558. His work, written first in Latin (*De rebus siculis, descades duae, nunc primum in lucem editae*. 1st ed. Palermo, 1558) was translated into Italian in 1628.²⁰ It described the aqueducts as follows:

As freshwater of this land was limited, Syracusan people dedicated their ingenuity and financial resources to excavate underground aqueducts, as we do nowadays; these aqueducts were perforated in depth and had the dimensions of a regular-sized man. And so that the water meets no obstacle and can be drawn easily by everybody in town, they excavated a lot of openings in different points, used as wells [...] Nearly twenty milia far from Syracuse westward, there is a big valley, which has a modern little castle named Sortino [...]. From there gushes some huge and abundant spring, which name is Guciuno nowadays; right away it becomes a river which flows some hundred paces and grows thanks to the arrival of two others springs, the one called Argentino, the other Rugio; the first is coming from the left bank and is named after its sands, which seems to be silver; the other one is coming from the right side; below the castle, there is another spring, called Primo, which flows into the other ones. Above Sortino, there is a hill, nowadays called Serramenzano. [...]

At its bottom, south, at the beginning of a valley situated between Pantalica and the city of Serramenzano now destroyed, which was called Herbessos in Antiquity, two other spring gurgle very abundantly: they are commonly called Buttigliarie nowadays, and form immediately a genuine river. From there Syracusan people, for lack of water, were forced to dig an underground channel and bring it up to the city with considerable effort and expense. It is called nowadays channel of 'the beautiful woman.' [...]Then thanks to numerous aqueducts,

19 Collin Bouffier 2000.

20 Fazello 1628, 72–96.

partly consisting in masonry, partly excavated underground, they led a lot of water to the city, nearly 20 milia far away: we can see still now many remains of these aqueducts. Then these channels at the time in which the Athenians were fighting against the Syracusans, were cut off to deprive the besieged of water, so that they should have to surrender because of the lack of water, according to the narrative of Thucydides in the 6th book. And as the channels are cut off, these water discharge in the river Anapo [...]

Theater in Napoli of Syracuse: it was surrounded all around with big walls which have been built in huge cut blocks, and it had, in the part toward Tica, one spring which was flowing from underground channels, very crafty excavated; this spring lost its once name and is called now from Saracen language 'Garelme,' that means in our language, hole of water, and nowadays is called Galermo by linguistic deformation.

His description is an essential starting point for a number of reasons. The first reason is that Fazello listed some monumental waterworks in urban areas, such as those in Trimilia, Garelmo, and Paradiso in the South and Targiuni, Targia, Bosco, and Targeta in the North. According to him, it is not possible to identify their intakes even if most people think that they come from Monte Climiti in the northwest hinterland. Another aqueduct, called 'Bella Femina' came from Sortino and was supplied by two main streams: Buttigliarie (oggi Bottiglieria o Calcinara, because it brings calcite), which is a tributary of the Anapo River, and the Guccio, another tributary of the Anapo River that is today called Ciccio. These rivers arose from karstic springs. The 'Bella Femina' is the aqueduct that is today called Galermi. From there, they created a lot of aqueducts, some built above ground and some completely underground. In the 16th century, these aqueducts could be seen, but that is often no longer the case.

As well as describing the channel, Fazello provided an important indication about its chronology. He visited the channel before 1576, the date of attribution of the monopoly of exploitation of the Marquis Gaetani of Sortino by the Syracusan Senate, and before the earthquake of 1693, before the big transformations that were applied to the Galermi Aqueduct. So his description is likely of the ancient water channel. The technical typology that we know from Fazello is that: an underground channel was dug into the limestone cliff; there was an arched bridge over the Anapo River, which still exists today; and there were several water intakes. Today, we know only the underground channel that was reconstructed and repaired over five centuries.

After Fazello, some local scholars proposed the first archaeological maps of the city²¹

21 Mirabella and Alagona 1613; Capodieci 1813.

and the first inventories of Syracusan monuments²² by repeating each other.

1.4 19th century historians and archaeologists

Among scholars, Schubring wrote the first summary about water management in the Greek city of Syracuse; in his work, he mostly agreed with Fazello.²³ According to him, all Syracusan water pipes came from the Monte Climiti and crossed underneath to the Ortygia Island. He calls the aqueduct of Galermi 'Anapo'. Fazello indicated that the aqueduct had two water intakes, drawing water from the Bottiglieria and the Santa Sofia/Ciccio River, that he called 'Guccio'. Then the aqueduct was completely underground and would have followed the Anapo as it meandered to the Syracusan shelf, where it passed south of Belvedere Village to a site called Buffalaro, where it fed two tanks before arriving into the city just north of the theater. According to him, the structure of the aqueduct cannot be traced after the area of the theater, in the vicinity of Contrada Zappalà, where Hellenistic baths were excavated in 1938.²⁴

A few works discuss Syracusan aqueducts in more precise detail, even if they were not the focus of the work itself; Cavallari and Holm's *Topografia archeologica di Siracusa*²⁵ provides scientific information and topographical maps. From these sources, they calculated that the aqueduct was 29.5 km long with a slope of 0.5%. At what is now the Casa dell'Acqua, the aqueduct split into two channels: one powers the Nymphaeum today and the other goes towards the eastern part of the city. The two authors described the typology of the aqueducts as entirely dug and opencast built, in *opus incertum* or in irregular blocks, and covered with slabs of stones. However, this peculiarity has since been attributed to modern repairs, as the two authors had suspected.

2 New investigations

We distinguish three various phases of the Galermi Aqueduct: the ancient; the modern, from Gaetani times; and the contemporary, after Italian Unity. Our primary mission has been to work to understand the water intakes, the layout, and progression of the aqueduct.

22 For example Logoteta 1788.

23 Schubring 1865.

24 Cultrera 1938, 261–301.

25 Cavallari and Holm 1883; Cavallari 1891.



Fig. 3 The Ciccio niche and water intake.

2.1 The water intakes

Nowadays, as in Fazello's time, the aqueduct's source stems from several places in the Hyblaeen Hills, which are about 30 km from the ancient city of Syracuse, via the tributaries of the Anapo River. There are at least four water intakes, including two that seem likely to be ancient and one that was created in the 19th century. One of the more ancient ones was created in the Ciccio River: it was carved into the limestone and presents a trapezoidal niche that still shows the remains of an inscription that is currently being decrypted. For the moment three Greek letters can be read: ι (iota), ε (epsilon), ω (omega) and maybe a fourth letter δ (delta), which form is certainly ancient, as we can deduct in contrast to another Greek inscription, which has been found in one of the openings and whose typology is clearly byzantine. The niche has been later coated by two coatings: a fresco and a thick mortar (Fig. 3).²⁶

The intake that is furthest from the city of Syracuse is the Bottiglieria; it recovers the water that has been stored in a dam (that seems to have been artificially made) on the Calcinara River (Fig. 4). A modern arrangement partially fills the entrance of the gallery, which prevents us from restoring the original typology. At a point where the stream broadens, before a vertical drop of around 5 m, the river forms a kind of tank (width 9 m and length around 20 m, for a surface 180 m²). Here, something like a dike has been created that blocks the full width of the stream. It is nearly impossible to restore

26 We have highlighted elsewhere that the intake has gone through several transformations. Sophie Bouffier, Vincent Dumas, Philippe Lenhardt, and Jean-Louis Paillet. "Nouvelles recherches sur l'aqueduc du Galermi". In *Politiques et techniques hy-*

drauliques en Méditerranée préromaine, HYDRΩMED Symposium II, Università di Palermo, décembre 2015. Ed. by S. Bouffier, O. Belvedere, and S. Vassallo. Aix-en-Provence: PUR, forthcomingb.



Fig. 4 The Calcinara water intake.

the initial form of the dam because of the limestone deposits that have transformed the site, but there are no other abrupt breaks of slope in the riverbed. It seems that those who constructed this dike exploited the natural slope of the riverbed and accentuated it by digging it deeper, to be ensure that the water would flow into the channel. A forebay opposite the intake of the aqueduct allowed the users to empty the dam in order to divert the water away from the channel. On the top of the dam, there are tracks of some rock-cuttings, which are visible on the map (Fig. 5): in case of overflow, they could be opened or closed and regulate the stream. A core drilling that is planned should help us to understand the configuration of this arrangement.

Actually, there is no comparison between this rudimentary work and sophisticated dams, such as those that we see in Greece from the Bronze Age, where we find the dams of Boedria and Thisbe in Boetia, of Kofini at Argos, Tiryns and Orchomenos, which

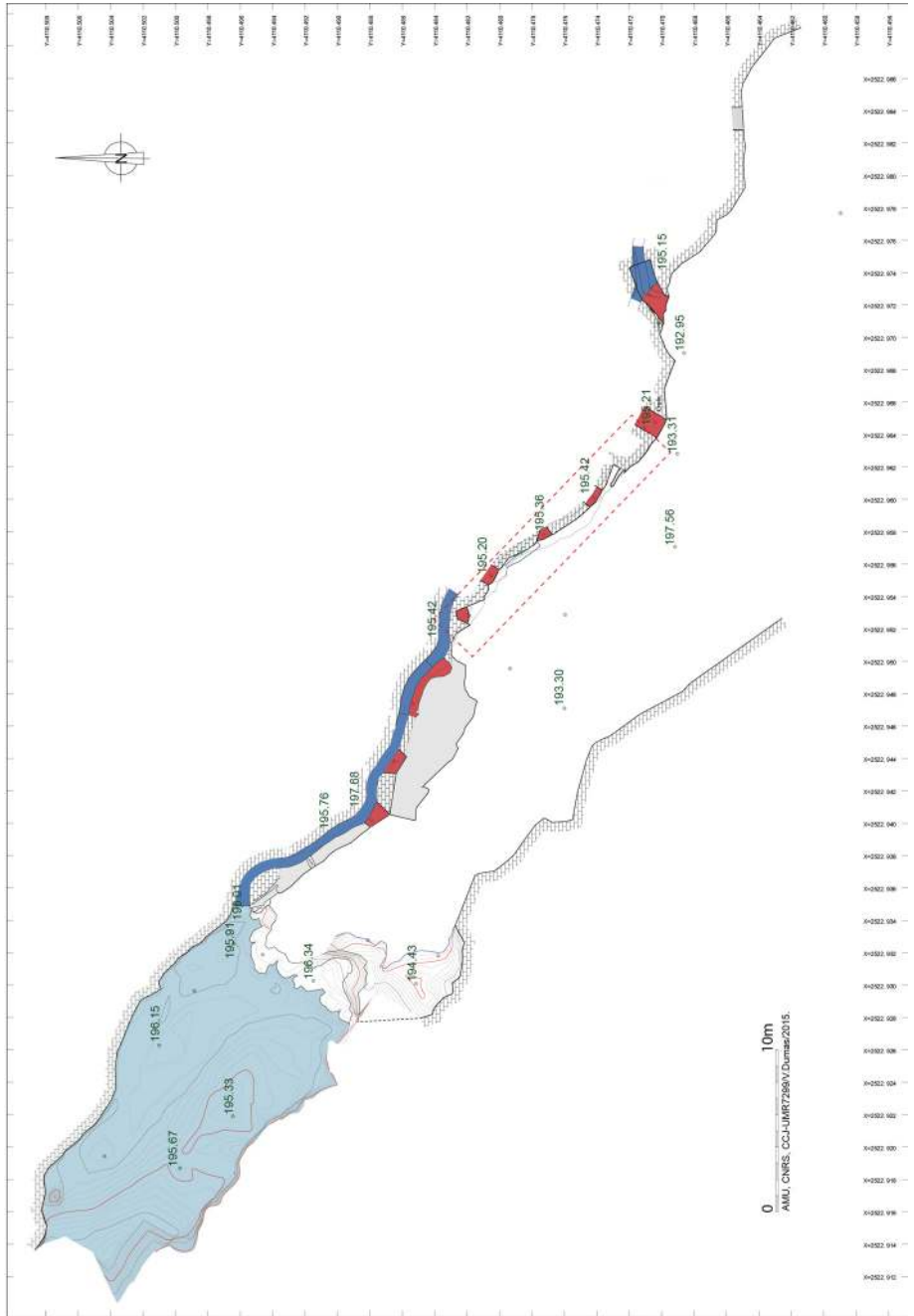


Fig. 5 Plan of the Calcinaia water intake.



