Trends in the History of Science

Ana Duarte Rodrigues
Carmen Toribio Marín
Editors

The History of Water Management in the Iberian Peninsula

Between the 16th and 19th Centuries

Birkhäuser

Birkhäuser

Trends in the History of Science

Trends in the History of Science is a series devoted to the publication of volumes arising from workshops and conferences in all areas of current research in the history of science, primarily with a focus on the history of mathematics, physics, and their applications. Its aim is to make current developments available to the community as rapidly as possible without compromising quality, and to archive those developments for reference purposes. Proposals for volumes can be submitted using the online book project submission form at our website www.birkhauser-science.com.

More information about this series at http://www.springer.com/series/11668

Ana Duarte Rodrigues ·
Carmen Toribio Marín
Editors

The History of Water Management in the Iberian Peninsula

Between the 16th and 19th Centuries

Birkhäuser

Editors
Ana Duarte Rodrigues
Centro Interuniversitário de História das Ciências e Tecnologia,
Faculdade de Ciências
Universidade de Lisboa
Lisboa, Portugal

Carmen Toribio Marín
Escuela Técnica Superior de Arquitectura
Madrid, Spain

CIUHCT

FCT
Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

This work was supported by the Fundação para a Ciência e Tecnologia under the research projects IF/00322/2014 and PTDC/HARHIS/28627/2017.

ISSN 2297-2951 ISSN 2297-296X (electronic)
Trends in the History of Science
ISBN 978-3-030-34060-5 ISBN 978-3-030-34061-2 (eBook)
https://doi.org/10.1007/978-3-030-34061-2

This book is published under the imprint Birkhäuser, www.birkhauser-science.com by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

The Thirsty but Educated Iberian Peninsula. As a Means of Introduction

The historical *Erlebnis* of the Iberian Peninsula made this territory into a cultural melting pot of Arabic culture, Islamic science, and the later accelerating engineering of Northern Europe. This melting pot developed over a centuries-long temporal dynamic that took place within a peculiar territorial and environmental context. This book explores the characteristics of such a melting pot by adopting a most fundamental material perspective, specifically, by focusing on the most relevant and pervasive of human needs: water.

Several overarching categories have been identified to trace the history of the role and utilization of water and the knowledge that was thereby created, accumulated, forgotten, re-created, and circulated about and because of the sheer need for water. Such categories, expressed in the main sections into which this book is divided, focus on the systems of water supply, on the capacity of changing and intervening at the landscape level, on the systems developed to manage such changes alongside the water systems themselves, and, finally, on the development of scientific knowledge itself, both theoretical and practical, because of and for the efficient use of water.

Such an ambitious plan cannot be realized by looking at a mere handful of case studies, geographically and temporally isolated from each other. The view thus needs to be broad and long, and the papers collected in this volume do, indeed, cover the Iberian Peninsula, both through single centers such as Lisbon, Madrid, Seville, and Toledo and entire regions such as the Algarve and the Guadarrama Mountain Range. Concerning the temporal distribution of the research set out in this volume, while the focus certainly falls on the early modern period, the previous centuries have not been disregarded, with the subsequent developments of the eighteenth and nineteenth centuries receiving particular consideration. This approach made a full display of the historical dynamics possible.

The aforementioned collective categories hold value as a means of orientation for observers who wish to take a step back and for those who desire a top-down perspective to study the culture of water. Nevertheless, several further readings of the historical material and the historical reconstructions are also plausible. For instance, it is possible to develop a rather anthropological, and somehow operative, approach to the same material. Accordingly, the collective categories may be disentangled along axes that ultimately assume an epistemic and hermeneutic nature.

A history of the culture of water may therefore be traced by following, firstly, the needs and urgencies related to water usage throughout history, secondly, the mechanisms that enabled both solutions to such urgencies and the means of satisfying those needs, and, finally, the historically realized solutions and just how their implementation processes were managed. All possible dimensions fit into the framework of this perspective. In particular, the historical reconstruction of the mechanisms that allowed for the search for solutions cannot but take into consideration the real social, political, and economic context in which such needs and urgencies emerged and were recognized.

Below, I would like to try to furnish a transversal reading in keeping with these three steps—needs, the search for solutions, and the solutions—as a means of introducing this volume.

The first and most relevant among these needs relates to the most fundamental facet for life: thirst. Thirst is historically associated with processes of urbanization, and this volume considers many of them according to this perspective. The cases of early modern Toledo (Chapter "Toledo: The Thirsty City") and Madrid (Chapter "Water for Madrid: The Problems of Water Supply in a Pre-industrial Capital") after the arrival of the Royal Court are fundamentally representative of this perspective. Urbanization, however, while being the most relevant of the processes that trigger the need for water, is not unique. On a minor scale, we may observe the *in-loco* movements of the court, for instance, within the same city or the necessity to develop new areas as expansions of already established and populated centers, as in the case of early modern Lisbon (Chapter "The Water Supply and Sewage Networks in Sixteenth Century Lisbon: Drawing the Renaissance City). Thirst, moreover, is not only a human need, but also one of animals and plants. Agriculture and farming in general therefore provide the frameworks in which, during landscape transformation processes, water needs arise in the respective regions involved. Thirst, therefore, constitutes the primary factor responsible for the development of water supply and irrigation systems (Chapters "Toledo: The Thirsty City", "Landscape and Water Heritage in Mountainous Areas: From the Atlantic to the Mediterranean, from Northern Portugal to Southern Morocco", "The Water that Passes Through Alcoa and Baça: The Hydraulic System of the Monastery of Alcobaça").

The second of the needs in terms of water's relevance for life involves attaining appropriate hygienic levels in areas where life is supposed to be preserved. In this respect, there is an explanation of the ample history of building sewage systems (Chapters "The Water Supply and Sewage Networks in Sixteenth Century Lisbon: Drawing the Renaissance City", "Toledo: The Thirsty City", "Water for Madrid: The Problems of Water Supply in a Pre-industrial Capital", "Engineering, Geology and the Water Supply to Lisbon in the Second Half of the Nineteenth Century. Expertise and Innovation"). But not only this, any kind of washing or laundry activity may also be approached from this angle (Chapter "The Water Supply and Sewage Networks in Sixteenth Century Lisbon: Drawing the Renaissance City").

Such fundamental needs are clearly interconnected and interwoven with the natural context, specifically, the given conditions that prevail in the territory under study. The specific orographic, geological, geographic, and meteorological conditions of the Iberian Peninsula, and of some of its regions, therefore cannot be excluded from the analysis of its needs for water. These aspects, resumed as aspects belonging to the general environmental dimension, are necessary to understand the human interventions undertaken as the ways and means of satisfying these needs. In particular, this incorporates the relevance of analyzing precipitation rates and the climate in general (Chapters "Dams in the Renaissance Gardens of the Iberian Peninsula", "The Technical and Social Scope of Irrigation in the Algarve"), the disposition and characteristics of the rivers (Chapter "Water for Madrid: The Problems of Water Supply in a Pre-industrial Capital", "Aranjuez and Hydraulic Engineering: Public Utility, Leisure Utility"), and the natural sources of drinkable water (Chapter "Engineering, Geology and the Water Supply to Lisbon in the Second Half of the Nineteenth Century. Expertise and Innovation").

The needs or urgencies described above emerge in concomitance with specific processes of institutional, social, economic, or even territorial nature. Therefore, any attempt to satisfy such needs relates to the context in which they emerge. I would therefore suggest differentiating and distinguishing among six major areas within which the contributions to this volume reconstruct the major characteristics of such contexts. These are the dimensions of a political, social, cultural, economic, normative and territorial-technical nature. Beginning with the last, this refers to a context in which two aspects can be determinant. First, when specific territorial organizations already exist and constitute, in conjunction with the local population, a traditional social-environmental ecosystem. Second, when a specific technical infrastructure, already in place as inherited from the past and not easily replaced or dismissed, represents the pivot around which further developments can take place. The first case refers to specific communities, such as mountain settlements, where the construction and management of the *caceras* or ditches, for instance, form part of an ecosystem in such a way that any change could not avoid taking them into consideration (Chapter "Water Communities on the Northern Slopes of the Guadarrama Mountain Range"). An example of the second case stems from the technological artifacts that have lasted over millennia, such as the great dams (Chapter "Dams in the Renaissance Gardens of the Iberian Peninsula"). The inheritance of social–technical ecosystems hints at the social dimension *tout-court*. The existence of traditional communities, as is the case with the aforementioned mountain communities, ensures a social context that cannot be instantaneously changed. They determine the conditions according to which the water supply and irrigation systems, for instance, can be set up and managed. The already referenced processes of urbanization, moreover, are not only the driver of the dramatic emergence of the need for drinkable water, but also represent the mechanisms that enable the satisfaction of such needs during, for instance, the construction of new urban areas and the decision as to how to govern them, as well as their target social groups (Chapter "Water Supply Management in Seville, 1248–1800"). Social structures often seem to be in conflict with the interventions necessary to satisfy such needs. This is the case both when social hierarchies are maintained while designing water supply systems (Chapter "The Water Supply and Sewage Networks in Sixteenth Century Lisbon: Drawing the Renaissance City") and when it becomes clear that social relationships among societal groups have dramatically changed *because* of the introduction of a new water supply system (Chapter "The Technical and Social Scope of Irrigation in the Algarve").

The social dimension intrinsically interconnects with the political domain. Within this framework, the historical cornerstones are represented by the political will to possess power, to achieve visibility, and to display prestige. Early modern courts especially acted within such a political framework, which, in turn, also determined, or at least influenced, the decisions made to solve the problems related to water usage. The need to establish the court of Lisbon as the central power (Chapter "The Water Supply and Sewage Networks in Sixteenth Century Lisbon: Drawing the Renaissance City"), the development of monumental architecture in Portugal as a way of expressing power and prestige (Chapter "Technology of Grandeur: Early Modern Aqueducts in Portugal"), the case of converting a city into a capital, such as that of Madrid (Chapter "Water for Madrid: The Problems of Water Supply in a Pre-industrial Capital"), and the quest for political autonomy by the heads of specific local bodies (Chapter "Thirsting for Efficiency: Technological and Transaction-Cost Explanations for the Municipalisation of Water Supplies") account for only a few of the cases that display the sheer relevance of the political and social context to designing and implementing the means to satisfy water-related needs.

Politically driven decisions, moreover, always incorporate an externalization that takes on the form of a normative structure. This is most evident in all of the historically identified attempts to rule over the distribution of water (Chapter "The Water Supply and Sewage Networks in Sixteenth Century Lisbon: Drawing the Renaissance City"), regulation over the application of water technology (Chapter "Toledo: The Thirsty City"), rule over the maintenance of water-related apparatuses (Chapter "Water Supply Management in Seville, 1248–1800"), and the various attempts to establish a balance between water supply and sewage systems (Chapter "Thirsting for Efficiency: Technological and Transaction-Cost Explanations for the Municipalisation of Water Supplies").

From a more general point of view, all of these dimensions display a dynamic that is susceptible to interpretation as a result of more profound cultural tendencies. These relate to the existing traditions, the identity of localities, regions, cities, and societal groups, and their habits, such as those in relation to leisure, itself a fundamental subject within the scope of water culture. The traditions of knowledge, and even their coexistence, represent the main paths along which history is able to convey their reconstruction. In reference to the Iberian peninsula, one fundamental coexistence is the one of the Latin and Islamic scientific traditions (Chapter "Toledo: The Thirsty City"). Both of these traditions trace their most fundamental roots all the way back to the Hellenistic epoch and classical antiquity (Chapter "Technology of Grandeur: Early Modern Aqueducts in Portugal"). Indeed, the underlying technical and management traditions for the exploitation and usage of water can also be detected and traced along such long historical axes (Chapters "Water Communities on the Northern Slopes of the Guadarrama Mountain Range", "Landscape and Water Heritage in Mountainous Areas: From the Atlantic to the Mediterranean, from Northern Portugal to Southern Morocco", "The Technical and Social Scope of Irrigation in the Algarve").

Such traditions tend to be reinforced, whether by strong identities or by processes of identity formation, as in the case of Toledo and its great technical achievements in the water supply system (Chapter "Toledo: The Thirsty City"). They may also be reinforced by the habits of social groups, for instance, when concerning the significance of leisure and of places of leisure, such as gardens. Gardens, *cigarrales*, with or without orchards, and country villas feature as some of the possible locations where the habits and identities of social groups went on display, both while such places were being designed and while they were being used. Such architectural achievements, moreover, provided an immediate means of entering into dialog with the major cultural and scientific partners of modern Europe (Chapters "Toledo: The Thirsty City", "Aranjuez and Hydraulic Engineering: Public Utility, Leisure Utility"). The interplay between farming and gardens, typical of the early modern period, is reproduced in the Iberian Peninsula according to a distinct, tradition-based approach (Chapter "Dams in the Renaissance Gardens of the Iberian Peninsula"), not only because of technical and architectural facets, but also because of traditional and regional esthetic values (Chapter "The Aesthetical Application of Water in Iberian Gardens").

The bench proof of culture and traditions always turns out to be the processes of transformation, whether of a technical, social, or political nature. Such processes began being discussed when the needs mentioned above became recognized as problems requiring solutions on large scales. This opens up the dimension of public utility as a political and, sometimes, rhetorical means of forcing changes to traditions and culture. The public utility dimension, in turn, emerges as the economic context in which solutions are sought out. The real economy is present in these studies in a variety of ways: for instance, when discussing the investments required to build technological infrastructures (Chapter "Water Supply Management in Seville, 1248–1800") or to establish new urban areas (Chapter "The Water Supply and Sewage Networks in Sixteenth Century Lisbon: Drawing the Renaissance City") or new waterways for communication and transportation (Chapter "Aranjuez and Hydraulic Engineering: Public Utility, Leisure Utility").

