From Hydrology to Hydroarchaeology in the Ancient Mediterranean

Edited by

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Cover: A public cistern of the Solunto agora. Photo by Giovanni Polizzi

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Contents

Introduction

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This work appears as part of an interdisciplinary programme, supported by the Foundation A*Midex between 2018–2021, which encourages cross-interdisciplinary initiatives on complex issues to advance knowledge in fields previously exploited by parallel disciplines, and to build knowledge shared by people from different backgrounds.[1] It follows on from a previous programme that led to the creation of an international network on water issues in pre-Roman societies: HYDRΩMED.[2] Within this framework, a scientific meeting was organised at Aix-Marseille University in May 2019 to strengthen links between archaeology and environmental sciences around water resources in ancient times, in terms of selected topics.

Context

Research on water has been generally conceived of within an environmental framework and focused on the issue of the contemporary risks and deficits of a resource threatened by climate change and anthropogenic over-exploitation, giving rise to latent crisis situations or open war in some parts of the world,[3] including the Middle East, as highlighted in certain international reports.[4] However, except for work on the Palaeolithic, or periods prior to the appearance of the human species, we too rarely have taken into account the natural habitat of ancient societies, faced with hydric situations comparable to those we know today. Thus, some teams have conducted pioneering work on a conceptual level, essentially on the palaeoclimate and on the very long duration, as, for example, the CEREGE project at Aix-Marseille University, with the work of Joël Guiot and his colleagues from the European Pollen DataBase:[5] the stated goals are clearly helping the understanding of contemporary climate change using the Quaternary palynological data.

In the Mediterranean area, the development of societies has always been intimately tied to the management of water resources. Very early on, from the 6th millennium BC, in Mesopotamia the first hydraulic facilities appeared, with the intention, among other things, of irrigating cereal crops.[6] These modifications to the hydrographic network, such as the digging of canals and the deviation of rivers by humans, produced major changes in the environment, itself subject to external forces (climate, eustasy, tectonics). This changing environment has had a significant impact on the establishment of occupation from the Neolithic, as shown, for example, in the articles by Ollivier[7] on the region of the Lesser Caucasus (Georgia, Armenia and Azerbaijan), as well as on water and land use management strategies.[8]

In addition, there is the vulnerability of populations, from the Mediterranean to the Caspian Sea basin, to seismic risk. This is often tragically illustrated,[9] to cite only recent earthquakes. The convergence of the Eurasian, African and Arabian plates creates an important regional North–South shortening, shaping landscapes and exposing prehistoric and historical societies to seismic hazards. These events affect also the hydraulic structures and methods of water supply and management.

In the field of archaeology *stricto sensu*, for a long time research has focused on two different and sometimes complementary aspects: ancient architecture and technological knowledge, political management of water systems.[10] The interest has been primarily focused on hydraulic facilities from an architectural point of view, and the technological knowledge that ancient civilizations, particularly the Mesopotamians and Romans, were able to develop in their own way, or from knowledge gained from societies that had preceded them in the Mediterranean. Most of the projects and international conferences, including

[1] The project leading to this publication has received funding from Excellence Initiative of Aix-Marseille University – A*Midex, a French 'Investissements d'Avenir' programme.
[2] https://hydromed.hypotheses.org/.
[3] Lasserre and Descroix 2011.
[4] Cf., e.g., the study of the World Resource Institute, American National Center for Environmental Research: Luo *et al.* 2015.
[5] http://www.europeanpollendatabase.net/index.php.
[6] Sherratt 1980.
[7] Ollivier 2022, Ollivier *et al.* 2018.
[8] Ricci *et al.* 2012.
[9] Notably the 1988 Armenian earthquake, in Spitak, Ms 6.7, Westaway, 1990; the 1908 earthquake in Messina, Sicily, Ms 7.1; the 1977 earthquake in Vrancea, Romania, Ms 7.2.
[10] Bouffier 2019: 5–9.