Fig. 6 Inscription of the Bottiglieria.

have been created for flood prevention,²⁷ and from Classical times at Delos, with the dam of the Inopos Reservoir.²⁸

When we know the origin of the water, as for the Eupalinos Aqueduct²⁹ and the Naxos Fleri Channels,³⁰ we can see that those who designed these systems utilized water caught in natural springs in a pond or a tank. In Roman times, even if those who constructed the structures rarely alluded to dikes in the construction of aqueducts, these kinds of water arrangement can be found in several of the aqueducts, such as the Glanum Aqueduct in Gaul.³¹ So the Bottiglieria water intake testifies a real mastery of hydraulic techniques, and is one of the rare examples of ancient dikes currently known.

The Bottiglieria water intake has another specificity: just inside the gallery, an inscription of five or six letters and symbols is deeply incised into the left pier (Fig. 6). At the moment, the inscription is difficult to read because of the calcareous deposits that have damaged it. It seems to present a Latin alphabet and further studies should be conducted to understand what was inscribed here more precisely and give us evidence of dating.

At least three other water intakes were established during the life of the structure: one that can be dated to the period following the concession of the waters to the Marquis Gaetani in 1576 (on the Anapo River, 2000 m after the Bottiglieria water intake); one established in 1921, which covered the preceding one because it was damaged by the floods of the Anapo River; and one established after 1953, to increase the capacities of irrigation of the channel that had been dedicated to land exploitation.

27 De Feo et al. 2012, 351–352.

28 Moretti and Fincker 2007.

29 Kienast 1995.

30 <http://www.hydraproject.info/en/> (visited on 27/10/2017) for example, <http://www.hydraproject.info/en/greece-naxos-ancient-flerion-aqueduct-importance13> (visited on 27/10/2017). Lambri-noudakis et al. 2017.

31 Augusta-Boularot and Paillet 1997.



Fig. 7 Track of the Aqueduct in the Hyblaean Mountains.

2.2 The track of the channel

After the Bottigliera water intake, the aqueduct runs along the valley of Calcinara and then along the Anapo River on a cliff that was carved directly into the limestone. It is uncertain if the track contained a clay or metal pipe for receiving the water. The channel adopts a zigzag path that is characteristic of the technique used for its construction (Fig. 7). The channel is 1.4 to 2.0 m in height and has a width of 0.4 to 0.8 m. In some places in the walls, cavities can be observed for the installation of lamps for the maintenance workers. The channel has several horizontal and vertical access shafts that were used for the digging of the channel and then for maintenance; there is no observable regularity of distance between these openings. In the parts near the Bottigliera, the space between these openings can vary from 2 to 13 m. The intervals seem to differ according to the slope of the cliff. The steeper the slope is, the greater the distance between two



Fig. 8 a and b: Some late inscriptions in the walls of the windows, c: Malta cross.

openings is. The width of the horizontal openings also varies from 0.9 to 1.35 m, and the height from 1.4 to 1.7 m. The dimensions of the vertical shafts have changed over history as they have been reused over the centuries. It is possible that those who constructed the channel excavated standard sized vertical shafts, and then the horizontal shafts were opened to extract the earth stemming from the excavation activities.

We also observed inscriptions in some access shafts. These inscriptions included crosses, sometimes oriental crosses, and symbols that remain to be decrypted (Fig. 8 a, c). Are these inscriptions simply signs of human presence and occupation in the times when they were made? Are they the marks of the tunnel and rock workers? We probably cannot assimilate all of them to the same process, as they are typologically and technically different. Some of them are only graffiti. Some refer to the use and transformations of the aqueduct. For example the Malta cross and another single cross have been cut at the point where we have identified a repair of the Gaetani period, in the 16th or 17th century (Fig. 8 a-b). In some Greek aqueducts that have been investigated, Greek letters have been interpreted as marks of the work of a particular mason, maybe in order to claim payment, as in Megara³² and Samos.³³ At the moment, as we do not have investi-

32 Panagiota Avgerinou. "Investigation of the Ancient Underground Aqueduct in Megara: Preliminary Results". In *Politiques et techniques hydrauliques en Méditerranée préromaine*, HYDRQMED Sympo-

sium II, Università di Palermo, décembre 2015. Ed. by S. Bouffier, O. Belvedere, and S. Vassallo. Aix-en-Provence: PUP, forthcoming, 44

33 Kienast 1995, 193-194.

gated a long part of the aqueduct, it is difficult to give an explanation of these marks.

After the Anapo Valley, the aqueduct runs through different geological levels and is entirely underground. The channel is at times carved into the rock and covered by slabs. Sometimes the channel is completely excavated underground, as in Contrada Sinerchia, or excavated in the sedimentary ground, requiring those who constructed it to fit in masonry walls in order to prevent collapse and water damage, which remain threats during the rainy season even today.

This is the part that has undergone the most repairs over time. While we have not studied this part physically yet, we can identify that a lot of work has been done on the track based on the Archives from the 19th century. Beyond that, however, it is difficult to draw any conclusions at this state of our research.

When one travels down into the plain, we observe vertical shafts at more or less regular intervals. The typology of these manholes is not homogeneous and we will reflect to see if it is possible to date them more precisely.

Based upon the points where we were able to make calculations, we found that the slope of the channel is irregular. At the water intake at Bottiglieria, the slope is greater than 7%, while in the Grottone area, it is about 0.02%. No conclusions can be drawn yet though, as the research is still ongoing.

Finally, though today the aqueduct reaches the Nymphaeum of the theater, it was not probably the case in antiquity, which will be the next focus of future study.

3 Some problems

The long life of the aqueduct and the numerous repairs and transformations that have been realized along its course have left testimonies of the technological knowledge of the past, some of which we present below. We will start by looking at the part of the channel that was dug into the Hyblaeon Cliff, where we noticed some anomalies that testify to the digging techniques used there, and we will then conclude with the problem of the siphon.

3.1 Side-by-side Channels

A few meters after the water intake at Bottiglieria, there are two channels that run alongside one another, side-by-side (Fig. 5 and 9): the upper channel, where water is still flowing, and the lower channel that is about 2 m below the upper channel, which has nearly disappeared.

The lower channel, running off the cliff, is 2 m high at the most and 0.5 m wide at



Fig. 9 The side-by-side channels.

its widest. The upper channel, running inside the cliff, has a lower height of 1.5 to 1.7 m and rests at a right angle behind the lower channel. On the external face of the cliff, we have the impression that the channel was closed with blocks, as in the internal face, the wall does not seem to have been dug. How can we explain this anomaly? First, we conceived two possibilities:

- Those who constructed the channel experienced difficulties during the digging and the carvers, who were working from two opposite ends of the channel and working towards one other, mistook the calculation of the slope, with one going too high, compared to the other one. Observations from inside the channel show that the top of the ceiling decreases extremely. Based upon this theory, the change to the higher channel could be the consequence of a quick remodeling.
- The lower gallery was the only original channel, but the channel was eventually covered by mud and dirt from the river during the winter floods, and the water was polluted. The channel could have even been damaged. They then decided to carve another channel at a higher level, where the floods would not reach.

Actually, the last field campaigns allowed us to date the transformation during the Gaetani period, so after the 16th century, thanks to the Malta cross which has been engraved at the starting point of the repair.

3.2 The preexistent chamber

About 12 m after the intake, as the crow flies, the channel crosses a more or less rectangular structure, a kind of room (3,65 m²) which has been carved in the limestone

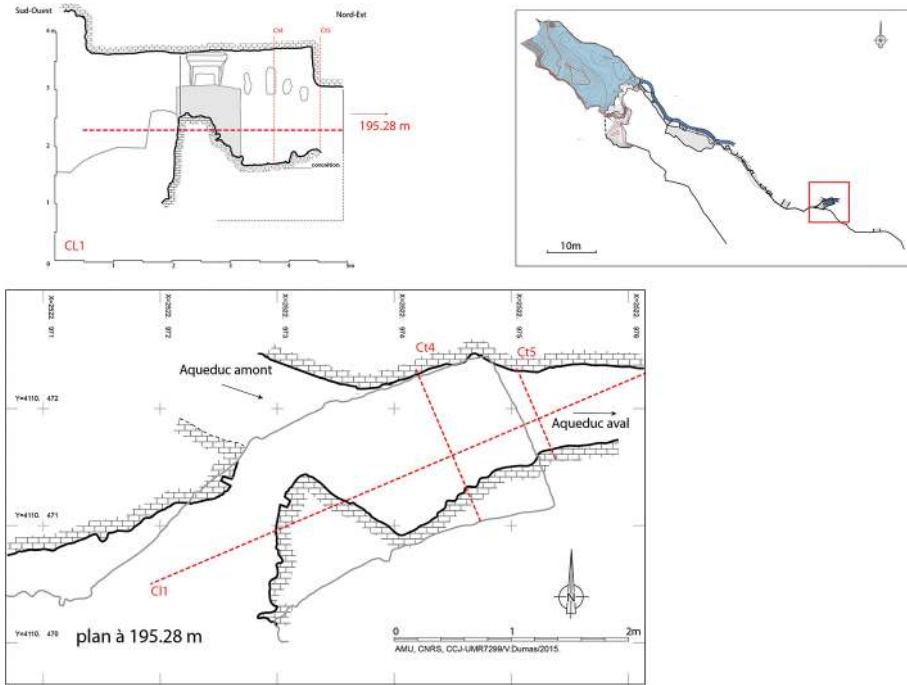


Fig. 10 Plan and elevation of the chamber.

before the aqueduct. Above the door jamb of the channel there is a decorated bas-relief (Fig. 10). It is a frame with a pediment for receiving a pillar *pinax* that would be attached via hinges or hooks (Fig. 11), as can be seen from the holes dug at the middle of the bas-relief.

Can we think of a layout recording a form of consecration of the water channel, as is the case in other water intakes?

This is unlikely, if we consider the location of the relief. Resting about 50 m from the water intake, it is located in a room that contains a bench that has been carved into the passage of the canal. Actually, it appears as though this room has no relation to the aqueduct. In addition to this bas-relief, there are other suspension holes on the other walls of the room, which are more difficult to understand. The pediment is characteristic of the Hellenistic period, and more precisely, at a time period after the 4th century BC. This kind of pediment spread during Roman times, as evidenced by the assumed tomb of Archimedes.³⁴

34 Ciancio 1965.



Fig. 11 The pediment of the chamber where a pillar *pinax* would be attached.

At first sight this structure seemed to be a burial chamber, which was a tradition in nearby Pantalica or Akrai, a sub-colony of Syracuse. Actually it was a tradition in the Bronze Age, no more at the Hellenistic period to which belongs the monument. It is more likely that this chamber is a cave shrine, dedicated to some god or goddess linked to the river, the mountains, or the wild land. No matter its function, it helps provide a clue for dating the channel.

3.3 The question of the siphon

The existence of a siphon would have been a good indicator for the date of the channel, as siphons did not appear in the Mediterranean world before the Hellenistic period. If the Galermi Aqueduct was created by Gelon or some tyrant before the Athenian Expedition in 415 BC, it could not have a siphon.

The channel had to cross several deep thalwegs, particularly the so called Grottone: the aqueduct has to cross a vertical drop of about 25-30 m. We could presume the presence of a siphon; however, the general survey and the speleological exploration have revealed that, in the first section, the channel follows the slope to the bottom of the valley before crossing it under the rock slopes without using a siphon. Two quadrangular manholes punctuate the peaks of the eastern and western slopes of the valley that are symmetrical in placement and similar in terms of their dimensions. Their depth exceeds 20 m and there is no longer water in the channel today, though some shafts that are located before and after this point are full of water. Following a landslide or collapse that we cannot date at the moment, the channel was closed by a wall and a pass-by was installed to permit the channel to cross the valley (Fig. 12).

So exploring this specific part of the aqueduct as much as other parts that present an important slope, we can deduct that there are no siphons in this hydraulic structure.