It is this last dimension—the economic dimension—that finally opens the doors to studying the solutions actually implemented in the Iberian Peninsula. Facing the need for investments, in fact, required solutions for collecting the necessary investment capital, its institutional location, and its management. References here span the taxation rules (Chapter "The Water Supply and Sewage Networks in Sixteenth Century Lisbon: Drawing the Renaissance City"), the fundamental roles of municipalization processes (Chapter "Thirsting for Efficiency: Technological and Transaction-Cost Explanations for the Municipalisation of Water Supplies") and private capital (Chapter "Water for Madrid: The Problems of Water Supply in a Pre-industrial Capital"), and, finally, managing the technical solutions when they are already in effect (Chapters "Water Supply Management in Seville, 1248–1800", "Water Communities on the Northern Slopes of the Guadarrama Mountain Range", "Landscape and Water Heritage in Mountainous Areas: From the Atlantic to the Mediterranean, from Northern Portugal to Southern Morocco").

In turn, the management dimension should be subdivided into two different branches. While, on the one hand, management initially means the collection, use, and distribution of the capital for investment in territorial interventions and/or the construction of technological devices, management is also required, within the frame of exploiting the new technical systems that are set up, to satisfy water-related needs. This second aspect of management, however, cannot be fully understood when not closely connected with the study of the technology itself. The great dimension of water technology ranges from the exploitation of water resources (Chapter "The Water Supply and Sewage Networks in Sixteenth Century Lisbon: Drawing the Renaissance City") and the construction of huge infrastructures, such as aqueducts (Chapters "The Water Supply and Sewage Networks in Sixteenth Century Lisbon: Drawing the Renaissance City", "Water Supply Management in Seville, 1248–1800", "Technology of Grandeur: Early Modern Aqueducts in Portugal") and dams (Chapter "Dams in the Renaissance Gardens of the Iberian Peninsula"), to the use of devices such as different kinds of water wheel (Chapters "Toledo: The Thirsty City", "The Technical and Social Scope of Irrigation in the Algarve", "*Noras*, *Norias* and Technology-of-Use"), wells and cisterns (Chapter "The Water Supply and Sewage Networks in Sixteenth Century Lisbon: Drawing the Renaissance City"), and ditches and canals (Chapter "Water Communities on the Northern Slopes of the Guadarrama Mountain Range"), as well as to entire systems (Chapters "The Water Supply and Sewage Networks in Sixteenth Century Lisbon: Drawing the Renaissance City", "Thirsting for Efficiency: Technological and Transaction-Cost Explanations for the Municipalisation of Water Supplies").

The needs, the contexts in which solutions emerged and the actual solutions themselves tell a story of an anthropological nature that, however, does not yet consider one of the most relevant actors in this story: knowledge. Knowledge displays historical dynamics that balance tradition and innovation, practical applications, and theoretical developments; it needs carriers for its transmission over time and space, and therefore easily gets forgotten. The first and most natural knowledge carriers are individuals, such as the many experts in water technology mentioned throughout this volume. These carriers, however, primarily convey the technological advances that have remained in use for many centuries: the territorial interventions, the treatises, and the schools. Knowledge may be produced through artisanal practices (Chapters "Toledo: The Thirsty City", "Technology of Grandeur: Early Modern Aqueducts in Portugal", "The Technical and Social Scope of Irrigation in the Algarve"), for instance, that of the agronomist monks (Chapter "The Water that Passes Through Alcoa and Baça: The Hydraulic System of the Monastery of Alcobaça"), forgotten at the theoretical level over the passage from Al-Andalus to the early modern era (Chapter "The Technical and Social Scope of Irrigation in the Algarve") or accumulated within the strata of technological systems (Chapter "*Noras*, *Norias* and Technology-of-Use").

Theoretical knowledge was codified, transmitted, and purposefully reflected on through dedicated teaching, as in the case of the *Aula de Esfera* (Chapter "Beyond Stevin and Galileo: Seventeenth Century Hydrostatics in the Jesuit Class of the Sphere"), and embedded, in its development, in the experiences of peculiar, transversal figures in society, such as engineers, who turned out to be the real international connectors and, therefore, those who mostly enabled both theoretical developments and knowledge accumulation processes (Chapter "The Making of a Hydraulics Expert: Estevão Dias Cabral (1734–1811)").

The Iberian Peninsula appears in this book in regard to its most lively dynamics, balancing needs and education, and through impressive interventions across the cultural, political, economic, and territorial levels. It was a thirsty peninsula that faced such fundamental problems by turning them into progressive dynamics of social, economic, and scientific development.

Matteo Valleriani
Max Planck Institute for the History of Science
Berlin, Germany

Technische Universität Berlin
Berlin, Germany

Tel Aviv University
Tel Aviv, Israel

Contents

City Water Supply Systems

The Water Supply and Sewage Networks in Sixteenth Century Lisbon: Drawing the Renaissance City

André Teixeira and Rodrigo Banha da Silva

Abstract

Towards the end of the fifteenth century, Portuguese monarchs began implementing a sewage network and the general cleaning of their capital city. The authorities also set out plans to enable access to clean water with the opening of wells and the building or renovation of public fountains, not only for the benefit of its inhabitants, but also to supply the needs of Lisbon's dynamic waterfront, where maritime and commercial activities were concentrated. This emerged simultaneously to an urban regulatory process with the clear aim of bestowing monumentality on the city, especially along the riverside area, where the king and the elites had established their palaces. Thus, during the sixteenth century, water and its control were not only a matter of necessity, but also a sign of modernity. The past few years of rescue archaeology have provided a huge amount of information on Lisbon's water systems prior to the 1755 earthquake, with most having been built in the sixteenth century. These data are here cross-referenced, both against sections of its architectonic remains and, especially, against archival documentary sources. This interdisciplinary approach has led to far more accurate knowledge about the importance of water in these early modern societies.

A. Teixeira (✉)
CHAM, NOVA School of Social Sciences and Humanities,
NOVA University of Lisbon, Lisbon, Portugal
e-mail: andreteixeira@fcsh.unl.pt

R. B. da Silva
Lisbon City Council, Lisbon, Portugal

A. Duarte Rodrigues and C. Toribio Marín (eds.), *The History of Water Management in the Iberian Peninsula*, Trends in the History of Science,
https://doi.org/10.1007/978-3-030-34061-2_1

1 Introduction

The subsoil of Roman Lisbon contained enough water to provide for the inhabitants of a city of some 10 ha, thus already including a considerable suburban area. Archaeology has unveiled various water supply solutions, ranging from domestic wells to cisterns, as well as small systems for supplying baths. Despite this, the presence of an important reservoir, dating to the imperial period, located around 12 km from the city, and its corresponding aqueduct, identified as spanning a length of 4 km, have been considered one part of the city's water supply system ever since the Renaissance (Moita 1990: 9–12; Mascarenhas 2012), even though no archaeological evidence of this relationship has yet been found.

There is general agreement that the collapse of the Roman Empire brought about disinvestment in the construction and maintenance of such public facilities as water transport systems. During the Islamic period, such structures were not only scarce in present-day Portuguese territory, but were also quickly abandoned following the Christian conquest. These facts led to widespread difficulties in water management during the Early Middle Ages (Trindade 2014: 368).

The sixteenth century brought about profound changes in the ways in which water was envisioned by the urban powers of Lisbon, the Crown and the municipality. Sixteenth century Lisbon found itself playing a dual role as the nation's capital: not only was it the leading Portuguese city, a status that had been under consolidation ever since the thirteenth century, it also became the first centre of a transoceanic empire (Rossa 2004: 947–48). There is also a general consensus that the city underwent a "transformation from a place of relative insignificance to Renaissance Europe's foremost global city" (Gechwend and Lowe 2015: 13 and 34). During this process, between 1415 and 1551, the population doubled to a total of 100,000 inhabitants, before reaching some 120,000 individuals by the end of that century, thus making Lisbon one of Europe's fifteen largest cities.

Just as the increase in population caused difficulties for sanitation and the water supply, Lisbon's new attributes required the conception of a new image for the capital in line with the trend that could be seen throughout Europe. The city should correspondingly be distinguished by its monumentality and order, structured around a new square that would concentrate the buildings of power in accordance with the precedent set by the classic models (Rossa 2004: 948). The great monumentalization and sanitation constructions of Lisbon date from this period (Fig. 1): the reorganization of the layout and configuration of the streets, such as Rua Nova dos Mercadores and Rua Nova d'El-Rei, making them more linear, wider and with a uniform aspect; the creation of squares, such as Rossio and Terreiro do Paço, new urban entities with large areas characterised by their magnificent buildings (Rossa 1995: 260–63). In this context, water management was also clearly one of the factors inherent to creating this new image, with its antecedents reaching back into the previous century (Trindade 2014: 372–73).

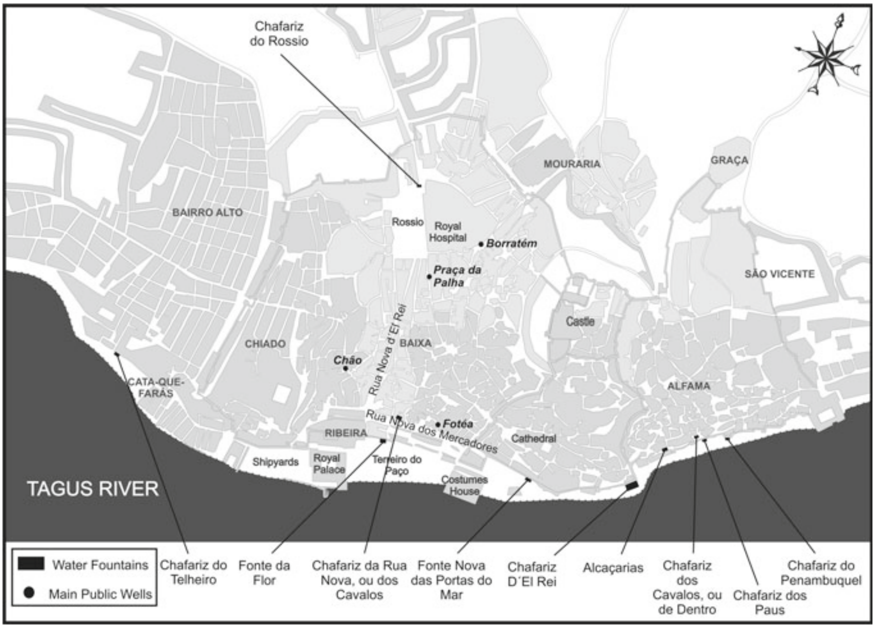


Fig. 1 Fountains and wells in 16th century Lisbon

Thus, on the one hand, new supply systems were established, not only for the purpose of seeking to meet the demands of the maritime and commercial activities, but also to ennoble the main squares. On the other hand, the city's first major sanitation system was implemented, sewerage designed to prevent filth from accumulating on the streets or forming garbage dumps while promoting public health alongside urban aesthetics. Water management thus seems to have constituted a fundamental facet of the affirmation of Lisbon's own modernity, even while it was certainly dictated by archetypes arriving from other European contexts from which the Court and some of the Portuguese elite sought inspiration.

Research on the subject of sixteenth century Lisbon is far from easy, especially as the 1755 earthquake and the subsequent reconstruction of the city largely obliterated all preceding urbanism and the corresponding structures. Nevertheless, Lisbon had generations of remarkable historians devoted to its study who unveiled and, in some cases, published abundant documentation on the city's past (such as Júlio de Castilho and Eduardo Freire de Oliveira); the municipal historical archive (the second largest national archive in the world[?]) still remains a source for much unpublished information. Simultaneously, while analysis of the scarce pre-earthquake cartography is essential, and there have been many attempts to combine it with present-day cartography (Silva 1987a: 52–57; Silva 1987b, I: 17–24), this task is clearly hampered by problems of scale, orientation and distortions in the older specimens. Sixteenth century iconography is also scarce, was mostly produced by foreign artists and tends to be centred on either Terreiro do Paço or the riverside area (Rossa 2004: 950–51; Gechwend and Lowe 2015: 13–21). Finally, while it is true that the significant growth in preventive archaeology provided an increase in data on Lisbon's past (Bugalhão 2008; Araújo et al. 2013) by disclosing extensive pre-1755 realities, this activity has not yet been integrated into any urban archaeology program, meaning that enormous outstanding potential as regards this period still exists (Gaspar et al. 1997). In any case, our objective here involves the further combination of different types of source for the study of Lisbon's past.

2 The Water Supply

During the Middle Ages, the population of Lisbon was supplied with water from the main underground sources located near the Tagus River. The peculiar geotectonic conditions under the area of Alfama—a toponym of Arabic origin meaning 'thermal spring'—provided multiple and widespread springs, some of them of hot, that were used well into the contemporary era. From the end of the thirteenth century, these springs were piped into two main fountains located on the riverside at the foot of the slope that hosted the growth of the historic city: the Chafariz d'El-Rei (lit.: 'King´s fountain'), emerging from the exterior of the *cerca velha* (the late-Roman and Muslim city wall), probably named after its founder, possibly King Dinis (1279–1325); and the Chafariz dos Cavalos (lit.: 'Horses fountain'), originally named after either its bronze equine head-shaped spouts or perhaps because it served to water the horses, but subsequently renamed the Chafariz de Dentro (lit.: 'Inside fountain') after the construction of the *cerca nova* (the new city wall built between 1373 and 1375). The protection provided by this rampart was crucial for ensuring the city's self-sufficiency during a siege, a shortfall that had been experienced in previous episodes of warfare. These structures primarily supplied the riverside population, while people living in the upper area or far from the riverbank would probably have drawn their water from wells or cisterns, such as the Poço de Borratém (Moita 1990: 12; Gonçalves 2017: 41–42). In the absence of more complex facilities, these structures were vital to daily life; they were true spatial and sociability references for the city, with their usage sometimes becoming a source of conflict and sometimes the subject of propagandistic actions enacted by the elites (Trindade 2014: 368–70).