those organised through the *Cura Aquarum* network by the Foundation Frontinus-Gesellschaft or the Deutsche Wasserhistorische Gesellschaft, have focused on technical, especially architectural, systems developed by the Romans.[11] The network HYDRΩMED highlighted pre-Roman water cultures, seeking to fill a documentary gap about cultures that have been neglected by traditional historiography.[12] Apart from the history of ancient technology, political history has been favoured, especially in the wake of Karl August Wittfogel,[13] as evidenced by publications on politics of the Assyrian Kings,[14] or the special issue of the *Annales. Histoire, Sciences Sociales* dedicated to *Politique et contrôle de l'eau dans le Moyen-Orient ancien*.[15]

The first joint investigations occurred between archaeologists, historians and environmentalists concerning the great rivers exploited for their drinking or irrigation water, notably those of the Tigris, Euphrates, and Nile.[16] It was between prehistorians that the closest and earliest dialogue was developed: on the site of Aix-Marseille, where work in geomorphology on the rhythms of sedimentation in water courses under climate and/or anthropogenic control in Mediterranean mountain areas initiated the first long-term collaborations.[17] Other partnerships in the fields of coastal and fluvial geomorphology, with the work of Philippe Leveau, Mireille Provansal, and Christophe Morhange,[18] and naval and maritime archaeology, by Giulia Boetto and Valérie Andrieu-Ponel, have also been developed recently.[19]

Collaboration is today more regular and seems both natural and necessary, but it is not sufficiently structured and leaves still a whole section of research undeveloped. In hydraulic topics, there have been some first initiatives from the end of the 1990s.[20] The interdisciplinary perspective gave archaeologists the opportunity to access closer readings on the problems faced by ancient users and the solutions adopted in response to variable resources due to climatic and geomorphological reasons. The water work developed in the arid and semi-arid areas, ranging from the valleys of the Tigris and Euphrates, passing through the Valley of the Nile as far as the shores of the Aegean Sea, underlined that in these regions, hydraulics developed under different natural constraints. In Alexandria, for example, these experiences gave birth to inventions, technology, and then to a science – a prelude to the Alexandrine innovations in the 3rd century BC. The confrontation between rational Greek thought and the hydraulic know-how of the East gave birth to a new science that began with Archimedes' hydrostatics and the first devices functioning with water pressure. Archimedes (287–212 BC) introduced into science various hydraulic machines, such as the shaduf, in use for millennia, and the screw. In the same epoch, the *sakieh* for irrigation, or the bucket chain, spread in Egypt. The Hellenistic world would rely on this major innovation to develop its agriculture by extending irrigated land. At the same time, archaeological research focused on the more unusual aspects of the history of techniques, such as running water networks[21] or evacuation practices,[22] in connection with the current issues of environmental pollution, and land irrigation.[23]

Additionally, the HYDRΩMED programme has encouraged an international network to emerge, establish partnerships, and evaluate hydraulic knowledge, even if over only a limited period, the 1st millennium BC, and in a limited geographical area: the Mediterranean. The network thus highlighted what was necessary to encourage and develop. Five international meetings have focused on four main themes:[24] the climatology and hydrology of the Mediterranean in the 1st millennium BC; ancient hydraulic facilities and exploitation of natural resources; history of science and technology in relation to economic and political history; and cults and cultures of water and waters. These conferences evaluated our knowledge of the different pre-Roman societies – including the Greek, Phoenician-Carthaginian, and Iberian worlds – in political, technological, and cultural areas. They also underlined insufficient exchanges between geosciences and archaeology, especially in the restitution of the natural conditions of past societies and the resources available, as highlighted by the 3rd international symposium (March 2016, *Geoarchaeological and palaeoenvironmental approaches to water resources management in Antiquity*),[25] which documented the findings of several researchers from France, Germany, England, Scotland, Spain and Austria, specialists in palaeoenvironmental (paleoclimatology, paleohydrology) and geoarchaeological issues