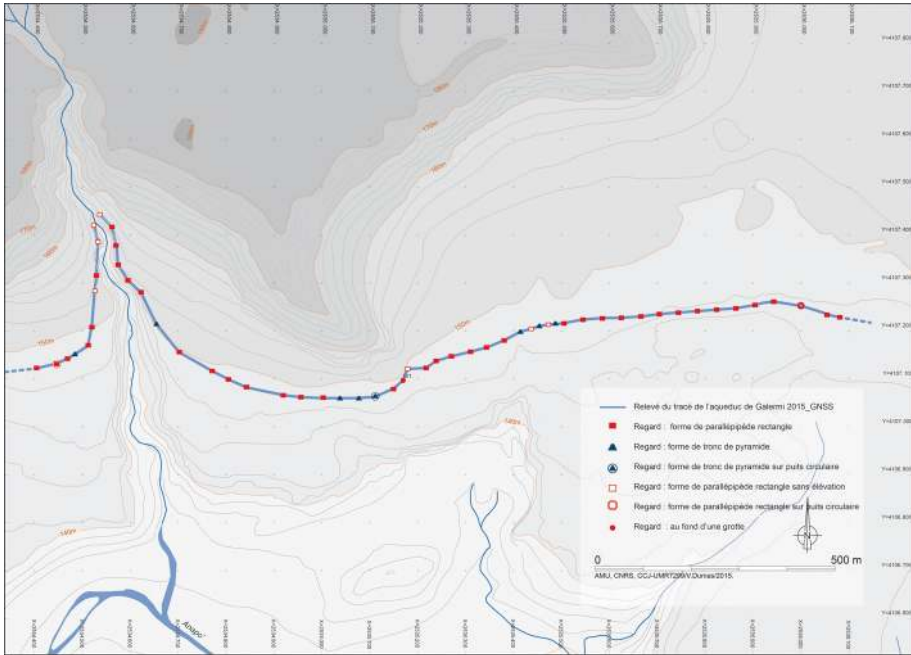


Fig. 12 The crossing of the Grottone Valley.

That evidence is a clue of a high-dating of the monument.

4 Conclusion

To conclude, in this research program, we have already gained some insights that can help us answer the essential question of dating the aqueduct: when was the aqueduct constructed, and by whom? At this point, typology and the apparent lack of technological requirements – the absence of a siphon, the very irregular course of the channel– might suggest a fairly early date, that is to say during the Classical period or at the end of the Archaic period. The relief of the pediment and the presence of an ancient bridge that allows the aqueduct to cross the Ciccio River, however, forced the chronology later than what we had originally thought. If the Athenians destroyed some channels, it was not the Galermi aqueduct, but presumably the so called Nymphem or Paradiso Channels. As the Ciccio inscription probably indicates this, the Galermi aqueduct seems to go back to the Hellenistic period between the 3rd and the 1st century BC. The person responsible for such a great structure could be Hiero the Second, who encouraged the

development of technology in his city and constructed several monuments of prestige in Syracuse; he was assisted in his efforts by the engineer Archimedes.

It should be noted that the absence of a siphon does not mean that those who constructed the aqueduct did not know the principles underlying the siphon. Actually, even Roman aqueducts have utilized channels that a track that ran along a slope over using a siphon, which is a typology that is rather fragile because it requires a great deal of accuracy when it comes to its maintenance. The continuation of our research program should provide us with more information about this work, which is rare in ancient Sicily, and give evidence to this hypothesis.

Bibliography

Agusta-Boularot and Paillet 1997

Sandrine Agusta-Boularot and Jean-Louis Paillet. "Le barrage et l'aqueduc occidental de Glanum: le premier barrage-voûte de l'histoire des techniques?" *Revue Archéologique* 1 (1997), 27–78.

Arnone 1952

Luigi Arnone. *Gli Ipogei dell'Agrigentino*. Agrigento: Edizioni Ente provinciale per il turismo, 1952.

Camp 1980

J. McKesson II Camp. *The Water Supply of Ancient Athens from 3000 to 86 B.C.* Ann Arbor, Michigan: University Microfilms international, 1980.

Capodieci 1813

Giuseppe Maria Capodieci. *Antichi Monumenti di Siracusa*. Syracuse: Presso D.F.M. Pulejo, 1813.

Cavallari 1891

Francesco Saverio Cavallari. *Appendice alla topografia archeologica di Siracusa*. Torino: C. Clausen, 1891.

Cavallari and Holm 1883

Francesco Saverio Cavallari and Adolf Holm. *Topografia archeologica di Siracusa*. Palermo: Tipografia del giornale Lo statuto, 1883.

Ciancio 1965

Salvatore Ciancio. *La tomba di Archimede: un sepolcro con colonnetta alle porte di Acradina*. Rome: IWA Publishing, 1965.

Collin Bouffier 1987

Sophie Collin Bouffier. "L'alimentation en eau de la colonie grecque de Syracuse. Réflexions sur la cité et son territoire?" *MEFRA* 99.2 (1987), 661–691.

Collin Bouffier 1992

Sophie Collin Bouffier. *Leau en Sicile grecque: réalistes et mythes*. PhD. Paris: Nanterre, 1992.

Collin Bouffier 2000

Sophie Collin Bouffier. "Quelles fonctions pour la kolymbethra d'Agrigente?" In *Cura Aquarum in Sicilia, Syracuse, 17–22 mai 1998*. Ed. by G. C. M. Jansen. BABESCH supplément 6. Leiden: Peeters Publishers, 2000, 37–43.

Collin Bouffier 2001

Sophie Collin Bouffier. "Les adductions hydrauliques des villes grecques de Sicile: des ouvrages techniques méconnus?" In *TEXNAI. Techniques et sociétés en Méditerranée*. Ed. by J.-P. Brun and P. Jockey. Paris: Maisonneuve et Larose, 2001, 513–528.

Collin Bouffier 2009

Sophie Collin Bouffier. "L'eau en Sicile grecque. Nouvelles perspectives de recherches?" *Pallas* 79 (2009), 65–79.

Crouch 1993

Dora P. Crouch. *Water Management in Ancient Greek Cities*. Oxford: Oxford University Press, 1993.

Cultrera 1938

Giuseppe Cultrera. "Siracusa. Rovine di un antico stabilimento idraulico in contrada Zappalà." *Notizie degli Scavi di Antichità* (1938), 261–301.

De Feo et al. 2012

Giovanni De Feo, Pietro Laureano, Larry W. Mays, and Andreas N. Angelakis. *Water Supply Management Technologies in the Ancient Greek and Roman Civilizations, Evolution of Water Supply through the Millennia*. London: IWA Publishing, 2012.

Fazello 1628

Tomaso R.P. Fazello. *De rebus siculis, decades duae, nunc primum in lucem editae*. 2nd ed. Palermo, 1628.

Hill 1964

Bert H. Hill. *The Springs. Peirene, The Sacred Spring, Glauke*. Corinth 1.6. Cambridge, MA: Harvard University Press, 1964.

Kienast 1995

Hermann J. Kienast. *Die Wasserleitung des Eupalinos auf Samos*. Bonn: Habelt, 1995.

Lambrinouidakis et al. 2017

Vassilis Lambrinouidakis, Alexandra Sfyroera, Themitoklis Bilis, Maria Magnisali, and Evangelos Kazolias. "The Ancient Aqueduct of Naxos". In *Cura Aquarum in Management and Hydraulic Engineering in the Mediterranean Region*. Ed. by K. Wellbrock. Vol. 27-2, sub-volume 2. Siegburg: DWhG, 2017, 377–394.

Logoteta 1788

Giuseppe Logoteta. *Le antiche Siracuse*. Catania: Presso F. Pastore, 1788.

Mirabella and Alagona 1613

Vincenzo Mirabella and Scoriggio Alagona. *Dichiarazioni della pianta dell'antiche Siracuse e d'alcune scelte medaglie d'esse*. Naples: Stampa di Lazzaro Scoriggio, 1613.

Moretti and Fincker 2007

Jean-Charles Moretti and Myriam Fincker. "Le barrage du Réservoir de l'Inopos à Délos". *Bulletin de Correspondance Hellénique* 131.1 (2007), 187–228.

Robinson 2011

Betsey A. Robinson. *Histories of Peirene: a Corinthian Fountain in Three Millennia*. Ancient Art and Architecture in Context 2. Princeton: American School of Classical Studies at Athens, 2011.

Schubring 1865

Julius Schubring. "Die Bewässerung von Syrakus". *Philologus* (1865), 579–638.

Tölle-Kastenbein 1990

Renate Tölle-Kastenbein. *Antike Wasserkultur*. Munich: C. H. Beck, 1990.

Tölle-Kastenbein 1994

Renate Tölle-Kastenbein. *Das archaische Wasserleitungsnetz für Athen [und seine späteren Bauphasen]*. Sonderhefte der Antiken Welt, Zaberns Bildbände zur Archäologie 19. Mainz: Philip von Zabern, 1994.

Wilson 2000

Roger A. Wilson. "Aqueducts and Water Supply in Greek and Roman Sicily. The Present Status Quaestionis?". In *Cura Aquarum in Sicilia, Syracuse, 17–22 mai 1998*. Ed. by G. C. M. Jansen. BABESCH supplément 6. Leiden: Peeters Publishers, 2000, 5–36.

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Anette Schomberg

The Karnak Clepsydra and its Successors: Egypt's Contribution to the Invention of Time Measurement

Summary

The invention and establishment of the water clock in Egypt, at first glance, seems to be one of the best-documented developments in the history of ancient technology. A closer look at these clocks, however, reveals that their form and function have not yet been described sufficiently. Meanwhile, acquisition of three-dimensional data enables novel analysis of the preserved examples scattered all over the world. Regarding the fragmentary condition of most of the clocks, 3D scans are indispensable to investigate developments and functions of particular examples more closely and to ascertain the knowledge that existed about fluid dynamics around 1500 BC.

Keywords: Egypt; time measurement; water clock; 3D scans; transfer of technology

Die Erfindung der Wasseruhr in Ägypten scheint auf den ersten Blick so gut dokumentiert zu sein wie kaum eine andere Entwicklung der antiken Technikgeschichte. Betrachtet man jedoch diese Uhren näher, so zeigt sich, dass ihre Form und ihre Funktionsweise längst nicht ausreichend beschrieben sind. Inzwischen macht die Aufnahme dreidimensionaler Daten neuartige Analysen der erhaltenen Stücke möglich, die heute auf der ganzen Welt verstreut sind. Im Hinblick auf den meist fragmentarischen Erhaltungszustand der Uhren sind 3D-Scans unerlässlich, um Entwicklungen und Funktionen der einzelnen Instrumente genauer zu untersuchen und so zu erforschen, welches Wissen um 1500 BC über das dynamische Verhalten von Flüssigkeiten herrschte.

Keywords: Ägypten; Zeitmessung; Wasseruhren; 3D-Scans; Technologietransfer

I would like to extend my gratitude to Ruti Ungar for her help on the translation.

Before the origin of time measurement in antiquity can be addressed, we must realize that the first clocks had only an extremely limited effect on people's lives. This may come as a surprise, given the importance that we attach nowadays to this instrument. Unlike today, however, ancient timetables and time clocks did not provide a rhythm to daily life.¹ Time measurement followed different rules, as the introduction of the clock in Rome demonstrates. Pliny the Elder's account gives a good impression of the implementation of this instrument and can be considered exemplary of antiquity in general:

Marcus Varro records that the first sundial in a public place was set up by the consul M. Valerius Messalla, on a pillar beside the Rostra, after the capture of Catania in Sicily during the first Punic war; and that it was imported from Sicily thirty years after the traditional date of Papirius' sundial, in 263 BC. The lines of this sundial did not agree with the hours, but they were followed for 99 years, until Q. Marcius Philippus, who was censor with L. Paulus, placed a more precisely constructed one next to it; a gift which was the most appreciated action of his censorship. (215) Even then, however, the hours remained uncertain on cloudy days until the next lustrum. Then, Scipio Nasica, the colleague of Laenas, was the first to use a water-clock [clepsydra] to mark the equal hourly divisions of night as well as day. He dedicated this clock, which was installed under cover, in 159 BC. For so long had the Roman people been without a means of dividing their day!²

A lack of precision was of no consequence, to Pliny's astonishment, since the Romans had lived quite well by a miscalculated clock for a hundred years. On the other side, Pliny stressed an important point – people appreciated the clock as a singular gift. In evaluating time measurement in antiquity, both aspects need to be taken into consideration, so that a standard different from the modern one is applied with regard to the importance, value, and accuracy of clocks within their inherent contexts. Clocks had

- 1 Historians and sociologists agree that the concept of time changed fundamentally in the medieval age. See, for example, the remark by Lewis Mumford that the mechanical clock and not the steam engine was the key invention of the modern industrial age; see Mumford 1934, 12–18; cf. also the historical survey by Dohrn-van Rossum 1995, 11–23, 202–295, 318–321.
- 2 Beagon 2005, 106. – M. Varro *primum statutum in publico secundum Rostra in columna tradit bello Punico primo a M. Valerio Messala cos. Catina capta in Sicilia,*

deportatum inde post XXX annos quam de Papiriano horologio traditur, anno urbis CCCCLXXX. Nec congreuebant ad horas eius lineae, paruerunt tamen ei annis undecentum, donec Q. Marcius Philippus, qui cum L. Paulo fuit censor, diligentius ordinatum iuxta posuit, idque munus inter censoria opera gratissima acceptum est. Etiam tum tamen nubilo incertae fuere horae usque ad proximum lustrum. Tunc Scipio Nasica collega Laenati primus aqua divisit horas aequae noctium ac dierum idque horologium sub tecto dicavit anno urbis DXCV. Tam diu populo Romano indiscreta lux fuit.