The late fifteenth century and the early years of the sixteenth century, however, marked an important turning point in this aspect of Lisbon's everyday life. In 1487, King João II (1481–1495) commissioned works at the Chafariz d'El-Rei that endowed it with its renowned looks, with three arches and a large tank, as depicted in the famous Leiden illustration (Fig. 2). This was also designed to better serve the ships calling in on the Tagus by ensuring a conduit to carry water to the waterfront. In 1494, the king backed the project to raise water from this fountain to the higher areas of the city, but this attempt ended in failure. He also ordered construction at the Chafariz de Dentro, including conduits to supply ships, new spouts and small subsidiary fountains for easier and more orderly public service; this project also

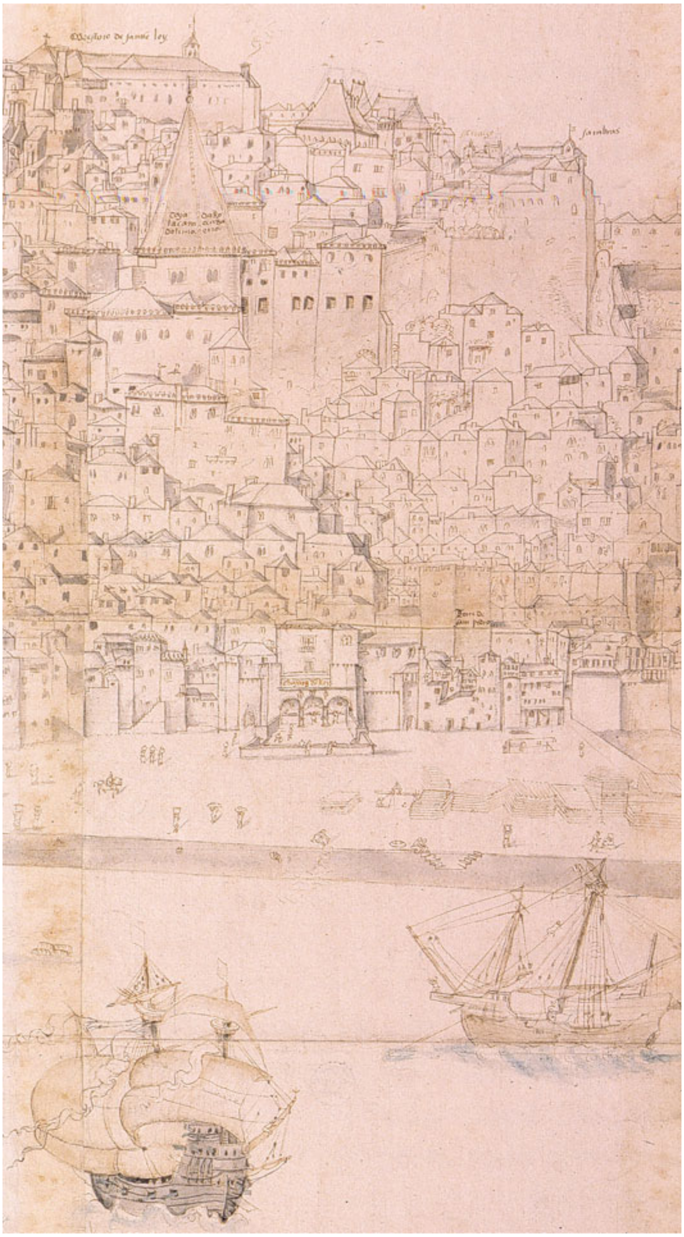


Fig. 2 The Chafariz d'El-Rei, detail of the anonymous *Panoramic View of Lisbon*, c. 1570; Leiden, Universiteit Leiden

does not seem to have been carried out, even if the foundations were laid for a more efficient and orderly strategy for water resource utilisation (Moita 1990: 13–14; Gonçalves 2017: 43).

Under the subsequent monarch, King Manuel I (1495–1521), a new water supply policy was more clearly established for the city. This encapsulated one of the fundamental dimensions of Lisbon's restructuring, under design from 1497 onwards as a global intervention strategy in the urban space, including works on streets, gates, fountains and other public facilities and buildings (Carita 1999: 54–55). The material testimonies of this building campaign are clearly documented in the subsoil of Lisbon, especially in *Baixa*, the lower section of the city, which was then becoming the centre of urban life (Bugalhão 2015a).

The intervention programme pertaining to the fountains mainly spanned the riverine area, where a new urban centre was simultaneously undergoing construction and incorporating the headquarters of the main political and administrative institutions, as well as the port and commercial functions of the imperial capital, a unique solution in Europe. In conjunction with the rationalization of the overseas administration, the king would have perceived a means to glorify his maritime achievements (Soromenho 1998: 75–76) or his imperial planetary ideology (Pereira 2007: 235) through this initiative. Thus, the monarch correspondingly transferred his residence from the old acropolis, the castle, to the riverside area, where the new royal palace was built, overlying the Casa da Índia warehouse, the institution that controlled the overseas trade (Senos 2002: 70–72). This change involved establishing a new square, Terreiro do Paço, "the central feature and generator of the city's new image," consisting of a building line of remarkable symmetry (Carita 1999: 62). This urbanism was associated with the official narratives, which turned the Tagus into one of the world's premiere rivers, due to the mythical origins of the city and an environment that "called for obvious imperial vocations" (Caetano 2004: 102–03; Pereira 2007: 240–41). The king was naturally followed by his nobles, who settled in large numbers along this riverine area (Moita 1994: 146–47).

The investment in the water supply for the riverine area also interlinked with the formation of the new "Ribeira," understood as a specific concept of Portuguese history and referring to a public waterfront area, a platform between the urban nucleus and the aquatic environment, with port facilities (quays, anchorages), shipyards, fiscal control institutions (factories, customs, warehouses) and maritime activity-related manufacturing structures (powder houses, smitheries, ironworks, ropeworks). These were all located in the vicinity of buildings for the civil powers, fortifications, churches and social and sanitary assistance facilities, bearing an identical configuration in all of the coastal burgs of the empire. This was an "authentic urban façade," with identity features that took the Lisbon *Ribeira* as their model (Caetano 2004: 76–93).

Therefore, renewed sources of water supply integrated this new physiognomy for riverine Lisbon, certainly interrelated with the expanding mercantile activities, but also with the affirmation of a new representation of power. The iconic character of part of these structures led to their representation in contemporaneous depictions of the city, as well as to their referencing in core descriptions (Gonçalves 2017: 44–45).

As a whole, the intervention program for the fountains involved, among other aspects (Fig. 1): the renovating and dignifying of the functions of the Chafariz de Dentro through removal of the laundry areas and the installation of several tanks for various functions; new improvements to the old Chafariz d'El-Rei, seeking to avoid its contamination from neighbouring houses; and the construction of the Cata-que-Farás and Santos fountains, both located on the western riverine area, which was undergoing considerable expansion. Repair work on another fountain, the Chafariz da Rua Nova, built before the fourteenth century, were directly associated with the installation of street piping to ensure the drainage of run-off water (Silva 1987b, I: 103–106; Carita 1999: 55–58; Caetano 2004: 151–53). Some consideration was also paid to the possibility of channelling water from the Chafariz do Andaluz into the city; this fountain, built inland close to one of the main roads in 1336, constitutes a fine example of a fountain with a back wall, displaying the coats of arms of both the Crown and the municipality, enhancing its role in the service of the community (Estrela 2017: 78 and 252–55).

The ennoblement of the Chafariz de Dentro called for the construction of new laundry tanks in an adjacent area, seeking to make use of the Alcaçarias hot water springs. We would note that the cleaning of laundry occupied a very considerable number of women around that time, 3500 according to a mid-sixteenth century source; moreover, laundry absorbed one of the most expressive shares of the population's service expenditures (Brandão 1990: 69). Since the Early Middle Ages, water sources had been simultaneously applied to different activities, such as washing clothes and containers, watering animals and supplying inhabitants; this had thus resulted in a proliferation of tanks near each fountain in order to meet these different needs, and in conjunction with the promulgation of different regulations prohibiting various uses in small fountains, even if these orders were commonly disregarded (Estrela 2017: 33 and 36–37). We would also mention that, in the Alcaçarias, wool processing and tanneries (from which the Arabic name comes) flourished during the sixteenth century, a by-product of the abundant groundwater resources (Moita 1994: 153).

Knowledge about the sixteenth century water supply to Lisbon quite noticeably derives from two laudatory accounts from the middle of the century, 1554s *Descrição da Cidade de Lisboa* (Góis 1988: XX) and, especially, 1552s *Grandeza e Abastança* (Brandão 1990: 103–06). At that time, the system was still essentially based on the water tables under the Alfama and on a succession of fountains and tanks that ran from west to east: the Chafariz d'El-Rei, with its six spouts, "a remarkable construction, with marble columns and arcades (…), which would be enough to provide water for everyone" (Góis 1988: 49); the Alcaçarias, "where three hundred women are soaping" and with "tanks where many hides and wool are washed"; the Chafariz de Dentro, which, by that time, already included several tanks and spouts for various uses; and the Chafariz do Penambuquel. In total, there were ten water reservoirs located close to this area, generating such flows that "they would be able to move eight watermills" (Brandão 1990: 103).

This area of Alfama, as well as its extension towards Baixa, was also well endowed with wells containing water just as good as that supplied by the fountains (Fig. 1). The aforementioned *Descrição* refers to six of these structures that belonged to members of the nobility, who charged for their usage. There are also references to: a fountain and seven public wells, partly municipal, some "with laundry facilities"; four public wells in Rua Nova dos Mercadores; a fountain in the same street, "very large and of great use to the people," particularly for construction works; Poço da Fótea, with its 3.3 m diameter and 6.6 m perimeter; Poço do Chão; the above-mentioned Poço do Borratém; a fountain next to the Paço da Ribeira; and the Chafariz dos Cavalos in Rossio (Brandão 1990: 104–05). The wells were scarcely mirrored in the coeval toponymy of Lisbon, with only seven references, all in the Baixa, out of a total of 328 streets listed as containing wells, nevertheless, still outnumbered the cisterns and fountains (Oliveira 1987: 114–27).

The archaeological findings from these public wells are also scarce. The old well on Rua da Praça da Palha stands out, located in the Baixa, not far from Rossio (Fig. 3). Backfilled with calcareous stones, its circular mouth was about 1 m in diameter, sitting on a floor paved with slabs of the crystalline white marble that was also applied to its stairs (Trindade and Diogo 2001: 197). Other more numerous findings are more consistent with private wells, such as those recovered from the Núcleo Arqueológico da Rua dos Correeiros (Bugalhão 2015b: 24).

The descriptions of Lisbon above may, however, be deemed to be excessively flattering when actually assessing the efficiency of the supply network and its capacity to meet the city's needs (Moita 1990: 13). Francisco de Holanda, a humanist and artist born in Lisbon who had a deep knowledge of Italian classicism (Bury 1981; Deswarte 1983; Osswald 2015), pointed out the poverty of a system that "has only a narrow fountain for so many people and others for horses" (Holanda 1984), in a clear reference to the continued survival of medieval fountains. The *Grandeza e Abastança*, despite its apologetic tone, also included solutions for improving the prevailing system, referring especially to making better utilisation of the aforementioned Alfama aquifers by installing pipes, reaching as far as Terreiro do Paço and even further west, so that less of their flow would be lost to the river. In the case of the Chafariz de Dentro, the idea of complementing it through the construction of two new fountains, closer to the waterfront, received praise (Brandão 1990: 105–06).

This idea was effectively put into practice, although only at a later date, through the construction of two subsidiary fountains connected to the Chafariz de Dentro: the Chafariz da Praia and the Chafariz dos Paus or da Aguada (Moita 1990: 13–14; Caetano 2004: 155–56). While the construction of the Chafariz da Praia can be securely dated to 1622, the Chafariz dos Paus may date back to the last quarter of the sixteenth century, and possibly interrelates with the preparation of the "Invincible Armada" by King Filipe I (1580–1598). According to archaeological evidence, the construction featured a strong masonry foundation sitting on a pine frame, rectangular in shape with two symmetrical lateral recesses, built up against the low-medieval wall, 15 m in width and with a tank made of slabs and ashlar masonry with an estimated capacity of at least 30 m^3 (Silva et al. 2012: 71–73).

Fig. 3 The well in Rua dos Correiros (sounding 9); Centro de Arqueologia de Lisboa

Furthermore, the Chafariz da Fonte Nova or da Preguiça, also on the riverside and close to a gate in the ancient city wall (Porta do Mar), already existed in 1569 (Silva 1987a: 124).