[11] Bouffier 1919.
[12] Bouffier and Fumadó Ortega 2020; Robinson, Bouffier and Fumadó Ortega 2019; Fumadó Ortega and Bouffier 2019; Bouffier, Belvedere and Vassallo 2019.
[13] Wittfogel 1957.
[14] Masetti-Rouaux and Defendenti 2020; Bagg 2000.
[15] 2002/3; 57e année.
[16] Hairy 2010.
[17] See the summary in the festschrift to Maurice Jorda led by Miramont 2004; and also, Provansal 1995; Bruneton1999; Ollivier 2006.
[18] Leveau and Provansal 1993; Leveau 2011; Morhange 1994.
[19] Boetto *et al.* 2012.
[20] The French School of Athens' programme on ancient water at Delos, 1999–2004: Brunet 2008; Desruelles and Fouache 2015; at Delphi, Perrier *infra*, the programme on water at Syracuse: Bouffier *et al.* 2018; in the Roman field, Hélène Dessales' work (2013).
[21] Abadie-Reynal *et al.* 2011.
[22] Bouffier and Brunet 2020; Nenna 2010.
[23] Bouffier 2002.
[24] Bouffier, Belvedere and Vassallo 2019; Bouffier and Fumadó Ortega 2020; Fumadó Ortega and Bouffier 2020; Robinson, Bouffier and Fumadó Ortega 2019.
[25] https://calenda.org/357764?formatage=print&lang=en. The meeting remains unpublished.

associated with the management of hydric resources. In terms of the Mediterranean climate, for example, Joël Guiot's work suggested mathematical modelling from pollen data, but for the ancient Mediterranean climate, and ongoing discussions show a complex situation, as data is too rare, with archaeologists from these regions still mostly unaware of palynological sampling.

Thus the *Watertraces* project has been conceived as part of closer links between environmental sciences and archaeology, which began at Aix-Marseille University with one-off collaborations, especially on Mediterranean fluvial-deltaic environments and the Mediterranean ports and environmental mountain changes. This has brought together historians and archaeologists, as well as hydrology, geology, and tectonic specialists, who worked on hydrologic and hydraulic problems – with investigations common to the humanities, social sciences and geosciences, sometimes using common methods and tools, but also specific ones. The aim was to understand the functioning of water resources in past societies, so as to draw lessons for our current behaviour, and the protection of a resource which has been declared a future scarcity. The interdisciplinary dialogue relied on specific methods: data archives, prospecting, excavations and samples, as well as physicochemical analyses which gave rise to confrontations between archaeologists, historians and environmentalists.

Project objectives

The project's aim was to highlight the resources around which human societies choose to settle, and their coping strategies when faced with a resource that is either too rare or too abundant. Investigations focused along three axes:

1. To procure water: the state of the resource

Near to which resources do human societies settle? What quality of water do they look for? What quantity of water do they use? Has the resource varied over the course of history? In what proportions? Why? For example, the formation of carbonated deposits in old aquatic systems is a source of data on climate and the gradual change in source water properties, but also a source for understanding the functioning of hydraulic systems: why were certain structures built the way they were? What knowledge do they reveal and how have they evolved? Can we identify knowledge transfer? How have water systems evolved? How long did they work? We asked all these questions when comparing water systems from different parts of the Mediterranean and the areas surrounding it. The interdisciplinary teams worked on several Mediterranean sites that offered different geomorphological and hydrological situations, such as sedimentary and semi-lagoon environments (Egyptian Alexandria, Sicilian Syracuse, Arpi in southern Italy), karstic ones (Solunto**,** Syracuse, Taormina in Sicily, Nimes in France, Locres Epizephyrii in southern Italy), clay and marshy soils (Arpi in southern Italy), karst, dolomite, marls, sandstones and terra rossa (Loron in Croatia). Some of their results are presented in this volume (Solunto).