Fig. 1 Athenian clepsydra.

not been necessary in everyday life, as a rule, because people relied upon observations of the sun and the stars, as well on estimations of the length of their own shadows.³

Nevertheless, monitoring the passage of time in detail was necessary in some cases. Unfortunately, these cases also contain the origin of a common misconception: the distinction between a true clock and a stopwatch.⁴ The problem is complicated further by the use of the word ‘clepsydra’ to refer to both devices. The most famous example of an ancient stopwatch of this type is the Athenian clepsydra,⁵ an instrument solely destined to limit the length of speeches at the law courts in Athens (Fig. 1). Similar instruments were used to divide vigils into equal lengths in the Roman army⁶ and in second millennium Mesopotamia,⁷ and to regulate irrigation intervals in northern Africa.⁸ Such instruments differed fundamentally from a real clock in one respect, they did not reveal the actual time, but rather the length of a (repeated) interval, and this makes all the difference. This kind of clepsydra consists of a simple vessel with a small outlet at the bottom that is either filled with water or placed empty into a larger vessel filled with water. In the former case, the interval in question lasts until the vessel is emptied, as with the Athenian clepsydra; in the latter, the interval lasts until the inflowing water submerges the so-called water-sinking bowl.⁹

3 Bilfinger 1888, 75–78.

4 For the distinction between a stopwatch, which is quite easy to construct, and a clock, which requires a high degree of sophisticated skills and preconditions with regard to antiquity, see for example Bilfinger 1886, 6.

5 See Last 1924, 169–173; Young 1939, 274–284.

6 Aen. Tact. XXII, 24; cf. Diels 1920, 195 n. 1.

7 See Hunger and Pingree 1989; Thureau-Dangin

1932, 133–136; Thureau-Dangin 1937, 51, and Al-Rawi and George 1991/1992, 52–73, while the work of Neugebauer 1947, 37–43, is still fundamental. The Mesopotamian water clock was recently the subject of several articles that provide an overview. Nevertheless, the authors do not discuss the distinction between a clock and a stopwatch, and hence do not even take into account that the Mesopotamian

It is often overlooked that in contrast to a stopwatch, the construction of a properly functioning water clock requires not only a high level of theoretical knowledge and practical abilities, but also a context in which the demand for such a clock exists, as well as the conditions to enable time measurement. In short, the amount of knowledge required before development of a water clock could begin was far more advanced than it appears at first glance. For example, time units had to be defined: in the case of ancient Egypt, twelve hours per night/day were the smallest measureable units.¹⁰ With regard to antiquity in general, this meant dividing the shifting time period between sunrise and sunset into twelve parts and operating with so-called unequal or seasonal hours.¹¹ As a consequence, a clock in antiquity had to show different hours over the course of the year (and, in an ideal case, each day): long daylight hours in summer and short daylight hours in winter, and of course vice versa at night. Only for a very limited period at the equinoxes in spring and autumn are the hours of day and night equal. Therefore, the geographic latitude had to be considered too, since the latitude determines the rising and setting of the sun. To put it the other way around, determining the running time of such a clock allows us to determine its appropriate latitude, or the latitude of its original site location.¹² The removal of such a clock from the particular latitude for which it was manufactured would, inevitably, result in an incorrect display.

A working (stable) calendar is an absolute necessity in order to determine regularities concerning the increase and decrease in the length of the hours over the course of the year reciprocal to a specific latitude; it provides a clear concept not only of periodic months, but also of each month, with corresponding hours of an appropriate length. Most ancient calendars were based on the lunar cycle, however, even with its inherent irregularities.¹³ For this reason, they created unfavorable framework conditions. Only in ancient Egypt is an entirely different situation apparent. According to the Egyptian civil calendar, a year of 12 months, at 30 days each, plus 5 additional 'epagomenal' days, results in 365 days in total. The civil year, thus nearly approaches the dimension of the modern calendar year of 365 $\frac{1}{4}$ days, although it lacks the addition of a leap-year day

sources may refer solely to stopwatches; cf. Brown, Fermor, and Walker 1999/2000, 130–148; Michel-Nozières 2000, 180–209; Fermor and Steele 2000, 210–222; Falk 2000, 197–132 and a more critical voice Høyrup 1997/1998, 192–194.

8 Diels 1920, 196–197 pl. XVI.

9 See Smith 1907, 319–334 fig. 2; Turner 1984, 9–11; Brown 2000, 119–120.

10 Cf. Borchardt 1920, 3–5.

11 This concept was used throughout antiquity, until the Middle Ages and the invention of the mechani-

cal clock, when these hours were gradually replaced by the equinoctial or equal hours common today; cf. Dohrn-van Rossum 1992; cf. for example, the mechanical clock by Giovanni de Dondi; Bedini and Maddison 1966, 1–69; cf. Flachenecker 1996, 391–398.

12 This has already been discussed in detail by Borchardt 1920, 17–19; cf. Hölbl 1984, 31, 35.

13 An early reference to the superior Egyptian civil calendar appears in Hdt. II. 4.

every four years. It follows that, beginning with the introduction of the civil calendar,¹⁴ Egypt provided calendrical conditions that encouraged the development of a clock to a much greater extent than Mesopotamia or Greece did. Given these challenges, however, there had to be a real need to measure time in order to engender a determined effort to construct a clock.

Only two devices were available for time measurement in antiquity before the invention of the mechanical clock, which took place at some point in the fourteenth century AD. Pliny refers to the differences between these devices: whereas sundials¹⁵ only work on sunny days, a water clock has the potential to operate independently from external circumstances. The operation of a sundial requires only sunshine and some kind of shadow-caster, combined with a few calculations, to form a time-measuring instrument. A water clock, by contrast, involves extending beyond observation, thus, creating a higher degree of abstraction: first, it requires the conceptual development of a device that is independent from its surroundings, and then it requires the conditions for the device's creation. As the invention of the water clock shows, both the concept and the conditions existed in Egypt before anyone came up with the idea of measuring time with a clock. In addition, the invention of the water clock occurred in response to a fundamental need.

As the quote by Pliny the Elder has already shown, Rome was without a doubt 'behind the time' in the second century BC as far as the invention and application of the water clock was concerned. Instead, another city played a leading role in technological innovation¹⁶ in early Hellenistic times, especially in the development of water clocks. The Roman author Vitruvius dedicates several chapters in his *De Architectura* to the description of water clocks¹⁷ – sophisticated and highly representative devices that he credited the famous engineer Ctesibius with inventing at the Museion in Alexandria during the reign of Ptolemy II. These clocks inspired admiration not only from Vitruvius but also from others throughout antiquity and beyond. However, as famous and

14 The exact date of the introduction of the civil calendar is still disputed; see Leitz 1989, 53–54.

15 The same applies, of course, for Egyptian star clocks on nights with a clear sky, the oldest time-measuring instruments of all. Without entering into a detailed study of Egyptian star clocks, it is worth mentioning that time measurement in Egypt not only started quite early, but also used a device that was limited to nocturnal use – a clear indication of the field of application of clocks in Egypt; cf. Leitz 1995.

16 Cf. for example Schürmann 1991; Argoud and Guilamin 1998; D. M. Lewis 2000, 631–648; Russo

2005.

17 Vitruvius IX, 8, 2–15. – “These same writers have also invented methods for assembling clocks that use water, Ctesibius of Alexandria first among them” (Rowland 1999, 116); for Vitruvius sources see Fleury 1998, 103–114; D. M. Lewis 2000, 361–369, gave an overview of the invention and development of water clocks in ancient times. Unfortunately, in his article he made no distinction between a water clock and a stopwatch like the Athenian clepsydra (see Fig. 1). Therefore, he fails to underline the unique role Egypt played in the development of water clocks.



Fig. 2 Karnak clepsydra.

sophisticated as the water clocks by Ctesibius may have been, the actual invention of this device took place more than a thousand years earlier, remarkably, in the same cultural area. Although Ctesibius' clocks left hardly any traces, except for descriptions made by authors like Vitruvius,¹⁸ pictorial reconstructions based on these descriptions turned out to be extremely formative. From the beginning, these pictorial reconstructions established the modern notion of ancient water clocks and their appearance.

As a consequence, the emergence of original fragments of Hellenistic water clocks in seventeenth-century Italy drew little attention.¹⁹ This initial lack of interest can be attributed to their fragmented condition and, therefore, to the common misinterpretation of the objects, but it continued later on because of their fragmented appearance. Only when G. Legrain discovered a nearly complete specimen in 1904, in the famous Karnak Cachette, did this type of water clock begin to attract researchers.²⁰ Examined first by G. Daressy²¹ in an article in 1915, the Karnak clepsydra (Fig. 2) undoubtedly constitutes the oldest preserved water clock, originating from the time of Pharaoh Amenhotep III (1379–1342 BC).²²

The famous Egyptologist Ludwig Borchardt was the first to recognize the fundamental importance of these pieces. Unaware of the article by Daressy, Borchardt published a thorough study in 1920 about time measurement in ancient Egypt that turned out to be perhaps the most influential and authoritative examination conducted in the

18 See Schomberg 2017.

19 Kircher 1654, 385; although Athanasius Kircher was the first to publish two fragments of water clocks and succeed in identifying them correctly ("probably a water clock"), his interpretation was not confirmed until the early twentieth century.

20 Cf. for the Karnak clepsydra: <http://www.ifao.egnet.net/bases/cachette/>, search term: 'clepsydra' (visited on 23/05/2018).

21 Daressy 1915, 5–16.

22 Cf. Warburton 2009, 134.

field of Egyptian time measurement to date.²³ Borchardt's rather condensed presentation has precluded any critical discussion of his groundbreaking investigation for almost a century, but such a discussion must now be the essential starting point for further examination of the present topic.

While Daressy focused only on the recently discovered Karnak clepsydra and a second vessel in the Egyptian Museum in Cairo, Borchardt took a much broader approach, using all of the means at his disposal. Just before his book was published, Borchardt learned of an inscription that provided a key to understanding Egyptian water clocks.²⁴ As he writes in a supplement to his book, K. Sethe had drawn his attention to a report inscribed at the tomb of an Egyptian official named Amenemhet.²⁵

This grave, which was discovered by fellaheen in 1885 at Sheikh Abd el-Qurna in western Thebes, is now lost. The only items preserved from it are a small fragment of the inscription, now in the Egyptian Museum Berlin, and two copies made immediately after the discovery.²⁶ Amenemhet, who lived under the pharaohs Ahmose I, Amenhotep I, and Tuthmose I, around 1500 BC,²⁷ explains in his inscription that he has recognized that the length of the night increases and decreases from month to month. For this reason, he has constructed an *Mrht* – an “instrument for telling time.”²⁸ This device, he claims, shows the hours precisely, has astronomical depictions on the exterior, and has no predecessors (although he had consulted older texts beforehand);²⁹ its water runs out through a single exit.

The significance of this inscription was revealed a few years later, when the aforementioned discovery of the Karnak Cachette brought to light the remains of a vessel that met all these conditions, as Borchardt and especially Sethe realized.³⁰ The Karnak clep-

23 See Borchardt 1920; as Borchardt explains on page 6 in note 1, he had had no access to the article by Daressy because of the war. In the same note, Borchardt also points out that his chapter on the Egyptian water clocks stems from a more detailed but only handwritten treatise he had been planning to publish. Unfortunately, he refrained from doing so. Borchardt's hitherto unpublished manuscript was discovered in the archive of the “Schweizerisches Institut für Ägyptische Bauforschung und Altertumskunde” in Cairo. Its publication is the subject of an ongoing *Topoi* project.