We would note that the transportation of water between fountains and houses employed more than one tenth of Lisbon's large slave population, an estimated 9950 people in the mid-sixteenth century. The slaves involved in this trade worked on their own, but had to deliver a percentage of the income to their masters, usually one half. Council orders sought to prevent slaves who were "selling water from jugs" from standing still and waiting for buyers, and therefore stipulated that they permanently circulate, carrying the containers on their heads (Fonseca 2010: 248–49). This routine was immortalized in the anonymous late sixteenth century painting of the Chafariz d'El-Rei, depicting the area as packed with black persons bearing the characteristic Lisbon red clay jugs, crowding around the spouts and wandering the surrounding square (Serrão 2002) (Fig. 4). Another noteworthy municipal order, from the middle of this century, regulated spout usage, assigning one spout for black and mulatto men (either slaves or free persons), another for

Fig. 4 The Chafariz d'El-Rei, detail of the anonymous painting, probably from the Netherlands, c. 1570–1580; Lisbon, Fundação Berardo

Muslims, the two in the centre for "white men and women," the following one for negro women (either slaves or free persons) and the last spout for "white women and girls" (Moita 1990: 174). This effort to supply water to the inhabitants of an increasingly global city thereby did not hesitate to use hierarchical, ethnic and gender segregation as a means of enforcing the prevailing social order.

But the modernity of the capital's new water supply system extended beyond sanitary issues and the rationality of the layout. The aesthetic assumptions behind the works in Lisbon's fountains clearly relate to the widespread classical vision and perspective that prevailed within the Portuguese Court. Such is the case with the two fountains designed by Francisco de Holanda (Fig. 5), which were never built, like so many of his other proposals aimed at transforming Lisbon into a true Renaissance city through the construction of monumental buildings that were to reshape the city's image. The first fountain was planned for the riverbank and consisted of a large circular tank surrounding the sculpture of an elephant from which the water would flow, an evocation of the triumphs of antiquity, "a sign of glory and eternity, found in the Malatesta sanctuary-mausoleum, in Rimini" (Soromenho 1998: 84). The second was meant to embellish the Rossio square and consisted of a feminine sculpture representing Lisbon, with a ship departing with two ravens—the city's symbol—sitting on a pedestal with four sculpted elephants from which water would flow (Moita 1990: 14).

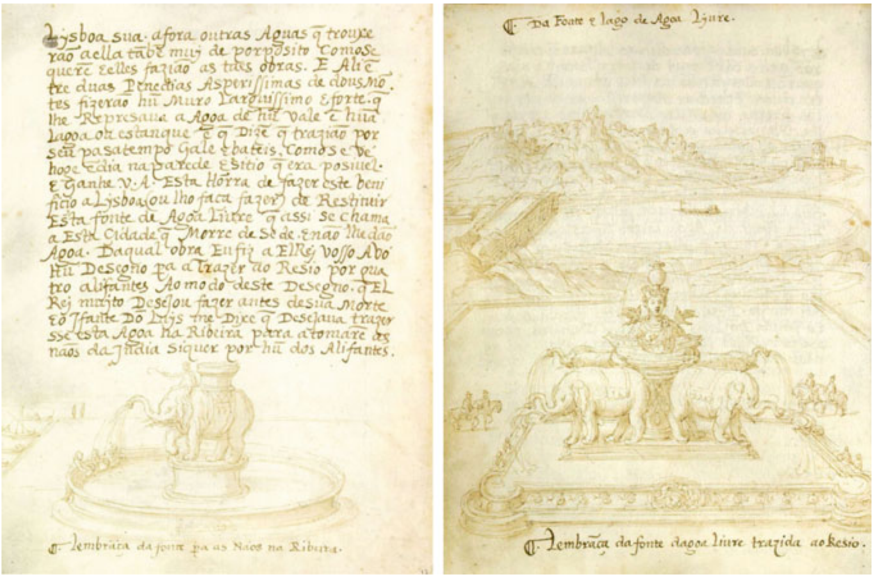


Fig. 5 Drawing of fountains in Rossio and Ribeira, by Francisco de Holanda, *Da fabrica que faleçe ha Çidade De Lysboa*, 1571; Lisbon, Biblioteca da Ajuda, 52-XII-24, fls. 18-18v

The Chafariz do Rossio was actually built, but only from 1589 onwards and on the initiative of King Filipe I; it was not completed until 1606. This fountain was established by purchasing a private well, alongside compensation payments to the owners of the land through which the piping ran (Moita 1990: 14–15). It was probably built by Nicolau de Frias, from Lisbon (c. 1550–1610), an architect working for the city and the Crown. This fountain featured a sculpture of Neptune, the god of water, a new reference to the classical past, this time installed in one of Lisbon's main squares, which, according to the archaeological evidence available, correspondingly underwent a significant renovation of its pavements (Silva and Guinote 1998: 65).

The achievements of Nicolau de Frias, the true "hydraulic specialist of Portugal", were not limited to this achievement. He devised numerous detailed projects in this field, particularly (once again) for the riverside area, even if few ever got built. For the Chafariz d'El-Rei, he proposed closing the cistern with a vault, a watertight covering for the reservoir, the reconstruction of the pipes in stonework (to avoid leaks) and the functional and aesthetic improvement of the facilities. For the Alcaçarias area, he contemplated the installation of a large laundry building (with "large, long and thick stones (…) lying in rows and at an appropriate angle, suitable for washing and beating") and a house with a chimney to store clothes; he also advocated the prohibition of tanning activities. For the Chafariz de Dentro and the Chafariz do Penambuquel, he proposed a larger number of spouts. All of his projects displayed extreme care in advancing solutions both for the public's benefit (in the functional aspects) and for the embellishment of the city (a new monumental aesthetic) (Caetano and Soromenho 1994: 68–70).

The Frias plan was, of course, part of the broader number of projects carried out during the period when the Habsburgs ruled Portugal (Soromenho 1998: 79–82). Among them, we would highlight the profound renovation of the royal palace, the administration headquarters buildings and, globally, the entire Terreiro do Paço, as well as the construction of the majestic religious complex of São Vicente de Fora, both by Filippo Terzi, the chief architect of the Crown and one of the exponents of Italianism in Portugal (Soromenho and Branco 2017). The royal tax on water was enacted in this period, under King Filipe II (1598–1621); this tax, levied on basic food products and intended to finance public works, was a clear sign of water's importance in people's daily lives and its relationship with the administration.

Nevertheless, the sixteenth century modernization of the Lisbon water supply did not entail the construction of an aqueduct, specifically one able to take advantage of the rich aquifer deposits in adjoining regions, such as the Fonte da Água Livre (12 km away), which, as mentioned, was used back in Roman times. This type of structure was either erected or reconstructed in several locations across Portugal over the course of that century in an otherwise unprecedented effort (Trindade 2014: 376–80). Francisco de Holanda, the aforementioned humanist, envisioned the construction of an aqueduct in Lisbon, explicitly seeking to restore the archetype of "ancient cities" such as Merida, Segovia, Cartago and, of course, Rome, while also referring to Lisbon's Roman aqueduct, its ruins then still visible (Holanda 1984: 99–102).

The project did not succeed, as was the case with that devised by Nicolau de Frias in the late 1500s despite the fact that this was considered the only solution for permanently solving the water supply problems (Moita 1990: 16–17; Mascarenhas 2012: 252). In the seventeenth century, new plans for constructing an aqueduct for Lisbon were proposed by the royal architects Pedro Nunes Tinoco and Leonardo Turriano, in 1617 and 1620, respectively, and there was even a royal visit to the Roman reservoir in 1619, but, again, without results. The Aqueduto das Águas Livres was only built in the second quarter of the eighteenth century, within a completely different context, but in accordance with the same strategy of water catchment on the city's outskirts. Only then did the real revolution in Lisbon's water supply system actually take place.

3 The Sewerage Network

The accumulation and lack of infrastructure for managing urban residues, both solid (waste) and liquid (sewage), constituted a chronic problem in Lisbon, in addition to being considered the main cause of the frequent and easy spread of diseases. There are countless fifteenth century documents that associate epidemics with the need to clean streets and public spaces (Rodrigues 1968: 114–15; Barros 2014c: 9–12). Medieval urban streets, with their numerous perishable buildings resulting from the extension of houses, and with no or, at best, deficient pavements, were spaces full of refuse, tossed by residents, produced by ongoing economic activities and/or resulting from the circulation of animals. Simultaneously, the rivers and the external spaces alongside the city's gates and moats became genuine, permanent open-air dumps (Rossa 1995: 252–53). There were some attempts to put an end to this situation, but these were far from effective (Caetano 2004: 44–45).

However, the late fifteenth century seems to have been a turning point in this regard, following the adoption of an urban sanitation and public health policy. In addition to sanitary issues, the desire for the monumentalization of urban centres, especially those that regularly hosted the Court, was also a contributing factor. Some measures were particularly relevant, such as the need for street cleaning by residents, the implementation of garbage collection systems, the removal of polluting activities from the city centre, the pavement of streets, the installation of sewerage pipes and the covering of open-air ditches. The regulation and enforcement of the utilisation of public spaces during the first dynasty was subsequently renewed by the *Ordenações Afonsinas* (1447) and considerably extended during the reign of King Manuel I, not only by the *Ordenações Manuelinas* (1521), but also in a series of piecemeal legislative acts (Rossa 1995: 261; Barros 2014b: 111–12).

The first reference to a "coherent and hierarchized sewerage system" dates back to 1486 (Rossa 1995: 261), in a letter from King João II to the municipality. Faced with the occurrence of a plague, the monarch ordered "that very large sewers have to be built in some of the main streets, and smaller ones in the other streets", recommending that "each house should be connected to the sewer by a branch pipe through which dirty water can be disposed of" (Oliveira 1887: 463). However, project implementation was not at all immediate, due to the high costs involved (Carita 1999: 51). We believe that this network was essentially installed over the early decades of the sixteenth century, as part of the aforementioned global renovation program for Lisbon undertaken by King Manuel I, which included extensive renovations of both streets and public facilities, along with the renovation of the riverine area. Street construction works were especially relevant for the installation of this sewerage network, especially in the Baixa neighbourhood, as they often involved demolitions, paving and the installation and maintenance of conduits (Carita 1999: 58). This program remained under implementation throughout the sixteenth century and may be considered one of the earliest European examples of its type (Silva and Guinote 1998: 67).

The archaeological fieldwork hitherto carried out in Baixa, correlated with data from documentary sources, has made it possible to identify and partially locate, in the cartography prior to the 1755 earthquake, a set of sixteenth century sanitation conduits (Fig. 6). These findings have also enabled the characterisation of these structures, not only in their formal and constructive aspects, but also in terms of the design and origins of the system itself. In fact, despite the architectural and urban changes over the centuries, stratigraphic analysis of this type of remains reveals that the majority of them originally date back to the 1500s (Bugalhão and Teixeira 2015: 92). Among the coeval written sources, there is a noteworthy document dated 1547 that contains the list of public and private wastewater conduits then in existence in

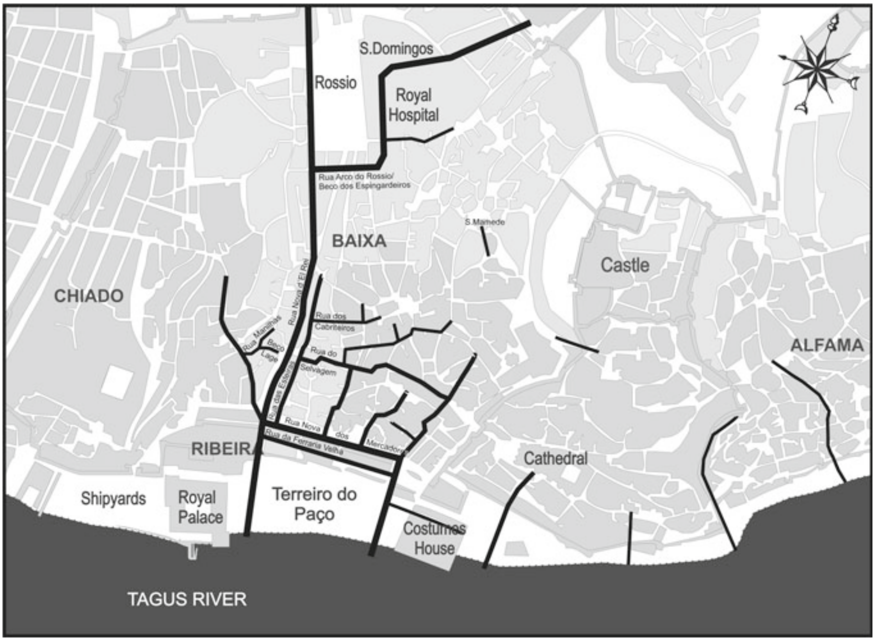


Fig. 6 Sewerage system in 16th century Lisbon

Lisbon, with its references spanning the locations, junctions, rights of use, types of waste (domestic sewage, piped water lines, rainwater, well runoff) and other aspects.[1] The existence of this document provides a good indication of the prevailing concerns over these aspects of collective life and municipal administration.

Thus, the sanitation network displayed an orthogonal tendency, generally following the North-South/East-West orientation of the urban grid, as, in most cases, the pipes were located underneath the main circulation routes, also designed in an increasingly regular pattern from the Late Middle Ages onwards (Carita 1999: 35–43). The structures therein recorded, in particular, their dimensions, materials and construction techniques, allow us to clearly perceive the hierarchized character of the network, while also revealing its rational and modern design. Accordingly, there were first-order conduits (the 'canos reais,' lit.: 'royal pipes'), second-order public conduits, third-order public conduits and, finally, private conduits (Bugalhão and Teixeira 2015: 106–08), in a hierarchy with a medieval background (Cardoso 2002: 158).