2. Water storage: waterproofing processes of hydraulic facilities

The aim here was to study, from a technical point of view, the process of waterproofing hydraulic facilities by means of hydraulic mortars, a field still insufficiently developed in archaeology. The presence and type of coatings need investigating to find cases of permanency and ruptures of technologies over time. Archaeologists are often faced with hydraulic installations that have been used over a very long period, without it being possible to date the construction and clarify the chronology of human occupation. The good functioning of the construction, through regular maintenance and repair, obliterates previous traces. The nature and composition of waterproofing mortars could provide clues for dating, but also give us information about the materials and the techniques used, that might reveal the artisans' know-how, circulation of materials, and technologies. Archaeological research is very underdeveloped on these aspects. For the Roman epoch, the architect Vitruvius left a work of incomparable value, providing us with a technical presentation on hydraulic mortars, concentrating only on *pozzolana*, whereas for earlier periods, and in the majority of Roman provinces, a crushed terracotta mortar was mainly used, so that archaeologists associate almost systematically crushed terracotta mortar with hydraulic structures. Actually these crushed terracotta mortars can be used in several contexts, being mainly characterised by their superior mechanical resistance, and thus considerable durability. The project under discussion, in addition to an in-depth literature review about hydraulic mortars, will allow advances to be made in terms of the physical characteristics of mortar samples from sites (porosity, capillary action, porometry, etc.), their mineralogical characteristics, certain possible organic additions (fats, oils, etc.) capable of providing waterproofing properties to these materials, chalk-crushed terracotta mortar reactions (*pozzolanic* reaction), and the study of their impact on the properties of these materials.

The *Watertraces* project programmed sample collection and systematic analysis at the sites studied within its framework, proposing further identification protocols available to all. The aim was to develop petrographical and chemical studies to determine the composition

of mortars, the provenance of granulates, and the hydraulicity factors of these mortars. In partnership with the *Centre interdisciplinaire pour la conservation et la restauration du Patrimoine* (CICRP, Marseilles) studies have been conducted to identify the materials and production techniques by observing them through stereoscopic or optical microscopes, complemented by chemical and particle size analyses, by mineralogical characterisations by X-ray diffraction on powder, and observations and analyses basic to the electronic scanning microscope, coupled with an energy dispersive spectrometer; whereas dating can be given by the street furniture found in stratigraphy at the site. A 'Mortars' database has been initiated on the French Archaeological Platform ArkeoGis[26] that provides the scientific community with the wide range of mortars and techniques developed by ancient societies.

3. Water Loss? The concretions, seismic risks, the natural vicissitudes of hydraulic facilities

One of the realities that archaeologists often have to face is the deterioration of facilities due to both anthropogenic and natural causes, particularly tectonic ones. The observations between geologists and archaeologists, which began with an example from Sicily, with the traces left by the earthquakes of the 17th century, particularly the 1693 Noto earthquake, on the hydraulic facilities and attested to by archives of the era, should encourage the highlighting of recurring phenomena in the history of local societies. Among the structural drivers that can cause damage to hydraulic infrastructures (erosion, floods, defects, wear and tear, defective maintenance, etc.),[27] the seismic component is one of the most radical and widespread within the geographical area included in our programme. Occasionally, main and/or secondary faults can promote hydrothermal lifts supplying sites (i.e. Solunto[28] or Germisara[29]), potentially steering the organisation of hydraulic infrastructures and urban morphology. At other times they can partly control the route of aqueducts or accentuate the loss of water from such structures, as we can find at Syracuse.

This present volume, therefore, proposes some current reflections on these questions, as well as some results to date from this programme, as well as showing work in progress and offering new ways of thinking. Centre stage is given to seven interdisciplinary teams, who have worked in various fields.

As a concise introduction to the relevant work from Sicily, Salvatore Pasta and his coauthors present the most recent discoveries and hypotheses concerning the factors driving human subsistence economy and landscape shaping during the Holocene, while explaining the role played by different disciplines (geology, paleogeography, climatology, palynology, archaeobotany, archaeozoology, anthropology, archaeology) in reconstructing the palaeoenvironment of the largest island in the Mediterranean. They do not overlook that the historical approach also makes it possible to highlight past episodes of unsustainable land-use and mankind's action on the environment, while the paleoclimatic studies emphasise the favourable/unfavourable conditions for the development of forests and vegetation long before the historical period. The seismic events appear to have played a major role in the socio-economic evolution of populations, particularly in the Aeolian islands. A wide assessment of the presence of man since his late arrival in Sicily, within a time lapse of 20.0 to 15.0 cal ka BP, assesses the development of the island's settlement process.