24 See Borchardt 1920, 60–63 pl. 18.

25 Sethe dealt with this inscription in an article published in 1920; cf. Sethe 1920, 114–115 n. 3; nevertheless, Borchardt partly disagreed with Sethe's conclusions; see Borchardt 1920, 61–62; the inscription has recently been reedited by A. von Lieven; see von Lieven 2016, 207–231.

26 Egyptian Museum Berlin, Inv.-No. 14470; see von Lieven 2016, 207–208 esp. n. 4; the copies were made by E. Schiaparelli and W. Golenischeff. Borchardt based his transcription on Golenischeff's copy.

27 Cf. Hornung, Krauss, and Warburton 2006, 492.

28 For the translation of this term see Borchardt 1920, 62 n. 4.

29 Cf. von Lieven 2016, 221: “[I] studied [?] by reading in all writings of the god's works.”

30 For the Karnak clepsydra cf. Daressy 1915, 5–16; Borchardt 1920, 6–7 pls. 1–3; Sloley 1924, 43–50; Sloley 1931, 174–176; Pogo 1936, 403–425; Chatley 1940, 68–72; Parker 1950, §207–208; Neugebauer and Parker 1969, 12–14; Desroches-Noblecourt 1976, 139–149, pl. 33; von Mackensen 1978, 13–18; Cotterell, Dickson, and Kamminga 1986, 31–50; Long 1989, 589–591; Mengoli 1989, 227–271; Clagett 1995, 66–73; Spalinger 1995, 111–114;



Fig. 3 Interior of the Karnak clepsydra.

sydra was found broken in pieces, and was made of alabaster. Its shape is reminiscent of a large flowerpot; the outside of this vessel has characteristic depictions in three horizontal rows and a vignette of pharaoh Amenhotep III. The vignette allows the clepsydra to be dated to the middle of the fourteenth century BC. The uppermost row shows decans and anthropomorphic representations of stars and planets depicted in barks. Below, in the middle row, are the more prominent constellations of the northern sky and deities on both sides. The bottom row has six frames, each displaying the king, flanked by two of the twelve gods of the months. The outflow aperture is located between two of the frames.

Twelve scales of various length, with hour markings, are inscribed on the inside of the vessel (Fig. 3). Above each scale, on the rim of the vessel, the name of the corresponding month is inscribed, with the god of that month depicted on the outside. The months containing the two solstices – and therefore the longest and shortest hours of the year – correlate with the longest and the shortest scale, respectively, while the months containing the equinoxes are represented by the medium-length scales (Fig. 4). The lengths of the other scales follow accordingly. At sunrise or sunset, the vessel could be filled with water, which flowed out gradually from the small aperture near the bottom of the vessel. The hour was obtained by comparing the dropping water level to the scales on

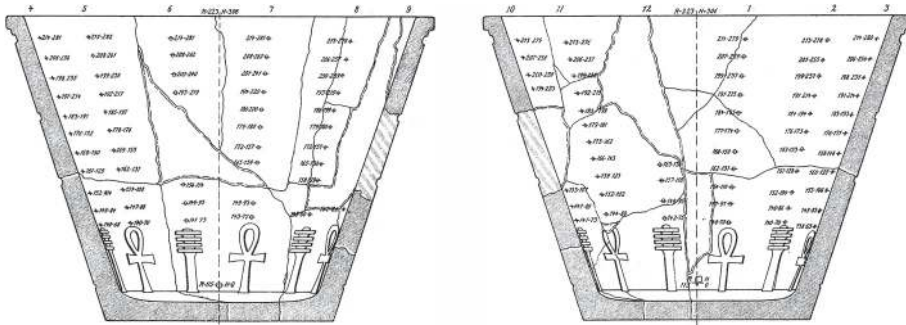


Fig. 4 Karnak clepsydra, scales.

the inside.

Having the Karnak clepsydra as a means of comparison made it obvious that several other collections contained fragments of Egyptian water clocks. The identification of these fragments was unmistakable: they shared not only the shape and the functional principle of the Karnak clepsydra, but also the depictions on its outside, in varying detail.³¹ Parallels to such depictions can be found in the astronomical ceiling decorations at the Tomb of Senmut and at the Ramesseum.³² All of them are based on an older tradition of ‘classical sky representations’ whose traces lead back to the Middle Kingdom.³³ Each of the Hellenistic pieces copies the depiction of the Karnak clepsydra accurately; some of them show the complete pattern of the clepsydra in three rows, while others reduce the decoration to the bottom row. Both versions existed in parallel in Hellenistic times.

Once there could be no doubt that these pieces of characteristic shape and decoration came from water clocks made in the tradition of the Karnak clepsydra from over a millennium earlier, the crucial question, according to Borchardt, was whether these kinds of clocks kept time properly.³⁴ Scholars have followed his lead since he first raised this issue in 1920, and they still focus on this question more or less exclusively, or confine themselves to an overview of the material.³⁵ Such means do not sufficiently interrogate Borchardt’s methods and procedures, however. This is by no means a criticism of his

Depuydt 1997, 110–119; Mills and Symons 2000, 18–20; <http://www.ifao.egnet.net/bases/cacheette/qv.clepsydre> (visited on 01/02/2018).

31 With one exception: a fragment in Cairo that stems from the time of pharaoh Necho II. The water clock fragment, discovered between 1929 and 1937 by P. Montet in Tanis, follows a different pictorial tradition; see Montet 1946, 35–39 pls. I–II.

32 See Neugebauer and Parker 1969, 8–62.

33 von Lieven 2012, 1–2; von Lieven 2007, 43; see J. F. Quack, *Beiträge zu den ägyptischen Dekanen und ihrer Rezeption in der griechisch-römischen Welt* (in prep.).

34 Borchardt 1920, 14.

35 Cf. for example the articles by von Mackensen 1978, 13–18, Hölbl 1984, 5–67, Cotterell, Dickson, and Kamminga 1986, 31–50, or Mengoli 1989, 227–271, and the overview by Lodomez 2007, 57–76.

accomplishments, but rather a call to reconsider our approach today, while still recognizing him as the most important forerunner in this area of study. Unfortunately, the way Borchardt expressed himself presents an obstacle to a critical analysis, even for native speakers. It, therefore, seems appropriate to first discuss his chapter on water clocks critically, and then focus on new research perspectives.

Borchardt's interest in water clocks must have been aroused more or less immediately after the discovery of the Karnak Clepsydra, as evidenced by the inventory book of the Egyptian Museum Berlin. In order to study these instruments, Borchardt endeavored to receive plaster copies of all Egyptian water clock fragments known at that time. The arrivals of these plaster copies are recorded as having occurred as early as 1911/1912, either as donations from other museums and researchers or as donations to the museum in Berlin from Borchardt himself. These copies formed the basis for his study and are still preserved in the Egyptian collection. They also denote the material basis available to Borchardt at the time. The collection comprises fourteen fragments, which according to Borchardt, originally belonged to twelve outflow water clocks.³⁶ The fact that this material basis has been significantly expanded since then is reason enough to reopen the issue of the Egyptian water clocks: new discoveries have led to knowledge of over thirty fragments, more than twice as many as Borchardt had at his disposal.³⁷

As simple as the water clock seems to be, on closer examination, it depicts a certain ingrained knowledge of fluid dynamics. Borchardt was the first to recognize that the shape of these water clocks revealed the application of a fundamental theorem in fluid dynamics, described for the first time in 1643 by the Italian scientist Evangelista Torricelli, and now known as Torricelli's Law. It states that the velocity v of a liquid flowing under the force of gravity out of an opening in a tank is jointly proportional to the square root of the vertical distance h between the liquid surface and the center of the opening and the square root of twice the acceleration caused by gravity, $2g$. In short $v = \sqrt{2gh}$, where g is the acceleration due to gravity. The exceptional importance of the Egyptian water clocks is that their design demonstrates the practical application of this theorem more than three thousand years before its theoretical formulation.

Applied to an open vessel filled with water and with an aperture at the bottom like the Egyptian clepsydra, or to an outflow water clock in general, Torricelli's law states that the velocity of the outflow is based on the water pressure inside. This pressure normally decreases as the water level sinks, and the outflow velocity drops accordingly.

36 All of these plaster copies conform to Borchardt's clock nos. 1–12 and are preserved in the Egyptian Museum, with the exception of one complete water clock—Borchardt's clock no. 11. This piece had been found in Rome and had belonged to the collections in Berlin since 1910, so Borchardt did not

require a plaster copy. It has since been lost; only a couple of photos have survived. One other water clock (Borchardt no. 13) has only a reference, since Borchardt already considered it lost at the time; for his compilation see Borchardt 1920, 6–10.

37 Cf. the catalogue in Schomberg 2017.

The problem for such an outflow water clock lies in ensuring constant water pressure inside and a steady outflow rate. The solution presented by the Egyptian water clocks is as simple as it is brilliant: reducing the circumference of a vessel and, hence, the water surface, to the shape of a truncated cone means that the sloping sides of the vessel (at a ratio of 1 to 3) can provide constant water pressure inside the vessel and consequently a steady outflow rate. This is the exact reason a cylindrical vessel is unsuitable:³⁸ the sinking water level would result in diminishing water pressure and therefore a declining outflow rate.

By applying Torricelli's Law, Borchartd³⁹ tried to calculate the actual accuracy of the Karnak clepsydra, as well as whether the designers of this clock had succeeded. Unfortunately, the outcome was disappointing. A vessel that would be able to manage a steady outflow has to have the shape of a fourth-order parabola, and the Egyptian water clocks lacked precision in this regard (Fig. 5): the vessels were too narrow at the top and too wide at the bottom. This would have caused the clocks to run too fast in the first half of the period of time to be measured and too slowly in the second. His calculations brought Borchartd to the realization that the Egyptian water clock was not able to display time correctly. In fact, he concluded:

This collection clearly shows that the ancients failed to divide the time consistently with their outflow clocks. The hours these clocks indicated during one and the same night or one and the same day were not consistent at all, but rather differed significantly [...] This must have had the consequence, for example, that not even midnight could be correctly determined with these water clocks, since the clock would have indicated it almost three quarters of an hour after its actual occurrence [...] The ancient [Egyptian] theory that the water flowing out of a round container with walls in a slope of 1:3 will drop at a consistent rate to a consistent level is therefore appreciably false.⁴⁰

38 Related to this, is the complete discussion of the water clock in ancient Mesopotamia, since the sources seem to suggest a cylindrical water clock; cf. for example the recent articles by Høyrup 1997/1998, 192–194; Fermor and Steele 2000, 210–222; and Brown, Fermor, and Walker 1999/2000, 130–148.

39 Although Borchartd did not mention his sources, Høyrup 1997/1998, 192, states that, “his choice of symbols shows that he has consulted the standard literature on hydrodynamics.”

40 Borchartd 1920, 15–16. “Diese Zusammenstellung zeigt deutlich, dass es den Alten nicht gelungen ist, mit ihren Auslaufuhren die Zeit gleichmäßig zu

teilen. Die Stunden, welche diese Uhren in einer und derselben Nacht oder in einem und demselben Tag anzeigten, waren keineswegs gleich, sondern erheblich verschieden, [...] Dies muss z. B. zur Folge gehabt haben, dass mit diesen Wasseruhren nicht einmal die Mitternacht richtig bestimmt werden konnte, da die Uhr sie beinahe $\frac{3}{4}$ Stunden nach ihrem wirklichen Eintritt angab [...]. Die Theorie der Alten, dass in einem runden Gefäß mit Wandungen in einer Neigung von 1:3 das auslaufende Wasser in gleichen Zeiten um gleiche Höhen sinkt, ist also beträchtlich falsch“ (translation from the German by Casey Butterfield).

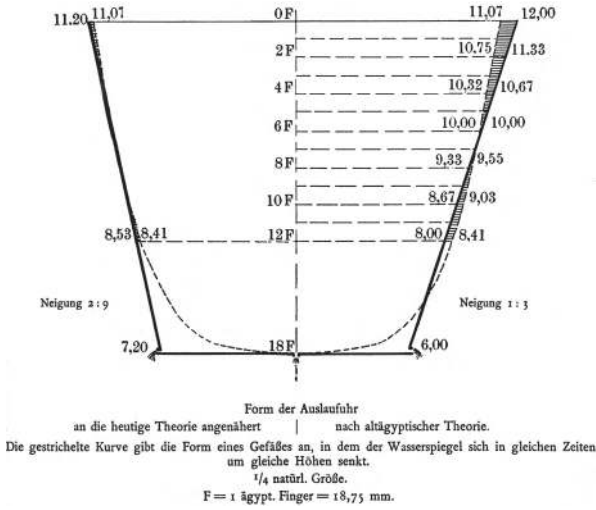


Fig. 5 Cross-section of a clepsydra and a fourth-order parabola.