The first-order conduits date back to the fifteenth century and were originally built to connect[?], inside the walled city, the water lines from the two valleys to the northwest and northeast, which, having already merged, crossed the city´s Baixa

[1]The original is in the Arquivo Nacional Torre do Tombo, *Corpo Cronológico*, I-79-43. There is a copy in the Arquivo Municipal de Lisboa, *Livro dos Pregos*, f. 333–335, first published by Oliveira (1887: I, 549–552), more recently in a full paleographic transcription (Bugalhão and Teixeira 2015: 118–122).

neighborhood (Silva 1987a: 25–33). At the turn of the fifteenth century, the Rua Nova d'El-Rei was built, connecting the two new squares of the city, Rossio and Terreiro do Paço; initially, this street was symptomatically called Rua do Cano Nova (lit.: New Pipe Street) (Carita 1999: 75–76). It should be noted that, on the east flank, this piping prevented the accumulation of water near the city gate (close by the Dominican convent), one of the main factors of insalubrity during this period (Silva and Guinote 1998: 66). Its importance was furthermore referenced by contemporaneous authors: "after entering the city, it flows through a very wide royal pipe, running all the way to the sea, always under the ground" (Oliveira 1987: 102).

Thus, two royal pipes have been identified, both with a dominant North-South orientation: one arriving from the northwestern valley before crossing Rossio, of which there are no remains; the other from the northeastern valley, passing under the São Domingos convent and the Todos-os-Santos royal hospital, and widely documented by archaeology, first, over a 120 m section (Moita 1964: 96) and, more recently revisited, over a 52 m section (Silva and Leite 2015: 49–50) (Fig. 7). The two pipes eventually flowed into one in the heart of the Baixa, where some sections were also excavated (Silva 1987b, I: 106 and 120; Bugalhão and Teixeira 2015: 97). Finally, the main conduit reached the Rua Nova dos Mercadores and ended in Terreiro do Paço, where remains were also discovered (Neves et al. 2014: 52–65).

The royal pipes inherited the functions of the aforementioned aid creeks, i.e., draining flash flood waters, a chronic problem in the city (Barros 2014c: 10). They also drained the more regular rainfall and domestic sewage, especially from the aforementioned large monastic complex and hospital. These conduits were

Fig. 7 The cano real (royal pipe) in Praça da Figueira, 2000; Centro de Arqueologia de Lisboa

imposing structures, of great dimension (with internal sections 2–2.2 m high and about 1.5 m wide), made of strong masonry, with an internal cladding of well-made limestone ashlar masonry, a vault and an earthen floor. This type of construction suggests that these conduits would be both maintained and cleaned from the inside, with access available during the summer through numerous manholes.

Second-order public conduits ran under or parallel to major streets, although there were also some perpendicular conduits. They featured internal sections ranging from 0.8 to 1.5 m in height and 0.7 to 0.9 m in width, covered by limestone slabs, with side walls made of stone-worked masonry, sometimes clad with the same type of slabs, with the bottom generally also lined with limestone slabs. Remains of these structures were identified in two locations: under the former Rua do Arco do Rossio, with an East-West orientation, with three conduits converging into the royal pipe; and in the middle of the Baixa, under the former Rua das Esteiras, with two domestic sewers (Amaro et al. 1994, I: 230).

Third-order public conduits ran either under or parallel to less relevant or smaller streets, correspondingly serving fewer users. They featured internal sections of a height between 0.25 and 0.6 m and from 0.3 to 0.5 m in width. The covering was made of limestone slabs, the side walls of stone or brick masonry and the bottom usually covered in bricks/brickwork. Among the findings, we would highlight those from the former Rua dos Cabriteiros, a small paved street with an East-West orientation that featured a parallel sewer, which was later transformed into a second-order public conduit, probably due to the need to increase the sewage flow (Amaro et al. 1994, I: 227–237). The sewage pipes discovered in the former Rua das Manilhas, with a North-South orientation, and in Beco da Lage, with an East-West orientation, are not referred to in the aforementioned list of the city's pipes, so they may well be slightly more modern, but at least one of them dates to the sixteenth century (Fig. 8). We would point out that the name of the street (lit.: 'slab alley') allows us to hypothesize that the covering of this conduit would be exposed, thereby serving as the street's pavement surface (Diogo and Trindade 2000: 232–33).

Finally, private conduits conveyed the sewage from buildings into the public system. Their usage by neighbours and private dwellings is widely documented in the aforementioned list of pipes, stressing the eminently public nature of the sewerage network in the 1500s that was meant to serve the inhabitants. These pipes show very different orientations, with internal sections ranging from 0.2 to 0.35 m in height and from 0.2 to 0.3 m in width. Their coverings were made from small limestone slabs, bricks, or reused materials; the side walls were made of rough stone and brick masonry overlaid with mortar, while the bottom was covered with bricks or simply with mortar. We would highlight the three conduits identified in Rua do Arco do Rossio, or in the former Rua do Selvagem, in the middle of the Baixa, covered by fragmented and re-purposed millstones; all three flowed into the aforementioned second-order public conduit in Rua das Esteiras (Bugalhão and Teixeira 2015: 101).

Fig. 8 Pipe in Rua de São Nicolau, nº107–111, 1990; Centro de Arqueologia de Lisboa

Naturally, a dense and hierarchized sewerage network required the existence of domestic structures connected to the public system. As regards this facet, it is interesting to note the 1548 royal order concerning dwellings on Rua da Sapataria Velha: "cylindrical clay pipes should be installed inside the houses, coming down through the walls, […] and brick sewers laid at street level that will feed into a large sewer that will be built in this street that, in its turn, will feed into the big one which lies in Rua Nova" (Oliveira 1887: 548–52). There is abundant archaeological evidence of this practice, such as in one of the wealthy dwellings located in the Palace of the Condes de Penafiel, whose central compartment contained a vertical ceramic pipe embedded in the wall and connected to the roof gutter, which then flowed into the underground brick drain (Bargão et al. 2017: 1784–5) (Fig. 9).

We would note that the type of covering used in both the second- and third-order public and private conduits reveals the need for their regular disassembly (uncovering) for maintenance and cleaning, widely mentioned in coeval documents (Barros 2014b: 119–20). When public conduits were cleaned by the municipality, which was generally responsible for urban hygiene, those that exclusively served private individuals, without sinkholes that drained rainwater, were mandatorily serviced by their users (Barros 2014a: 99–101). In this respect, it is worth mentioning the identification of a structure interpreted as a manhole for the sewerage network between the former Rua da Ferraria Velha and the Rua Nova dos Mercadores: this was a circular well mouth with a diameter of 0.4 m built out of arched calcareous stones, set on a limestone slab pavement; this mouth gave access to a

Fig. 9 Ceramic pipes in the palace of Condes de Penafiel, 1992; Centro de Arqueologia de Lisboa

0.53 by 0.57 m sub-quadrangular box, which was connected to two separate conduits on its eastern and northern sides, respectively (Fernandes and Ferreira 2004: 466; Bugalhão and Teixeira 2015: 102–03). Three other examples of this type of structure were found in one of the dwellings under the Palace of the Condes de Penafiel; the atrium and the back yard of the house were connected by brickwork feeders or sinkholes (Bargão et al. 2017: 1784–5). Here, as in other locations in this sewerage system, the subsoil of Lisbon still seems to conceal a lot of information that may be capable of returning a better overview of the system.

4 Final Remarks

The sixteenth century brought along substantial changes in water management at the behest of Lisbon's powerful. These changes were clearly part of the city's modernisation programs, fostered by models from other parts of Europe, with their epicentre in Italy. The various urban renewal programs of the 1500s, although reasonably distinct, always entailed some investment in these water-related issues, a sign of recognition of their importance across various domains. On the one hand, these were functional prerequisites, such as supplying water to a growing population or to the armadas involved in the flourishing international trade, as well as the awareness of the need to create a healthier urban environment. On the other hand, they were based on aesthetic assumptions, which considered water fountains as components for the monumentalization of public spaces and which rejected the accumulation of garbage in the city's neuralgic centre, a space for the representation of power.

As regards the water supply, we would highlight the reformulation of the rich and ancestral supply sources located in the riverine area near the Alfama quarter. In addition to the aesthetic renovation of the fountain structures themselves, the concern about the removal of differentiated activities from their spaces (laundry, watering animals and supplying inhabitants) and the multiplication of services to meet the rising levels of demand (from residents and the armadas), there was a constant concern about making the most of this valuable resource, especially through increasing the number of subsidiary fountains. At the same time, the network was extended to other areas of the city, including through wells, although it was still very concentrated in the riverside and Baixa areas. Furthermore, we also must acknowledge that, at this time, there was no revolution in the water supply to the capital, for example, through seeking out new water sources, something that would only actually occur in the second quarter of the eighteenth century.

In terms of wastewater, it seems clear that the sewerage network outlined at the end of the 1400s, which was effectively implemented throughout the following century, was a very noticeable transformation of Lisbon's urban landscape, largely preceding the system implemented during the reconstruction of the city following the 1755 earthquake. The archaeological and documentary evidence proves the extent of the sixteenth century piping network, as well as its hierarchization in keeping with different layouts matching the importance of the respective streets above, with the corresponding application of different dimensions, materials and construction techniques also being in accordance with its importance within a coherent whole.

Acknowledgements CHAM Strategic Project (FCSH, Universidade NOVA de Lisboa, Universidade dos Açores) by FCT-Fundação para a Ciência e Tecnologia (UID/HIS/04666/2013).

Bibliography

(a) Manuscripts

AML, *Livro dos Pregos*.

(b) Printed Sources

Brandão, João. 1990. *Grandeza e Abastança da Cidade de Lisboa em 1552*. Lisbon: Livros Horizonte.

Góis, Damião de. 1988. *Descrição da cidade de Lisboa*. Lisbon: Livros Horizonte.

Holanda, Francisco de. 1984. *Da fábrica que falece à cidade de Lisboa*. Lisbon: Livros Horizonte.

Oliveira, Cristóvão Rodrigues de. 1987. *Lisboa em 1551. Sumário em que brevemente se contêm algumas coisas assim eclesiásticas como seculares que há na Cidade de Lisboa*. Lisbon: Livros Horizonte.

Oliveira, Eduardo Freire de. 1887. Elementos para a história do município de Lisboa. Lisbon: Typ. Universal, tomo I, pp. 549–552.

(c) Studies

Amaro, Clementino *et al.* 1994. A Baixa pombalina: alguns aspectos urbanísticos. In *V Jornadas Arqueológicas*. Lisbon: Associação de Arqueólogos Portugueses, vol. I, pp. 227–237.

Araújo, João *et al.* 2013. A Arqueologia urbana em Lisboa: análise da actividade arqueológica entre 2006 e 2011 e divulgação patrimonial. In José Morais Arnaud *et al.* (Eds.), *Arqueologia em Portugal. 150 Anos*. Lisbon: Associação dos Arqueólogos Portugueses, pp. 97–102.

Bargão, André *et al.* 2017. Policromias e padrões: azulejos "de aresta" e de "corda-seca" do Palácio dos Condes de Penafiel, Lisboa (séculos XV-XVI). In José Morais Arnaud, & Andrea Martins (Eds.), *Arqueologia em Portugal 2017 Estado da Questão*. Lisbon: Associação dos Arqueólogos Portugueses, pp. 1781–1794.

Barros, António Salgado de. 2014a. "Os canos na drenagem da rede de saneamento da cidade de Lisboa antes do terramoto de 1755", *Cadernos do Arquivo Municipal*, II:1, pp. 85–105.

Barros, António Salgado de. 2014b. "Em defesa do ambiente da cidade: o papel regulador do poder real e do Senado de Lisboa", *Cadernos do Arquivo Municipal*, II:2, pp. 103–128.

Barros, António Salgado de. 2014c. *O saneamento da cidade pós-medieval: o caso de Lisboa*. Lisbon: Ordem dos Engenheiros.

Bugalhão, Jacinta. 2008. "Lisboa e a sua Arqueologia: uma realidade em mudança", *Era Arqueologia: revista de divulgação científica de estudos arqueológicos*, 8, pp. 217–230.

Bugalhão, Jacinta. 2015a. Um novo centro urbano, junto ao Tejo: o contributo da arqueologia. In André Teixeira *et al.* (Eds.), *Lisboa 1415 Ceuta: historia de dos ciudades*. Ceuta & Lisboa: Ciudad Autónoma de Ceuta & Câmara Municipal de Lisboa, pp. 45–47.

Bugalhão, Jacinta (Ed.). 2015b. *Uma casa pré-pombalina na Baixa Lisboeta. Núcleo Arqueológico da Rua dos Correeiros*. Lisbon: Centro de História de Aquém e Além-Mar, Faculdade de Ciências Sociais e Humanas - Universidade Nova de Lisboa, Universidade dos Açores, pp. 19–29.

Bugalhão, Jacinta, & Teixeira, André. 2015. "Os canos da Baixa de Lisboa no século XVI: leitura arqueológica", *Cadernos do Arquivo Municipal*, II:4, pp. 89–122.

Bury, John. 1981. *Two notes on Francisco de Holanda*. London: University of London.

Caetano, Carlos. 2004. *A Ribeira de Lisboa na Época da Expansão Portuguesa, Séculos XV a XVIII*. Lisbon: Pandora.

Caetano, Joaquim, & Soromenho, Miguel. 1994. "Projectos hidráulicos na Lisboa filipina", *Olisipo*, II:1:1, p. pp. 65–79.

Cardoso, Isabel Freitas Botelho. 2002. El Agua en las Ciudades Portuguesas Medievales. In Maria Isabel del Val Valdivieso (Ed.), *Usos Sociales del Agua en las Ciudades Hispánicas de la Edad Media*. Valladolid: Universidad de Valladolid, pp. 156–168.