Several contributions here, mostly focused on Sicily, highlight sites that have been the object of interdisciplinary projects between archaeologists and environmentalists.

Antonio Contino, Patrizia Bova,[30] and Giuseppe Esposito look at northern-central Sicily, especially the Trabia-Termini Imerese mountains. The geological study, combined with the historical approach, sheds light on water resources in the Augustan colony of Termini Imerese. The ancient town was supplied via an aqueduct that brought potable water from the springs of Brocato-Fridda and Favara-Scamaccio. The team presents the history of this aqueduct, in association with climatic vicissitudes that forced the authorities to overhaul and restore it several times during its history until the output from the Favara-Scamaccio springs ceased. This case-study is paralleled with another aqueduct at Galermi (Syracuse), restored on several occasions and studied by an interdisciplinary team from Aix-Marseille University.[31] Both monuments show how past hydraulic installations evolved and were transformed by local populations to meet their needs.

Aurelio Burgio's contribution looks at the countryside around the ancient city of Alesa, which is known, fortunately, thanks to an archaeological survey and the extant epigraphy. The fact that prospection teams are now interdisciplinary makes it possible to cross-reference data and raise questions that archaeologists have not been used to asking, or could not answer.

[26] The 'Mortars' database has been initiated on the Publication Platform ArkeoGis: https://app.arkeogis.org/#/database/562
[27] Passchier *et al.* 2013.
[28] Polizzi *et al.* 2017.
[29] Ollivier *et al.* 2008.
[30] Very sadly, Patrizia Bova left us in 2021 and will not see the publication of her chapter; we would like here, of course, to salute her memory.
[31] Bouffier and Wateau 2019.

Luca Zambito examines the Agrigento region, richly endowed with sulphurous springs and mineral deposits which ancient populations exploited for thermal and therapeutic purposes, and where ancient groups established cults, and passed down their legends.

Giovanni Polizzi, Vincent Ollivier, and their colleagues, present the ancient cities of Solunto, on an intensely fractured dolomitic limestone massif, and Tindari, situated on metamorphic rocks, limestones and flysch, affected by deep karst/pseudo-karstification processes in the fractured areas. Previously considered to be exclusively from the collection of rainwater through systems of tanks, the water supply to the site appears, in fact, to be much more abundant and more complex. This seems to have resulted from the exploitation of systems of tectonic fractures guiding hydrothermal lifts, and to have provided additional and sustainable thermal mineral water via a significant number of the identified hydraulic infrastructures.

Two further papers extend beyond this geographical area – one relating to Campanian Baia, characterised by its volcanic geological situation, and the other to Apollo's famous sanctuary at Delphi.

Daniele De Simone's ongoing PhD is exploring Baia's thermal Baths, a huge architectural and engineering complex that has exploited the numerous hydrothermal springs of the Phlegrean fields from at least the 3rd/2nd c. BC. Notably, the area lacks drinking water and the Romans were obliged to construct an entire water collection, storage, and distribution system – initially relying on rainwater, then constructing a huge aqueduct, the 'Acqua Augusta' pipeline, in the 1st c. BC. The chapter starts with the geomorphology of the area, highlighting the expedients used by Roman designers (from the Late Republican era to the entire 4th c. AD., to exploit these exceptional resources.

Crossing to the Greek Cyclades, Amélie Perrier, Isabelle Moretti, and Luigi Piccardi focus on the natural calamities experienced by the celebrated Sanctuary at Delphi, which suffered from many disasters, such as earthquakes and landslides. The team from the French School of Archaeology at Athens, with its long association with the site, start by looking at the architectural remains, and using a geological approach, show how the buildings were damaged, how the ancient Greeks approached the natural hazards, and how they responded to water-related risks by exploiting them and channelling the water to their own ends.

Thus this present volume, modestly aims to shed light on the new paths that have emerged and linked our teams of classical archaeologists. If perhaps not exactly new in terms of several of the fields we explore, then these paths have been insufficiently followed in the past, and the creative dialogue between ourselves and geomorphologists have allowed us to understand many situations we have found obscure, especially in the field of hydraulics.

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