Borchardt states in his summary that the display of the clock must have been wrong to an extent that should have been obvious even back then.⁴¹ However, the question remains: If this type of outflow clock did not work properly, then why were so many of them reproduced in the time of Alexander the Great and Ptolemy II? This is even more astonishing in light of the knowledge that this was the era in which the famous Greek engineer Ctesibius constructed his much more elaborate clocks at Alexandria, with far more advanced theoretical knowledge.⁴²

More than ten Hellenistic fragments of this type of outflow clock had already come to light when Borchardt wrote his book, giving the impression that he himself was quite puzzled by this obvious contradiction. Nevertheless, there can be no doubt as to their dating. Some fragments bear the names of Alexander the Great, his brother Philip Arrhidaios, and Ptolemy II. In other cases, empty cartouches point to production in a relatively short period between 320 and 246 BC, and inscriptions or find circumstances at least reveal their origins in Hellenistic times. On an overall basis, the chronological distribution of the finds is remarkable. Depictions dating from after the first appearance of the outflow clepsydra, at the time of pharaoh Amenhotep III (1379–1342 BC), have been found in four Ramesside grave chambers.⁴³ A fragment from Tanis bears the cartouche of pharaoh Necho II (610–595).⁴⁴ Nearly twenty pieces were created in the comparatively short period in the early Hellenistic times that followed. Moreover, some of these Hellenistic water clocks have been discovered outside Egypt in Turkey and Italy,

41 Borchardt 1920, 59.

42 See Schomberg 2017.

43 Barguet 1978, 52–55; Roberson 2012, 179–188.

44 Cf. Hornung, Krauss, and Warburton 2006, 494.

near Egyptian sanctuaries. In some cases, they even bear secondary Greek or Latin inscriptions, revealing their adaptation in Roman times.⁴⁵ This also means that they must have been removed from Egypt and, therefore, from the latitude for which they were originally made. It appears, therefore, that there was a deliberate acceptance of the loss of accuracy, at least in Roman times. One must take this realization into consideration before imposing modern standards on the clocks' accuracy.

Indeed, Borchardt disregards this dislocation. He even wrote, "now we must also approach the question of whether they reached this goal, whether their outflow clocks ran correctly *according to our perceptions*."⁴⁶ After having stated that the Karnak clepsydra did not work properly, however, he detected several 'Hellenistic' improvements related to the influence of Greek science and advances in theory, which according to him would have improved accuracy.⁴⁷ This served as his explanation for the revival of the Egyptian outflow clock in Hellenistic times. Since it was obvious that shape and inclination stayed the same, these improvements concerned the scales of the clocks exclusively.

Borchardt was convinced that the Hellenistic scales contained new and vital insights.⁴⁸ The lengths of the scales inside the Karnak clepsydra increase and decrease linearly, meaning that the lengths of the days/nights or measured hours did as well. This linear increase/decrease did not, however, correspond to reality: change in the lengths of days and nights is nonlinear – it happens faster around the solstices and slower around the equinoxes.⁴⁹ Since only the Hellenistic clocks would reflect such an adapted scale system, he concluded that the ancient Greeks would have been able to measure time with greater accuracy. Borchardt's evidence of this adaption, unfortunately, is based entirely on hypothetical reconstructions of scales that in fact contradict the genuine values of the preserved scales.⁵⁰ Upon closer examination, the scales of the Hellenistic clocks show linear development, just like the scales of the Karnak clepsydra.

Another of the improvements Borchardt cited, concerns the relationship between a clock's scales and the distribution of the months/length of the hours according to the contemporaneous calendar.⁵¹ He referred, in this context, not to the engraving of the hour marks on the scales in detail (the execution of these was always imprecise) but to

45 Cf. for example a fragment at the Musei Capitolini in Rome (Fig. 11; Borchardt 1920, 9 no. 12; Winter 2013, 532 no. 10) or at the British Museum in London (Inv.-no. 938; see Borchardt 1920, 8 no. 6; Winter 2013, 407).

46 Borchardt 1920, 14. Original: "jetzt müssen wir aber auch der Frage näher treten, ob sie dieses Ziel auch erreicht haben, ob ihre Auslaufuhren *nach unseren Begriffen* richtig gingen" (translation by Casey Butterfield).

47 On this point see also Hölbl 1984, 27–28.

48 Borchardt 1920, 14. "Bei der Steigerung der Skalen ist also ein Fortschritt der Theorie bemerkbar"

49 This observation was first mentioned by the Greek astronomer Kleomedes; see Bilfinger 1888, 153.

50 This discrepancy is even reflected in the data given by Borchardt himself: compare, on the one hand, his data evaluation on pages 12–13 and, on the other, his figures of the clepsydras with genuine marked scale values on plates 2 (clepsydra of Karnak) and 5 (clepsydra in the Museo Barracco).

51 Borchardt 1920, 19–21.

the question of the extent to which the length of a given month-scale corresponded to the length of the hours in exactly that month. This was due to the fundamental deficiency of the aforementioned Egyptian civil calendar: despite this calendar's advantages in comparison to the irregular lunar calendars, the lack of an intercalary day every four years inevitably had serious consequences regarding the correct display of a clock. After 120 years of missing leap-year days, the calendar would be off by a whole month. A water-clock scale for one month would display the hour length of the preceding month, and so on. In other words, the monthly display of an Egyptian clepsydra would have become irrevocably outdated after no more than 120 years.

By focusing on the distribution of the solstices and equinoxes (or the corresponding longest, shortest, and both middle scales) as representative of the entire scale system, Borchardt's analysis of the Karnak clepsydra showed that their scales did not fit the calendar at the time of Amenhotep III. Rather, they reflected the calendar of 120 years before. He saw this realization as evidence of another basic error made by the clockmakers. He categorically excluded the option that the Egyptian designers may have been aware of this fact⁵² and subsequently constructed a hitherto undocumented 'astronomic year' in order to find an explanation. R. Parker pointed to another coincidence instead:⁵³ that the established time frame might not correspond to the dating of the Karnak clepsydra but to the time of the tomb inscription by the inventor Amenemhet, from whom the scale system of the Karnak clepsydra, thus, had probably been copied.

Unfortunately, the scale system of the Karnak clepsydra does not fit the period of the inventor Amenemhet either, as revealed via an examination of the preserved scale values in contrast to the values given by Borchardt.⁵⁴ In fact, considering the scale marks that have actually been preserved, the shortest and the longest scale are to be identified with the third and ninth scale/month, respectively. These do not correspond to the fourth and tenth scales as depicted by Borchardt,⁵⁵ whose result was achieved by simply adding a hypothetical line at the top (to mark the water level at the beginning) and an imaginary twelfth point at the bottom of every scale except one – scale 10 (Fig. 6).⁵⁶ While the line

52 Borchardt 1920, 21. "ganz ausgeschlossen erscheint es aber, dass man zur Zeit Amenophis' III. eine Uhr hergestellt hat, die vor reichlich 100 Jahren einmal richtig gegangen wäre."

53 Parker 1950, 76 n. 73. "It seems to me quite safe to conclude that the scale of the Karnak clock, fitting as it does the period of the inventor, is simply another manifestation of Egyptian conservatism."

54 Compare Borchardt 1920, 12 and pl. II. While plate II reproduces the actual values, the chart on page 12 reflects an idealized version.

55 Cf. Daressy 1915, 12 fig. 5, who indicates – independ-

ently from Borchardt – the correct scales. Unfortunately, Borchardt's 'revised' values were the ones adopted following Borchardt's publication in 1920.

56 The completely preserved scales have eleven marks. Yet, according to Borchardt's concept, such a clock, which runs for twelve hours, would need twelve marks. As a consequence, he postulated that all of the scales should have had twelve marks, but with the exception of the 'shortest' scale of the tenth month, the space under the scales would not have been sufficient for another – a 12th – mark. Hence, he added one mark to the bottom of the other

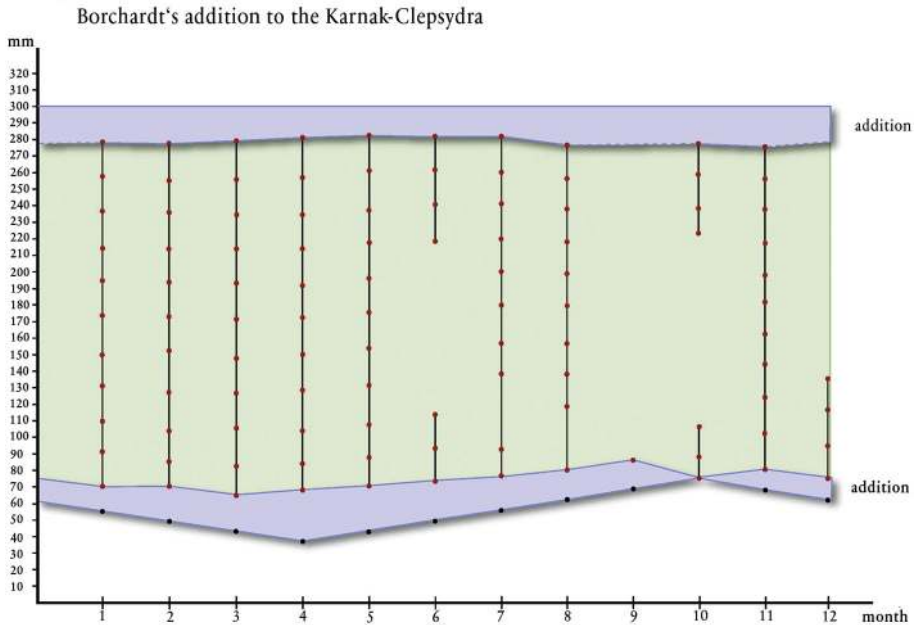


Fig. 6 Scale system of the Karnak clock with Borchardt's additions.

at the top applied to all scales to the same extent and hence had no consequences, the supplemental interval at the bottom did make a difference, since Borchardt chose the length of the added interval arbitrarily in order to restore the fourth and tenth scales as the longest/shortest scales, in contradiction to the preserved condition. According to the Egyptian civil calendar, in the years between 1700 and 1597 BC, the solstices fell in the third and the ninth month, and in this period, the scale system of the Karnak clepsydra would have been correct. Thus this clepsydra 'conserved' a calendar pattern from over 250 years prior – a pattern even older than the inventor Amenemhet himself.

By contrast, Borchardt declared that the scale systems of the Hellenistic clocks had been adapted and, therefore, accurately reflected the contemporaneous calendar situation. The problem is that most of the later specimens are only poorly preserved, making their scales too incomplete to draw such a conclusion in most cases. Borchardt, again, largely based his assumption on 'reconstructed scales.'

eleven scales and then obtained the absolute length of the scales in relation to the only complete preserved scale of the tenth month. Unfortunately, his concept was based on an incompletely preserved tenth scale and stands in contradiction to the other scales. The tenth scale has a large gap at the cen-

ter, so that only the upper four and the lower three marks are preserved. Instead of four missing marks, he assumed five – and used this assumption to justify all of his amendments; cf. Borchardt 1920, 10, 12, 15, 20–21 pl. 3.



Fig. 7 Plaster copy of the Karnak clock with reconstructed outlet.

Even the assumption of improved readability turned out to be wrong.⁵⁷ On closer examination, none of the Hellenistic improvements can be proven. Instead, a preliminary check shows that the Hellenistic water clocks seem to be faithful copies of the Karnak archetype. This calls for a new examination and estimation of the preserved material, without any hypothetical additions or reconstructions based on fixed ideas.