Carita, Hélder. 1999. *Lisboa Manuelina e a formação de modelos urbanísticos da época moderna (1495–1521)*. Lisbon: Livros Horizonte.

Deswarte, Sylvie. 1983. *As Imagens das Idades do Mundo de Francisco de Holanda*. Lisboa: Imprensa Nacional - Casa da Moeda.

Diogo, António Manuel Dias, & Trindade, Laura. 2000. "Intervenção arqueológica na Rua de São Nicolau, n.º 107/111 (Lisboa)", *Arqueologia & História*, 52, pp. 231–253.

Estrela, Gisele Freitas. 2017. *Fontes e Chafarizes. O abastecimento de água nos espaços públicos na Baixa Idade Média portuguesa*. MA (Archaeology), Faculdade de Letras, Universidade do Porto.

Fernandes, Lídia, & Ferreira, Manuela. 2004. "Intervenção arqueológica num dos quarteirões da Baixa Pombalina em Lisboa: estudo do espólio vítreo", *O Arqueólogo Português*, IV:22, pp. 453–489.

Fonseca, Jorge. 2010. *Escravos e Senhores na Lisboa Quinhentista*. Lisbon: Edições Colibri.

Gaspar, Alexandra *et al.* 1997. Arqueologia Urbana em Lisboa. In *Actas do III Congresso Peninsular de Arqueologia*, VII: *Terrenos da Arqueologia da Península Ibérica*. Porto: Adecap, pp. 53–74.

Gechwend, Annemarie Jordan, & Lowe, K. J. P. (Eds.). 2015. *The Global City: on the Streets of a Renaissance Lisbon*. London: Paul Holberton publishing.

Gonçalves, Luís Ribeiro. 2017. "Sistemas de circulação de água e poder na Lisboa medieval – séculos XIV a XVI", *Cadernos do Arquivo Municipal*, II:8, pp. 37–54.

Mascarenhas, José Manuel. 2012. "O aqueduto romano de *Olisipo*: viabilidade ou utopia? Ensaio de traçado apoiado em modelação geográfica", *Revista Portuguesa de História.* 43, pp. 239–264.

Moita, Irisalva. 1964. "Hospital Real de Todos os Santos: relatório das escavações a que mandou proceder a C.M.L. de 22 de Agosto a 24 de Setembro de 1960- I", *Revista Municipal*, 101/102, pp. 77–100.

Moita, Irisalva. 1990. O Aqueduto das Águas Livres e o abastecimento de água a Lisboa. In Irisalva Moita (Ed.), *D. João V e o Abastecimento de Água a Lisboa*. Lisbon: Câmara Municipal de Lisboa, pp. 9–25.

Moita, Irisalva. 1994. Lisboa no Século XVI. In Irisalva Moita (Ed.), *O Livro de Lisboa*. Lisbon: Lisboa 94, Livros Horizonte, pp. 159–160.

Neves, César *et al.* 2014. "Lisboa pré-pombalina: vestígios do Terreiro do Paço no subsolo da Praça do Comércio", *Rossio. Estudos de Lisboa*, 3, pp. 52–65.

Osswald, Cristina. 2015. Francisco de Holanda. Da fábrica que falece à cidade de Lisboa. In Álvaro Baraibar, & Martina Vinatea Recoba (Eds.), *Viajes y Ciudades Míticas*. Pamplona: Universidad de Navarra, pp. 95–112.

Pereira, Paulo. 2007. Lissabon im 16 und 17 Jahrhundert. In *Symposium «Novos Mundos - Neue Welten: Portugal und das Zeitalter der Entdeckungen»*. Berlin: Deutsches Historisches Museum, pp. 227–245.

Rodrigues, Maria Teresa Campos. 1968. *Aspectos da Administração Municipal de Lisboa no Século XV*. Lisbon: Câmara Municipal de Lisboa.

Rossa, Walter. 1995. A cidade portuguesa. In Paulo Pereira (Ed.), *História da Arte Portuguesa*. Lisbon: Círculo de Leitores, vol. III, pp. 233–323.

Rossa, Walter. 2004. Lisboa Quinhentista, o terreiro e o paço: pronúncios de uma afirmação de *capitalidade*. In Roberto Carneiro, & Artur Teodoro de Matos (Eds.), *D. João III e o Império. Actas do Congresso Internacional comemorativo do seu nascimento*. Lisbon: Centro de História de Além-Mar, Centro de Estudos dos Povos e Culturas de Expressão Portuguesa, pp. 947–967.

Serrão, Vítor. 2002. O Chafariz d'El-Rei da Ribeira Velha, em Lisboa, numa valiosa pintura do fim do século XVI. In Vítor Serrão (Ed.), *Estudos de História da Arte: novos contributos*. Lisbon: Câmara Municipal de Lisboa, pp. 69–76.

Silva, A. Vieira da. 1987a. *A Cêrca Moura de Lisboa: estudo histórico descritivo*. 3rd edition, Lisbon: Câmara Municipal de Lisboa.

Silva, A. Vieira da. 1987b. *As muralhas da Ribeira de Lisboa*. 3rd edition, Lisbon: Câmara Municipal de Lisboa.

Silva, Rodrigo Banha da *et al*. 2012. Largo do Chafariz de Dentro: Alfama em época moderna. In André Teixeira, & José Bettencourt (Eds.), *Velhos e Novos Mundos. Estudos de Arqueologia Moderna*. Lisbon: Centro de História de Além-Mar, pp. 71–84.
Silva, Rodrigo Banha da, & Guinote, Paulo. 1998. *O Quotidiano na Lisboa dos Descobrimentos*. Lisbon: Grupo de Trabalho do Ministério da Educação para as Comemorações dos Descobrimentos Portugueses.
Silva, Rodrigo Banha da, & Leite, Ana Cristina. 2015. Hospital Real de Todos os Santos. In André Teixeira et al. (Eds.), *Lisboa 1415 Ceuta: historia de dos ciudades*. Ceuta & Lisboa: Ciudad Autónoma de Ceuta & Câmara Municipal de Lisboa, pp. 49–53.
Soromenho, Miguel. 1998. À Espera das Naus: a Ribeira de Lisboa e a Carreira da Índia. In Simoneta Luz Afonso *et al.* (Eds.), *Catálogo Oficial do Pavilhão de Portugal da Exposição Mundial de Lisboa de 1998*. Lisbon: Parque Expo 98, pp. 75–91.
Soromenho, Miguel, & Branco, Ricardo Lucas. 2017. The architectural career of Filippo Terzi in Portugal (1577–1597). In Sabine Frommel, & Micaela Antonucci (Eds.), *Da Bologna all´ Europa: artisti bolognesi in Portogallo (secoli XVI-XIX)*. Bologna: Bononia University Press, pp. 101-124.
Trindade, Laura, & Diogo, A. M. Dias. 2001. "Intervenção arqueológica de emergência na Rua dos Correeiros em Lisboa. As Sondagens n.ºs 2, 6, 7, 9 e 10", *Revista Portuguesa de Arqueologia*. 4:1, pp. 187–204.
Trindade, Luísa. 2014. A água nas cidades portuguesas entre os séculos XIV e XVI: a mudança de paradigma. In María del Mar Lozano Bartolozzi, & Vicente Méndez Hernán (Eds.), *Patrimonio cultural vinculado con el agua. Paisaje, urbanismo, arte, ingeniería y turismo*. Mérida: Editora Regional de Extremadura, pp. 363–376.

Toledo: The Thirsty City

Magdalena Merlos Romero and Victoria Soto Caba

Abstract

During the early modern period, many solutions were proposed to overcome the challenge posed by supplying water to the city of Toledo, whose level was one hundred meters above the Tagus. On the Vega, outside of the city, the river flow enabled both agricultural and industrial prosperity. In addition, the storage of water in reservoirs and the formation of gardens were possible within the walls of the city. The survival of classical and Muslim hydraulic techniques and the legacy of their advanced water culture were instrumental, through both the conservation of the old systems and the creation of new ones—dams, water wheels, mills, pipes, in inspiring the achievements of the medieval era. However, Toledo was no stranger to the treatment and hydraulic innovations of the Modern Age. One exceptional milestone was the water-lifting device created by Juanelo Turriano, in operation for a short period during the sixteenth century. This machine, based on several water wheels, was the result of its creator's knowledge of hydraulics, as well as the collective expertise on machine-building that had been gathered up to this moment. However, it remained a unique case, as it was followed by several unsuccessful attempts to raise water to that urban area.

M. Merlos Romero (✉)
Archivo Municipal de Aranjuez, Ayuntamiento de Aranjuez, Madrid, Spain
e-mail: mmerlos@madrid.uned.es

V. Soto Caba
UNED (Universidad Nacional de Educación a Distancia), Madrid, Spain
e-mail: vsoto@geo.uned.es

A. Duarte Rodrigues and C. Toribio Marín (eds.), *The History of Water Management in the Iberian Peninsula*, Trends in the History of Science,
https://doi.org/10.1007/978-3-030-34061-2_2

1 Introduction

The image of Toledo that has gradually taken shape over the centuries emerged from a historiography founded upon certain historic milestones, its glorious past, and its urban identity. From the second half of the sixteenth century, with the transfer of the court to Madrid and the installation of convents in the city—a significant phenomenon in the late medieval period, when the religious orders took over the main houses, the city fell into a decline that would lead it to become a dry, arid city *par excellence*. This image was to be enhanced by hackneyed clichés and travel references that were then copied and repeated by chroniclers and writers throughout the nineteenth century.

This travel literature sketched out a waterless Toledo resulting from the breakdown and decay of the device built by Turriano in the sixteenth century to raise water from the river which had somehow maintained the cultivated areas that surrounded Toledo and the peaceful tree-lined avenues outside of its walls along its northern section, as well as the secluded gardens within the walls, as referred to by medieval sources. Nevertheless, that fertility in Toledo supposedly disappeared throughout the course of the seventeenth century, when the city became the paradigm for the waterless city.

In a city where, due to its orography and geology, wells could not be sunk, the townspeople were forced to descend to the edge of the Tagus to collect water. The absence of water, the repeated references in the literature to the failure of Turriano's device, and the unfortunate tendency of travellers to take away a very superficial impression of the city left many people ignorant of the fact that a sophisticated water transportation system had survived from long-standing tradition. This paper argues that, although there were difficulties in supplying the urban centre during the early Modern Age, it is no less true that the presence of this vital liquid resource remained consistently possible practically up until the 20th century, thanks to the machinery and resources that were inherited from and respected throughout the late Middle Ages.

The formulas that Toledo developed to cushion itself against the lack of water and inclement weather conditions (experiencing droughts and a lack of river flow at certain times and river overflow at others), taking into account the difference in height of almost one hundred metres between the river and the city, need to be examined in the light of the background of Roman and Hispano-Moresque water transportation methods.

The geostrategic importance of Toledo favoured providing it with a water supply, and the Roman water transportation scheme had contained three collection systems, including the Alcantarilla dam and the waters of many different streams. In the first century AD, a catchment reservoir was built (*castellum ad caput*), including a *speculum* that reached as far as the city (Aranda et al., 1997), as well as archways (*castellum aquarium*) and aqueducts across steep terrain. The aqueduct located next to Turriano's waterwheel, possibly an aqueduct-siphon based on the principle of communicating vessels, corresponded to the aqueduct system. The various pipelines joined up before entering the city, and then branched out through underground channels, with distribution tanks placed at intervals, such as the Cave of Hercules, which is the best known (Aranda et al. 1997, 197), and other notable ones beneath the Treasury Delegation and Tornerías Mosquee basaments.

Both the Romans and the Arabs had engaged in capturing and carrying water to Toledo, however, their mechanisms and philosophy differed, as did the behaviour of the water in each case. After the containment and direction of water by the Romans, the Muslim technique of violently moving the water from below to above (Fernández-Casado 2008) was implemented through a contraption that the citizens of Rome were, nevertheless, perfectly acquainted with: the waterwheel. In any case, in Hispano-Muslim Toledo, the model was that of the Roman water-carrying network, and the Toledan people adapted to the pre-existing utilitarian constructions, such as the aqueducts, cisterns, wells and sewers.

And it is, in fact, through this survival that one can delve deeply into the supply of water that, for centuries, enabled the city of Toledo to be a habitable and refined location, quite apart from the exceptional device of Turriano. This is how we can understand the widespread presence of gardens behind the walls of houses, convents and civil buildings (Soto Caba and Perla 2016). On the other hand, to talk of Toledo necessitates talking about its fertile plain, dotted with orchards and recreational estates, where there has been seamless continuity through to contemporary times.

However, although the establishment of the kingdom's capital in Madrid (1561) kept the population of Toledo at a very consistent level, the early modern age was forced to face up to both the traditional and the new demands for agricultural and industrial production; the culture and leisure dimension of gardens; the supply of water for urban and domestic use; sanitation in the city; and the supply of drinking water.

During the early modern age, we can see the harmony that existed between the surviving Roman and medieval models and techniques and the newly introduced Renaissance innovations, based on classical treatises and the Hispano-Muslim tradition. This characteristic reality of modern peninsular engineering encountered a clear exponent in the city of Toledo.