It was already high time, however, to reconsider Borchartd's negative judgment about the accuracy of these clocks and the modern expectations placed upon them. In a frequently overlooked article, published in 1978 in a remote journal, a German astrophysicist reported on a series of experiments with a plaster copy of the Karnak clepsydra (Fig. 7).⁵⁸ By simply filling the vessel and recording the course of the water flow, as well as the effects of cohesion and surface tension, it became apparent that, contrary to earlier assumptions, the clock displayed the time quite precisely. The clepsydra may have been an average of ten minutes too slow in the first six hours, and too fast in the second six, leaving it running around ten to twenty minutes fast after twelve hours (Fig. 8), but no other clock around 1350 BC could have revealed this lapse.⁵⁹

How could Borchartd have been so wrong? First of all, he wasn't a physicist, and in adapting Torricelli's Law to the Egyptian water clock, he made a mistake. What's more, all of his reflections on this subject were completely theoretical. The aforementioned experiments with this clock have demonstrated that cohesion, surface tension, and the

57 Borchartd 1920, 10; cf. von Mackensen 1978, 18, whose experiments with a copy of the Karnak clepsydra proved otherwise.

58 von Mackensen 1978, 16–18.

59 von Mackensen 1978, 17; similar results are provided by Cotterell, Dickson, and Kamminga 1986, 44–48.

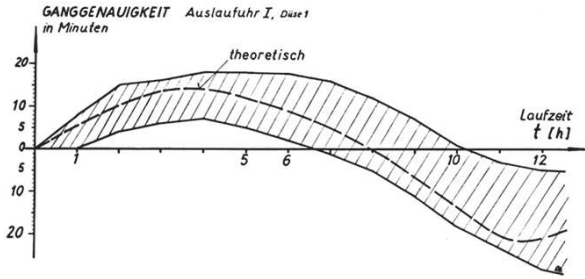


Fig. 8 Diagram showing the accuracy rate of the Karnak clock (based on 15 measurement rows).

shape of the aperture must not be neglected. In fact, they may improve the clock's proper functionality. Imposing modern standards, in terms of precision, does not help either: after twelve hours, the sun is going to rise anyway. It would not matter if the clock were ten minutes fast, since one look at the horizon would make this clear. For an Egyptian of the time, this clock would have been a precise measuring instrument. Since no other corrective instruments existed, contemporaries of the inventor Amenemhet would most likely have agreed with his assessment of the clock's accuracy.

As important as the discussion about the accuracy is, however, other aspects of these instruments have also been neglected for too long, such as their use in practice. Why was it so important for the Egyptians to have a clock available? Conveniently, the reason is written on the clepsydra itself. There to tell the time when the sun and stars are not visible, in order to make offerings at the right time.⁶⁰ Find contexts have consistently been Egyptian sanctuaries, both inside and outside of Egypt.⁶¹ On some clocks, it is mentioned that they belong to a sanctuary.⁶² These water clocks were even exported to Egyptian sanctuaries in the Roman Empire, without regard for their accuracy.⁶³ From this, it is apparent that at some point the application of this specific type of water clock or the provision of an original water clock from Egypt became more important than any precision or improved accuracy, probably because of their symbolic meaning.

This shows that the use and the development of this type of outflow clepsydra has to be put into a wider perspective. The prevailing assumption is that the invention of

60 Borchardt 1920, 8 (see London, BM, Inv.-no. 933); translation from the German by A. S.

61 Cf. Cairo, Egyptian Museum JE 37525 (Temple of Karnak); Cairo, Egyptian Museum JE 67096 (Tanis, near the great temple/Anta-temple); Turin, Museo Egizio Suppl. 8 (Rome, Iseum Campense); Rome, Museo Barracco 27 (Rome, Iseum Campense); St. Petersburg, Hermitage 2507b (Rome, Iseum Campense), Ephesus (near Serapeum); Alexandria, Greek and Roman Museum Reg. No. P. 9161 (Alexandria, Serapeum); Rom, Musei Capitolini (Rome, Regio

III near a sanctuary of Isis and Serapis).

62 Cf. St. Petersburg, Hermitage 2507a ("to offer sacrifices at the right time"); London, BM 933 ("to determine the hours [...] for the sacrifices at the right time"); Naples, Museo Nazionale 2327 (probably Temple of Osiris); Turin, Museo Egizio Suppl. 8 (originally probably a temple of the Nile god); Rome, Museo Barracco 27 (temple of Osiris); Ephesus (temple of Serapis).

63 Rouillet 1972, 145–146; Lembke 1994, 246–248; Quack 2003, 59.



Fig. 9 Roman clepsydra in the Archaeological Museum, Frankfurt.

sophisticated inflow water clocks in Hellenistic times by the Greeks in Alexandria and the subsequent innovative enhancement of such clocks in Greek and Roman antiquity exposed the apparent weakness of the old outflow clock and established much better alternatives.⁶⁴ Such an argument focuses solely on technological innovation, however, and misses a central point. The use of Egyptian clepsydras for time measurement in the Egyptian cult may have been inspired by innovation in the sixteenth century BC, but their existence in Greek and Roman times was not determined by technical feasibility. In this regard, technological progress did not make them redundant because tradition superseded innovation.

Nevertheless, the absence of this type of clock in later contexts seems to imply that the production of the outflow water clock came to an end because it could be replaced by more technologically advanced types of clocks. A closer look paints a different picture. First of all, Borchardt himself quoted a papyrus from Oxyrrhynchus that contains a partially preserved calculation of an outflow water clock.⁶⁵ Although Borchardt based his assumptions on these ancient calculations to a great extent, he could not fail to observe that the papyrus was full of mistakes, which were probably due to errors by a copyist.

A bronze vessel in the Archaeological Museum in Frankfurt provides clear evidence for the survival of this clock type.⁶⁶ Although its shape and material are different, the basic features are the same and characterize the piece as an outflow clock. Instead of

64 Cf. for example the description by Vitruvius, *De architectura* IX, 8, 2–15 (see Schomberg 2017).

65 Grenfell and Hunt 1903, no. 470; cf. Borchardt

1920, 10–12; Couchoud 1988, 25–34.

66 Stutzinger 2001, 5–12, 22–46.



Fig. 10 Fragment of a Roman clepsydra from Vindolanda.



Fig. 11 Fragment of an Egyptian clepsydra in the Musei Capitolini in Rome.

a truncated cone, it has the shape of a bowl, with a specific inclination to meet the flow requirements (Fig. 9). Inscriptions on the rim give the names of the months, the equinoxes, the solstices, the calends, the nones, and the ides. Drilled into the rim are 368 holes for the days, and two holes can be found at the bottom: a large one, with traces of a different material, and a very small one made of gold⁶⁷ that served as the outflow aperture. The time was indicated by the sinking water level against twelve scales on the inside. Unfortunately, the accuracy of the clock has not yet been examined. Another inscription on the outside reveals that it was dedicated to a Gallo-Roman sanctuary. This Roman clepsydra can be dated to the second century AD for epigraphic reasons.

Recently, another fragment has come to light in a remote area of the Roman Empire. In the fort of Vindolanda at Hadrian's Wall, a small bronze stripe was discovered in the remains of a granary dating to the second/third century AD (Fig. 10). The inscriptions on this stripe have led to its interpretation as a calendar or as part of a bronze disc from an anaphoric clock.⁶⁸ Seen in comparison to the rim of the clepsydra in Frankfurt, however, it proves to be a fragment of another Roman outflow clock. The origin of these Roman pieces is still recognizable, as a look at a fragment of an Egyptian forerunner in the Musei Capitolini at Rome shows (Fig. 11).⁶⁹ This type of clock was obviously such a success that even in the face of more advanced devices, and despite the end of antiquity, it continued to be used. Even a medieval Arabic manuscript in the British Library contains a description of how to build such an outflow clock (Fig. 12–13),⁷⁰ which attests to a much more persistent tradition of this type of clock than previously thought.



Fig. 12 Page 13 of an Arabic manuscript, in which various technological texts are detailed (691/1292 AD).



Fig. 13 Page 10 of an Arabic manuscript, in which various technological texts are detailed (691/1292 AD).

As stated at the beginning of this paper, the study of the use of water clocks to measure time in Greek and Roman antiquity suffers from one major problem: until now, such investigations have relied almost entirely on written sources. Sophisticated devices like the Ctesibius clock left no traces and survived only in descriptions. Yet, as we have seen, nearly thirty outflow water clocks ranging from 1400 BC to AD 300 have been preserved in various states of fragmentation. An inventor’s description, as well as a Greek and an Arabic manual, provide insight into their construction. Even pictorial representations of this instrument in certain contexts are available. Unfortunately, the material

67 This aspect can be attributed to technological progress with reference to Vitruvius. As he reported, it was the Greek engineer Ctesibius of Alexandria who first created an aperture made of gold or a perforated gem for a water clock; see Vitruvius IX 8, 5; cf. Rowland 1999, 116.
 68 M. Lewis 2009, 12–17; Birth 2014, 395–411; Meyer 2014, 109–115.
 69 Borchardt 1920, 9; Winter 2013, 532.

70 The manual is preserved in two Arabic manuscripts: one in the British Library in London (Ms. Or 14270) which is available online, see http://qdl.qa/en/archive/81055/vdc_100023698323.oxo00001 (visited on 23/05/2018), dated 12th October 1292, and the other in the Bibliothèque nationale de France in Paris (Ms. 2468); cf. Wiedemann and Hauser 1915, 25–29.

Bibliography

- Argoud and Guillaumin 1998**
Gilbert Argoud and Jean-Yves Guillaumin, eds. *Sciences exactes et sciences appliquées à Alexandrie: IIIe siècle av. J.-C. – Ier siècle apr. J.-C. XVI*. Saint-Étienne: Publications De l'Université de Saint-Etienne, 1998.
- Barguet 1978**
Paul Barguet. "Remarques sur Quelques Scènes de la Salle du Sarcophage de Ramsès VI". *Revue d'Égyptologie* 30 (1978), 51–56.
- Beagon 2005**
Mary Beagon. *The Elder Pliny on the Human Animal: Natural History Book 7: Natural History*. Clarendon Ancient History. Oxford: Oxford University Press, 2005.
- Bedini and Maddison 1966**
Silvio A. Bedini and Francis R. Maddison. *Mechanical Universe: The Astrarium of Giovanni de Dondi*. Philadelphia: The American Philosophical Society, 1966.
- Bilfinger 1886**
Gustav Bilfinger. *Die Zeitmesser der antiken Völker*. Stuttgart: Carl Liebich, 1886.
- Bilfinger 1888**
Gustav Bilfinger. *Die antiken Stundenangaben*. Stuttgart: Kohlhammer, 1888.
- Birth 2014**
Kevin K. Birth. "The Vindolanda Timepiece: Time and Calendar Reckoning in Roman Britain". *Oxford Journal of Archaeology* 33.4 (2014), 395–411.
- Borchardt 1920**
Ludwig Borchardt. *Die altägyptische Zeitmessung*. Berlin and Leipzig: De Gruyter, 1920.
- Brown 2000**
David Brown. "The Cuneiform Conception of Celestial Space and Time". *Cambridge Archaeological Journal* 10.1 (2000), 103–121.
- Brown, Fermor, and Walker 1999/2000**
David Brown, John Fermor, and Christopher Walker. "The Water Clock in Mesopotamia". *Archiv für Orientforschung* 46/47 (1999/2000), 130–148.
- Chatley 1940**
Herbert Chatley. "The Egyptian Celestial Diagram". *The Observatory* 63 (1940), 68–72.
- Clagett 1995**
Marshall Clagett. *Ancient Egyptian Science: A Source Book II: Calendars, Clocks and Astronomy*. Philadelphia: American Philosophical Society, 1995.
- Cotterell, Dickson, and Kamminga 1986**
Brian Cotterell, Frank P. Dickson, and Johan Kamminga. "Ancient Egyptian Water-Clocks: A Reappraisal". *Journal of Archaeological Science* 13 (1986), 31–50.
- Couchoud 1988**
Sylvia Couchoud. "Calcul d'Une Horloge à Eau". *Bulletin de la Société d'Égyptologie* 12 (1988), 25–34.
- Daressy 1915**
Georges Daressy. "Deux Clepsydes Antiques". *Bulletin de l'Institut Égyptienne* 9 (1915), 5–16.
- Depuydt 1997**
Leo Depuydt. *Civil Calendar and Lunar Calendar in Ancient Egypt*. *Orientalia Iovaniensia Analecta* 77. Leuven: Peeters, 1997.
- Desroches-Noblecourt 1976**
Christiane Desroches-Noblecourt, ed. *Ramsès le Grand. Catalogue de l'Exposition de Grand Palais*. Paris: Presses Artistiques, 1976.
- Diels 1920**
Hermann Diels. *Antike Technik*. 2nd ed. Leipzig and Berlin: Teubner, 1920.
- Dohrn-van Rossum 1992**
Gerhard Dohrn-van Rossum. *Die Geschichte der Stunde. Uhren und moderne Zeitordnung*. Munich: Hanser, 1992.

Dohrn-van Rossum 1995

Gerhard Dohrn-van Rossum. *Die Geschichte der Stunde. Uhren und moderne Zeitordnung*. Munich: Deutscher Taschenbuch Verlag, 1995.

Falk 2000

Harry Falk. "Measuring Time in Mesopotamia and Ancient India". *Zeitschrift der Deutschen Morgenländischen Gesellschaft* 150 (2000), 107–132.

Fermor and Steele 2000

John Fermor and John M. Steele. "The Design of Babylonian Waterlocks: Astronomical and Experimental Evidence". *Centaurus* 42.3 (2000), 210–222.

Flachenecker 1996

Helmut Flachenecker. "Mechanische Uhren". In *Europäische Technik im Mittelalter*. Ed. by U. Lindgren. Berlin: Mann, 1996, 391–398.

Fleury 1998

Philippe Fleury. "Les Sources Alexandrines d'Un Ingénieur Romain au Début de l'Empire". In *Sciences Exactes et Sciences Appliquées à Alexandrie: IIIe Siècle Av. J.-C. – Ier Siècle Apr. J.-C. Actes du Colloque International de Saint-Étienne*. Ed. by G. Argoud and J.-Y. Guillaumin. Saint-Etienne: L'Université de Saint-Etienne, 1998, 103–114.

Grenfell and Hunt 1903

Bernard P. Grenfell and Arthur S. Hunt. *The Oxyrhynchus Papyri III*. London: Egypt Exploration Fund, 1903.

Hölbl 1984

Günther Hölbl. "Die ägyptische Wasserauslaufuhr aus Ephesos". *Jahreshefte des Österreichischen Archäologischen Institutes in Wien* 55 (1984). Beiblatt, 21–68.

Hornung, Krauss, and Warburton 2006

Erik Hornung, Rolf Krauss, and David A. Warburton. *Ancient Egyptian Chronology*. Leiden and Boston: Brill, 2006.

Høyrup 1997/1998

Jens Høyrup. "A Note on Water-Clocks and on the Authority of Texts". *Archiv für Orientforschung* 44/45 (1997/1998), 192–194.

Hunger and Pingree 1989

Hermann Hunger and David E. Pingree. "MUL.APIN: An Astronomical Compendium in Cuneiform". *Archiv für Orientforschung* 24 (1989). Beiheft, 101–102.

Kircher 1654

Athanasius Kircher. *Oedipus Aegyptiacus III*. Rome: Mascardi, 1654.

Last 1924

Hugh Last. "Empedokles and his Klepsydra Again". *The Classical Quarterly* 18 (1924), 169–173.

Leitz 1989

Christian Leitz. *Studien zur Ägyptischen Astronomie*. Wiesbaden: Harrassowitz, 1989.

Leitz 1995

Christian Leitz. *Altägyptische Sternuhren*. Leuven: Peeters, 1995.

Lembke 1994

Kaja Lembke. *Das Iseum Campense in Rom*. Archäologie und Geschichte 3. Heidelberg: Verlag Archäologie und Geschichte, 1994.

D. M. Lewis 2000

David M. Lewis. "The Hellenistic Period". In *Handbook of Ancient Water Technology*. Ed. by Ö. Wikander. Leiden and Boston: Brill, 2000, 631–648.

M. Lewis 2009

Michael Lewis. "A Roman Clock at Vindolanda". *Current Archaeology* 228 (2009), 12–17.

Lodomez 2007

Guy Lodomez. "Les Fragments de Clepsydra de la Dynastie des Argéades". *Chronique d'Égypte* 82 (2007), 57–76.

Long 1989

Charlotte R. Long. "The Gods of the Months in Ancient Art". *American Journal of Archaeology* 93.3 (1989), 589–595.

Mengoli 1989

Pierangelo Mengoli. "La Clessidra di Karnak: L'Orologio ad Acqua di Amenophis III". *Oriens antiquus* 28 (1989), 227–271.

Meyer 2014

Alexander Meyer. "Notes on the Vindolanda 'Calendar': Related Artefacts and the Purpose of the Vindolanda Fragment". In *Life in the Limes*. Ed. by R. Collins and F. McIntosh. Oxford: Oxbow Books, 2014, 109–115.

Michel-Nozières 2000

Catherine Michel-Nozières. "Second Millennium Babylonian Water Clocks: A Physical Study". *Centaurus* 42 (2000), 180–209.

Mills and Symons 2000

Allan Mills and Sarah Symons. "The Karnak Clepsydra". *Bulletin of the Scientific Instrument Society* 66 (2000), 42–47.

Montet 1946

Pierre Montet. "Inscriptions de Basse Époque Trouvées a Tanis". *Kémi* 8 (1946), 29–39.

Mumford 1934

Lewis Mumford. *Technics and Civilization*. London: Routledge & Kegan Paul, 1934.

Neugebauer 1947

Otto Neugebauer. "Studies In Ancient Astronomy VIII: The Water Clock in Babylonian Astronomy". *Isis* 37 (1947), 37–43.

Neugebauer and Parker 1969

Otto Neugebauer and Richard A. Parker. *Egyptian Astronomical Texts III: Decans, Planets, Constellations and Zodiacs*. Brown Egyptological Studies 6. Providence: Brown University Press, 1969.

Parker 1950

Richard A. Parker. *The Calendars of Ancient Egypt*. Chicago: University of Chicago Press, 1950.

Pogo 1936

Alexander Pogo. "Egyptian Water-Clocks". *Isis* 25 (1936), 403–425.

Quack 2003

Joachim F. Quack. "Zum ägyptischen Ritual im Iseum Campense". In *Rituale in der Vorgeschichte, Antike und Gegenwart*. Ed. by C. Metzner-Nebelsick. Rahden/Westf.: Marie Leidorf, 2003, 57–66.

Al-Rawi and George 1991/1992

Farouk N. H. Al-Rawi and Andrew R. George. "Enūma Anu Enlil and Other Early Astronomical Tables". *Archiv für Orientforschung* 38/39 (1991/1992), 52–73.

Roberson 2012

Joshua A. Roberson. *The Ancient Egyptian Books of the Earth*. Atlanta (GA): Lockwood Press, 2012.

Rouillet 1972

Anne Rouillet. *Egyptian and Egyptianizing Monuments*. Leiden: Brill, 1972.

Rowland 1999

Ingrid D. Rowland, ed. *Vitruvius. Ten Books on Architecture*. Cambridge and New York: Cambridge University Press, 1999.

Russo 2005

Lucio Russo. *Die vergessene Revolution oder die Wiedergeburt des antiken Wissens*. Berlin: Springer, 2005.

Schomberg 2017

Anette Schomberg. "'To Amaze the World': A Contribution to the Shape and Meaning of the Water Clock in Antiquity". In *Cura Aquarum in Greece. Proceedings of the 16th International Conference on the History of Water Management and Hydraulic Engineering in the Mediterranean Region, Athens, Greece, 28–30 March 2015*. Ed. by K. Wellbrock. Schriften der Deutschen Wasserhistorischen Gesellschaft 27-1. Siegburg: Deutsche Wasserhistorische Gesellschaft, 2017, 301–340.

Schürmann 1991

Astrid Schürmann. *Griechische Mechanik und antike Gesellschaft*. Stuttgart: Franz Steiner, 1991.

Sethe 1920

Kurt Sethe. *Die Zeitrechnung der alten Ägypter im Verhältnis zu der der anderen Völker*. Göttingen: Nachrichten der Königlichen Gesellschaft der Wissenschaften zu Göttingen, 1920.

Sloley 1924

Robert W. Sloley. "Ancient Clepsydrae". *Ancient Egypt* 9 (1924), 43–50.

Sloley 1931

Robert W. Sloley. "Primitive Methods of Measuring Time". *Journal of Egyptian Archaeology* 17 (1931), 166–178.

Smith 1907

Reginald A. Smith. "Timekeepers of the Ancient Britons". *Proceedings of the Society of Antiquaries of London* 21.2 (1907), 319–334.

Spalinger 1995

Anthony Spalinger. "Notes on the Ancient Egyptian Calendars". *Orientalia* 64.2 (1995), 17–32.

Stutzinger 2001

Dagmar Stutzinger. *Eine römische Wasserauslaufuhr*. Berlin and Frankfurt a. M.: Kulturstiftung der Länder, 2001.

Thureau-Dangin 1932

François Thureau-Dangin. "La Clepsydre chez le Babyloniens". *Revue d'Assyriologie et d'Archéologie Orientale* 29 (1932), 133–136.

Thureau-Dangin 1937

François Thureau-Dangin. "La clepsydre Babyloniennne". *Revue d'Assyriologie et d'Archéologie Orientale* 34 (1937), 144.

Turner 1984

Anthony J. Turner. *The Time Museum I: Time Measuring Instruments*. Rockford, IL: Time Museum, 1984.

von Lieven 2007

Alexandra von Lieven. *Grundriss des Laufes der Sterne. Das sogenannte Nutbuch*. Copenhagen: Museum Tusulanum Press, 2007.

von Lieven 2012

Alexandra von Lieven. "Astronomical Ceilings, Egypt". In *The Encyclopedia of Ancient History*. Ed. by R. S. Bagnall. Oxford: Wiley-Blackwell, 2012, 1–2.

von Lieven 2016

Alexandra von Lieven. "The Movement of Time. News from the 'Clockmaker' Amenemhet". In *Rich and Great. Studies in Honour of Anthony J. Spalinger*. Ed. by R. Landgráfová and J. Mynářová. Prague: Faculty of Arts, Charles University, 2016, 207–231.

von Mackensen 1978

Ludolf von Mackensen. "Neue Ergebnisse zur ägyptischen Zeitmessung. Die Inbetriebnahme und Berechnung der ältesten erhaltenen Wasseruhr". *Alte Uhren* 1 (1978), 13–18.

Warburton 2009

David A. Warburton, ed. *Time's Up! Dating the Minoan Eruption of Santorini*. Aarhus: Aarhus University Press, 2009.

Wiedemann and Hauser 1915

Eilhard Wiedemann and Fritz Hauser. "Über die Uhren im Bereich der islamischen Kultur". *Nova Acta. Abhandlungen der Kaiserlichen Leopoldinisch-Carolinische Deutsche Akademie der Naturforscher. Nova Acta. Abhandlungen der Kaiserlichen Leopoldinisch-Carolinischen Deutschen Akademie der Naturforscher Band C.5* (1915), 1–207.

Winter 2013

Eva Winter. *Zeitzeichen. Zur Entwicklung und Verwendung antiker Zeitmesser*. Berlin and Boston: De Gruyter, 2013.

Young 1939

Suzanne Young. "An Athenian Clepsydra". *Hesperia* 8 (1939), 274–284.

Illustration credits

1 Young 1939, 282 Fig. 4. 2 Neugebauer and Parker 1969, Pl. 2. 3 Desroches-Noblecourt 1976, 141. 4 Borchardt 1920, Pl. 2. 5 Borchardt 1920, 16 Fig. 3. 6 Anette Schomberg. 7 Von Mackensen 1978, Fig. 2. 8 Von Mackensen 1978, Fig. 7. 9 Stutzinger 2001, Fig. 2. 10 Birth 2014 Fig. 1. 11 Anette Schomberg. 12 San'at al-zāmir صنعَة الزامر Apollonius the carpenter and geometer أبلونيوس النجار الهندسي [20r] (13/15), British Library: Oriental Manuscripts, Or 14270, ff 14r-21r, in

Qatar Digital Library <https://www.qdl.qa/archive/81055/vdc_100023867439.0x00002e> [accessed 7 June 2018]. 13 San'at al-zāmir صنعَة الزامر Apollonius the carpenter and geometer أبلونيوس النجار الهندسي [18v] (10/15), British Library: Oriental Manuscripts, Or 14270, ff 14r-21r, in Qatar Digital Library <https://www.qdl.qa/archive/81055/vdc_100023867439.0x00002b> [accessed 7 June 2018]. 14 Anette Schomberg (Berlin Waterclock Project).

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