It is within this European and peninsular framework that the water companies of Toledo are contextualized. Leaving aside the medieval heritage, these companies cannot be understood without taking into consideration the figure of Phillip II, the greatest promoter of hydraulic engineering on the Iberian Peninsula. His interest in regaining the Tagus River in Aranjuez, as well as Juan Bautista Antonelli's navigation projects, represented ventures that were in parallel with Turriano's creation, and turned the river that flows into Lisbon into a hydraulic and political centre at a time when the peninsula was one single kingdom (Merlos Romero 1998). We must not forget the importance of the river, not only for the wealth of the court, but also for rural artisans and the agricultural economy, propitiated by the water mills (López Gómez et al. 1998, vol. 2, 501–525), whose presence on the Iberian Peninsula reaches back both to antiquity and the early Middle Ages, according to the latest research (Palomo and Fernandez 2006–2007).

The water supply proposals that followed those of Turriano sprang up in parallel with the treatises on water in the early modern age that generally lacked any outstanding contributions, instead being defined by their continuation and improvement of existing models.

2 La Vega

It was on the fertile plain (vega), the surrounding areas outside of Toledo's walls, where the weirs (or *azudes*) and river waterwheels were deployed, which, by means of the force of the water, moved mills, *aceñas* (water mills) and *batanes* (fulling mills), as well as irrigating the crops (Hurtado 1576) (Fig. 1).

The mills, many with medieval foundations, had been rebuilt, and continued to function during the early modern age. The local economic impact of these mills, *azudas* and *batanes* did not go unnoticed by Francisco de Pisa (1605, I: 24–25). In turn, the most unusual usage was that of the Azumel mill, which was alongside the weapons factory built by Francesco Sabatini.

The somewhat anachronistic industrial uses of the fertile plain (water mills and fulling mills) and the private interests that they incorporated constituted one of the main reasons for the failure of a feasible project for navigating the Tagus as far as Lisbon (Cabanes 1829), already devised for Phillip II and readopted by Carduchi (1641) in the seventeenth century. Indeed, this was still a much sought after goal in the final years of the Enlightenment, as well as in the 1790 work of Benito Bails, inspired by the Treaty *Architectura Hydraulique* by B. F. Belidor (Crespo Delgado

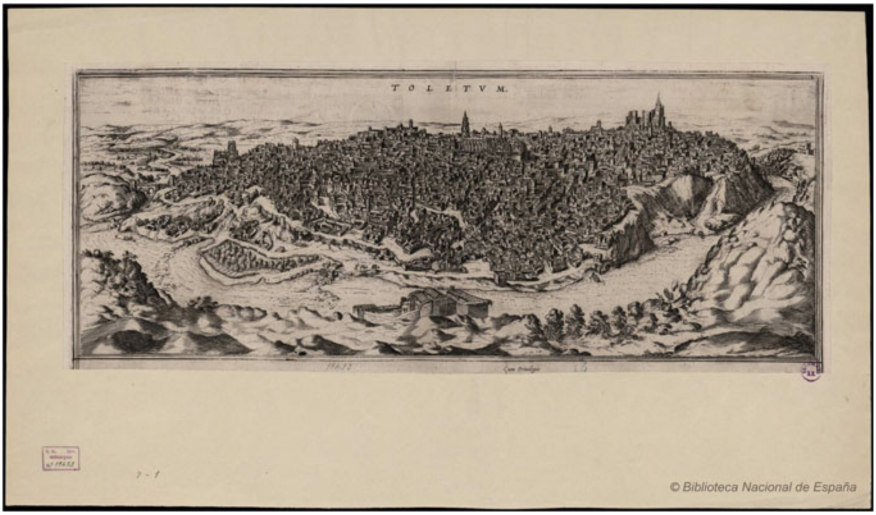


Fig. 1 G. Hoefnagel. 1566. Vista de Toledo. Biblioteca Nacional de España

2017: 138). However, the most unusual artefacts on the fertile plain of Toledo were the numerous *norias* on the river, or *azudas* (waterwheels), which raised water up to locations far from their source, such as those that Pisa (1605) describes, and which, after technical conversion in the late Middle Ages and early Modern Age, continued to function, whether thoroughly rebuilt or newly constructed, well into the twentieth century.

In 1525, the ambassador and traveller Andrea Navagero (García Mercadal 1999, II, 18) saw how the *azudas* drew water from the river to irrigate the fruit trees, fields and other orchards and gave testimony of a splendid sight: the still surviving waterwheels in the *Huerta del Rey*, or King's Orchard (which were the gardens of Al-Mamun close to the Tagus), particularly the ruins and possible restoration of what was formerly the great *azuda*. This was also demonstrated in the sixteenth and seventeenth centuries, in both literature and art, such as Pero's *azuda* and the *azudas* of the *Huerta del Rey*, which enabled the cultivation of numerous harvests there (Figs. 2)

Brambilla's bird's eye view represents an oversized impression of these *azudas* on the fertile plain downstream from the city, showing the visual impact that they produced on the landscape (Fig. 3).

These are the same watermills as those painted by Carduchi (1641), next to the Azuel windmills, on the dam named, appropriately, the *Azudas Corrientes* (*running waterwheels*), on the other side of the convent of the Capuchinos on the site where the weapons factory would be built a century later.

The map of the Tagus and Guadiela rivers by Briz y Simó (1755) and the faithful copies of maps with hydrographic details by the authors, depicting the bridges, mills and *norias* on the Tagus as it passes through Toledo (Cabanes 1829: 43–68), are truly interesting. In these views from the sixteenth and seventeenth centuries, in addition to these sections, we can see mills and *norias* sketched in the area of Azucaica, upstream from Toledo, and downstream to those of the enclave known as the *Lavadero de Rojas* (washing area).

These graphic descriptions enable us to imagine that fertile plain dotted with numerous *azudas*:

> Of these azudas, three or four go to the orchard of the King, and one they call *de Raçaçu*; another *de la Aluerca*; another *de la Islilla;* another belonging to the palaces of Galiana, and further on, another in front of the garden of Don Pedro Manrique, and this belongs to the orchard of Laytique. Without these, there are another four azudas on the fertile plain, two in the fulleries, one for San Pedro *el verde*, and another for the orchard of Agenjo Díaz (Pisa 1605, I: 25).

The literary connection among the *azudas*, orchards and gardens evokes the Muslim concept of the kitchen-garden, delightful places that survived into the early Modern Age, under private ownership, and consequently restricted to usage by the more affluent classes, as reflected by their sometimes-inherited names (Rey, Palacios de Galiana). In these orchards, there were buildings, luxurious domestic possessions, heirs to the medieval *almunias* (houses with orchards) that were used to consolidate a common typology of a recreational nature and, at the same time, for

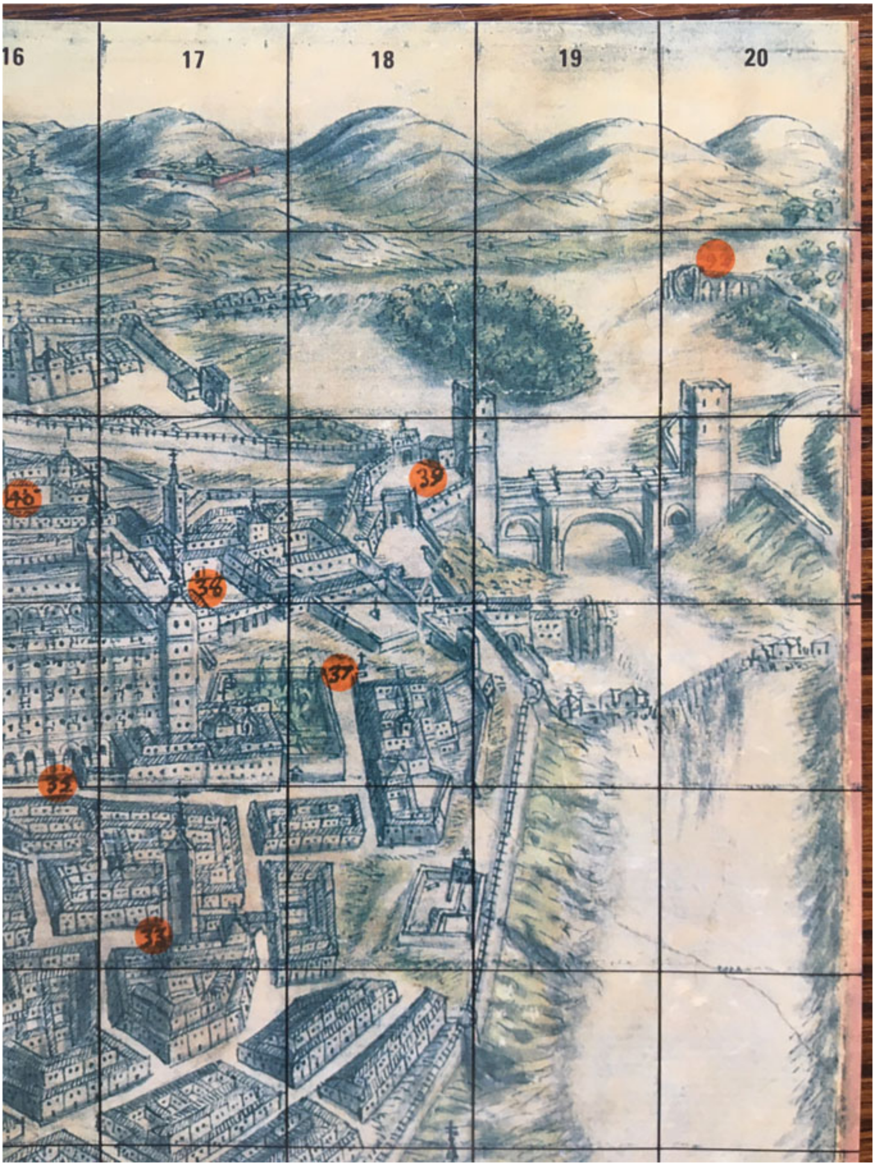


Fig. 2 Arroyo Palomeque, J. *Panorámica de Toledo*. c. 1720. Spain. Archivo Histórico Provincial de Toledo. Detalle. Noria, molinos y conventos con zonas de jardín intramuros

agricultural purposes. Hurtado de Toledo (1576: 20) sums up the image of the irrigation in these orchards: "…some orchards had their own noria with wooden channels… wells with their *albueras*… with their *aceñas*."

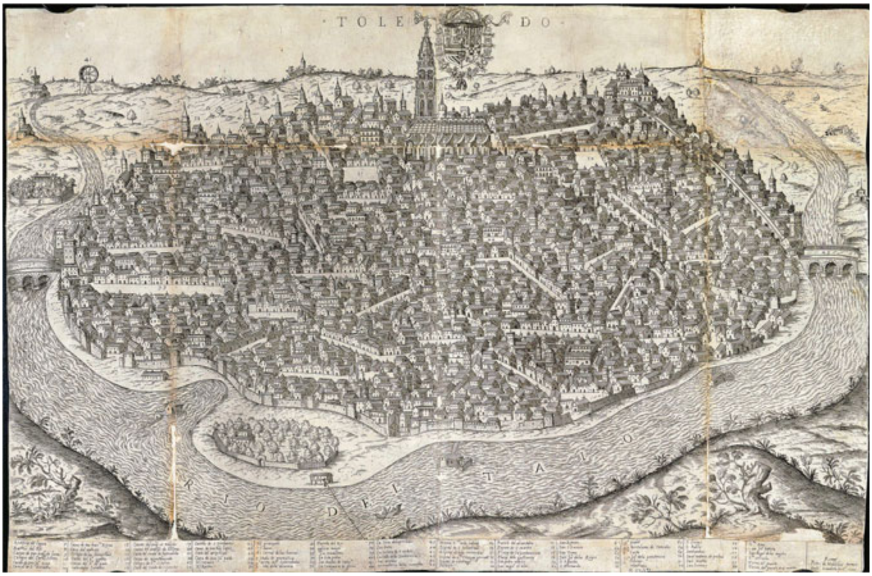


Fig. 3 Brambilla. 1585. *Vista de Toledo*. Spain. Biblioteca Nacional/Biblioteca Digital Hispana (BN/BDH). Detalle. Arriba la azuda, abajo la Huerta de la Alcurnia

Not only was this tradition not lost—it lives on to this day. Throughout the sixteen and seventeen hundreds, the residences outside of the city walls and around the city multiplied as the Muslim system of irrigation continued to be in operation. Thus, the upper classes continued to acquire houses with orchards, the old *almunias*. Marineo (1530, Chapter 21: 45) offers an extensive list of these. Some recreational homes were metonymically termed *huertas* or orchards, irrigated by ditches and walled, with a main door, garden and orchard on the inside and a summer house with a covered balcony, such as that belonging to the Commander, identifiable in the landscape by Brambilla (1585) and the panoramic view of Arroyo Palomeque, on the left bank of the river, to the west of the city. Further west was the orchard attached to Capiscol's country house, a monumental estate built in the mid-sixteenth century and a scene of royal celebrations.

Similar to Capiscol's, some of these orchards also have extensive gardens inspired by the Italian and Spanish Renaissance styles, with fountains and ponds, and, in the subsequent century, by Baroque aesthetics. Their irrigation was made possible by their proximity to the river and the direction in which the *azudas* faced. The orchard of Diego Vargas, secretary to Phillip II, called a *vergel* (orchard) by Pisa (1605, I, 26), and "casa de recreo (residence for leisure) and *Cigarral* (country house)" by Hurtado de Toledo (1576), was built in 1570 and was irrigated by the ditches coming from "the houses that are called Capiscol's, (…) and from there they come past the *azudas* to the garden and home of Secretary Vargas" (Marineo 1530, Chapters 21 and 45). Furthermore, the neighbouring *cigarral del Ángel*, the "old orchard and country house" that the Marquis of Villena had built in the fifteenth century, later restored by the Archbishop at the beginning of the seventeenth century (Hurtado de Toledo 1576), possessed Renaissance gardens.

In this western area, Buenavista's so-called *cigarral* (although, strictly speaking, a leisure estate on the banks of the Tagus) was especially renowned. Built from 1610 onwards by Sandoval, with parterred gardens and *ars topiaria*, fountains and a pond (Marineo 1530, chapter 45) supplied by channels from the Tagus (Marineo 1530, chapter 21), the property was praised by writers, including Tirso of Molina and Baltasar Eliseo de Medinilla.

In the eastern part of the fertile plain, Marineo (1530, chapter 21) located the "artificial garden" and orchard of Antonio de Córdova, "the house, inheritance and garden" of Rodrigo Niño, the "house and garden" of Alonso Manrique, the orchard of Higares "with its mills, church and meadow," and the "dwelling and leisure houses… of judge Alonso, those of Dr. Toro and others that are being gradually built" very close to the orchards of Alaytique, of medieval origin and "of great freshness and recreation, where we find one of the most famous *azudas* on this river "and the King's" [most] celebrated and enjoyable".

However, the sixteenth century brought another type of recreational house, the *cigarrales* (the protagonists of the work of Tirso de Molina *Los cigarrales de Toledo*), a name documented in the sixteenth century for the first time according to Vázquez and Morollón (2005), country villas kept exclusively for leisure, but that also became the sites of plantations, nurseries and herbariums, in keeping with the scientific interests of the time. These recent studies (Vázquez and Morollón 2005) reject the Muslim origin of the *cigarrales*, and it should be noted here that, although they appeared in the sixteenth century, some of the orchards documented in that century came to be called, by extension, *cigarrales,* such as "the house of Hernán Pérez de Guzmán with his orchard" (Marineo 1530, Chapter, 45), which was to be the *Cigarral* of Solanilla or the Mercedarios, and the aforementioned orchards of Capiscol, Diego de Vargas, and the Marquis of Villena, the future *Cigarral del Ángel* (Country House of the Angel).

In general, the *cigarrales* commonly share the features of the Hispano-Muslim orchard, but, unlike the latter, they occupied the hills south of Toledo on the bank opposite the city and opposite the San Martín Bridge. In contrast, the orchards were distributed around the *vega* (fertile plain) and, although the orchards were closed areas, cordoned off as private property intended for recreation, the *cigarrales* were fenced off for protection against marauding livestock, due to being located in the middle of the commonly owned grasslands. The ambiguity of the synonyms of orchard, holiday residence, and country house (*huertas, casas de recreo* and *cigarrales)* in the sixteenth century, deployed to describe identical estates, makes it clear that there were no obvious differences and that the development of *cigarrales* during the seventeenth and eighteenth centuries as agricultural holdings, and the subsequent recovery of their recreational role in the nineteenth and twentieth centuries, determined the almost exclusive usage of the generic term *cigarral,* as illustrated by the *Cigarral de Buenavista*, the Vargas and the Angel, which were, in reality, summer residences with orchards and gardens, located in the fertile plain.

The relationship between these suburban farms and water needs to be traced back, in depth and in detail. The planting of orchards and gardens on the upper reaches of the left bank of the Tagus during the early modern age was only possible due to the spring waters that came from living rock, distributed by means of channels of medieval construction, collected into catchment basins, and used alongside rainwater stored in water tanks and wells. The *Cigarral* of *Juan Vergara* had a fountain. The Cigarral del Bosque possessed a tank, a catchment basin and a water mine, or *qanat*, to supply its fountain with the flow from the Ciciones spring (Vegue and Goldoni 1927). Similarly, the *Cigarral* of Cardinal Quiroga, with its "ponds, orchards and very nice gardens, fountains, baths and all kinds of recreation" (Román 1700, cfr. Vázquez and Morollón 2005), gathered its water through channels and a nearby spring.[1] In this case, and for the purposes of water management, it is curious that the spring was owned by the city of Toledo and was ceded to the cardinal in 1588 with the sole condition that a basin fountain be erected so that the water might supply a public drinking trough. Other secondary underground channels were also incorporated, such as those documented in the country house of the Jesuits, the *Cigarral de los Jesuitas* and the *Cigarral de la Cadena* -supplied by the water mine and fountain of the *Cigarral de Pisa*-, and in the *Cigarral de Menores*[2] (Pisa 1605) to supply its ornamental fountains and gardens. This was in response to the service agreements or easements for fountains and water mines, as opposed to open ditches, while adapting to the new aesthetics of the Renaissance. These formulas were designed to alleviate the scarcity of water, as we shall return to later, and were equal to those that served the city from the sixteenth to the nineteenth centuries.

The orchard and *Casa de la Alcurnia* deserve special mention: the permanent property of the archbishops of Toledo to the south and the only orchard on the banks of the city, "of pleasant recreation and very much frequented, considering it is inside the city." The site was accessed without any need to cross the river, as cited in the anonymous sixteenth century novel *Lazarillo de Tormes*. However, these sites[?] were washed away when the Tagus burst its banks in 1545. The enclosed orchard is still visible in the panoramic views of Brambilla and Hoefnagel, under cultivation and with a door providing access for small channels from the river for irrigation and connected to the *azuda* cited by Francisco de Pisa. It also possessed "a pool (*alberca*) collecting water that flowed from the river to water it" (Pisa 1605: 26).

In 1503, the city demanded "that the Huerta de la Alcurnia on the banks of the Tagus be left for recreation for the local people (…) as before it was said to have been."[3] This demand for green spaces for citizens contrasts with the profusion of privately-owned landscaped areas. Thus, we can understand the concerns of the Toledo residents - and also of the town hall itself, which found one of their few material expressions in the formation of a grove on the banks of the Tagus,

[1]AMT. (Archivo Municipal de Toledo). Archivo Secreto. Alacena 2ª, legajo 4º, nº 6.
[2]AMT. Archivo Secreto. Alacena 2ª, legajo 4º, nº8.
[3]AMT. Archivo Secreto.Cajón 4, legajo 1, núm. 14.

downstream from the bridge, on the fertile plain “on the banks of the Tagus, for the recreation of the people” in the first decade of the sixteenth century.[4]

During the eighteenth century, this walk was complemented with the addition of another, called the *Cabrahigos* or Fig Trees, now the *Paseo de la Rosa.* Alexandre Laborde (1809, III: 281–282) was able to view this shortly after its construction «*les arbres sont encore jeunes; lorsqu'ils seront grands, cette promenade sera très-agréable»,* finding it punctuated by squares and with a marked aesthetic value. The plant life was irrigated by two fountains belonging to the municipality, one of them the *Cabrahigos,* famous for its drinking water, for which reason it also provided a drinking supply. In 1791, the chief magistrate of Toledo had to order

> all the residents and those residing in the city, who carry water from the fountains of the new Cabrahigos promenade, each time they draw water from them, that they should refill their buckets with another load of water that they shall then carry there to prevent the poplars on the promenade from drying out.”[5]

These supply problems had also occurred since the early days of the Modern Age, due to the construction of the Colmenar irrigation channel upstream, which siphoned off water that consequently no longer reached Toledo. There were complaints, such as the “opposition of the City to building a millrace on the Tagus in Colmenar, upstream, before Aranjuez” in 1532[6]—protests that lasted a significant length of time, given the excessive consumption of water in summer, and leading to appeals “to the town hall of Colmenar to close off the channels through which water is siphoned off from the river, with irrigation prohibited between June fifteenth and October first.”[7]

3 Water Management in the City

The proverbial and endemic problem of supplying the city with water is a matter that must be relativized. By virtue of the characteristics of supplies, we need to distinguish between the needs for irrigation, urban, domestic and personal hygiene and sanitation requirements on the one hand and the supply of drinking water on the other hand.

The water supply was mainly possible thanks both to the Roman and medieval infrastructures that were restored and to the application of their techniques to new projects. New wells and *aljibes* were built and then added to those that already existed.[8] The brackish water stored in them (only the cathedral's *aljibe* had drinking

[4]AMT. Archivo Secreto. Alacena 2ª, legajo 2, núm. 46.
[5]AMT. Bandos y proclamas. 1791-02-28. Toledo.
[6]AMT. Archivo Secreto.Cajón 7, legajo 1, núm. 19.
[7]1584. Carta de Hernán Suárez Franco y Baltasar de Toledo, regidor y jurado de Toledo. AMT / 1-3.03//DC-113. 1584. Carta de Hernán Suárez Franco y Baltasar de Toledo, regidor y jurado de Toledo.
[8]AHPT (Archivo Histórico de Protocolos de Toledo). Contratos entre particulares y albañiles entre los siglos XVI y XVIII.

water) was essential to meeting the hygiene needs of cleansing streets and homes and bodies.

Sanitation was a constant feature of the city of Toledo. From the times of ancient Rome, there was an "effective sewage network, organized around sewers or main conduits called 'mothers,' which flowed into the river, into which the 'pipes' or conduits flowed from the houses" (Blasco Esquivias 2014: 271).

This inherited sewage system was modernized in the time of the Catholic Monarchs during the sixteenth century, and continued to be extended over successive centuries by networks of smaller pipes and sewer pipe structures.[9] It was a great concern of the town council, a continuous job that was, nevertheless, always favoured by the precipitous nature and slope of the city streets. The supply of drinking water represented the real problem for Toledo, which was located in a dry and arid climate and experiencing an economic and population crisis, turning the Tagus into an obligatory stop for muleteers, water carriers and washerwomen alike. The baths of the Moorish tradition disappeared from the city at the end of the sixteenth century and their function was taken on by the river itself, but only exceptionally.

The old fountains were a crucial element in this drinking water supply. Improvements in the access roads to the city brought better interconnectivity with the fountains located in the surrounding areas. It was during the eighteenth century that far-reaching repair and reform works were undertaken, with the building of pipelines that came in from outside of the walls and attempts to increase the flow of water, in addition to engaging in new works, especially in the last quarter of the century, coinciding with the archbishopric of Cardinal Lorenzana.[10] Some works were regulated by municipal initiative, such as the aforementioned *Cabrahigos*. An asset so scarce and so commercially valued – the water from many fountains had to be paid for—gave rise to constant complaints and municipal proclamations (Macías and Segura 1999: 94–95).

The water movement system - the Islamic *Qanat* - enjoyed great circulation during the early Modern Age and constituted the standard supply system in many cities (Blasco Esquivias 2014: 274), such as Madrid itself. In the village of Toledo, the main canal gave its name to the Alcaná neighbourhood; it supplied the *aljibe* for the cathedral and passed under the archbishop's palace. Precisely because it was always in operation, it was respected in the successive enlargements of the building (Merlos 2001: 264–265).[11]

The *aljibes* under the village, the cisterns and water tanks, and their respective wells, were key to survival, and therefore subject to regulation. After being filled by water from the Tagus and rainfall—either with a current of groundwater or conveniently at rest, decanted and filtered using lime—this supplied the town with the traditional Toledo water source that is still maintained today. In the mid-nineteenth century, Madoz (1849) noted how the water was deposited "in *aljibes* that people

[9]AMT. Archivo Secreto. Exp. Varios.
[10]AMT. Archivo Secreto. Exp. Varios.
[11]1711. ADT (Archivo Diocesano de Toledo). Lg Toledo-22 exp. 87.

have in houses, which fill up in February or March, and remain the whole year unsoiled and crystalline."

However, the cliché of thirst was perpetuated. Laborde also affirmed, out of a certain ignorance:

> Elle n'a ni puits, ni fontaines; elle manque absolument d'eau;on va chercher au loin celle qui sert à la boisson des habitants; on la transporte sur des ânes; on la conserve dans les maisons pendant quatre, cinq ou six mois. (Laborde 1809, III: 287)

In the high city of Toledo, gardens also developed. Today, this might be hard to believe, unless one actually enters the houses and private enclosures, however, chronicles and notes by travellers talk of the excellent courtyards, with pools and wells, that survived despite the fossilization of the convent city due to Toledo's change of direction towards an ecclesiastical capital (its cathedral takes pride of place in Spain) after it lost its position as the capital city. What is clear is that the great river *noria* that dazzled the traveller al-Edrisi in the twelfth century enabled the water to enter the city in such a way that intramural gardens developed, regardless of what developed in the *almunias*, and then later in the *cigarrales*. We must talk of fenced gardens with walls or partitions, which had a well, pond and *aljibe* for the purpose of irrigating fruit trees, a type of garden that is primarily a small kitchen garden, although there were also possibly cruise gardens (Perla and Soto Caba 2015). Many of the extraordinary courtyards of Toledo today are to be found in convents within the walls (Soto Caba and Perla 2015, 2016).

Some of these newly founded convents chose enclaves closest to the river, seeking, on the one hand, withdrawal and silence and, on the other hand, a water supply for their orchards and cloisters. At the beginning of the seventeenth century, the convent of San Agustín sought to expand "towards the river bank," a project that was rejected by the local council of the time.[12] The Convent of San Francisco Descalzo set out its kitchen garden on a terrace constructed over the Tagus. In turn, the Convent of *La Concepción,* to the north of the city, owned an ample space of orchard that reached as far as *Las Covachuelas,* or *The Hovels;* and the Orchard of Granadal in the Convent of San Pablo was located on a slope alongside the outer side of the city wall. Additionally, among the intramural orchards were the Convent of Carmen and the Hospital of Santiago. At the beginning of the eighteenth century, the panoramic view by Arroyo Palomeque depicted all of these green spaces. Similar examples can be traced in noble civil constructions, although the aristocrats in the Toledo population fell into decline during the early Modern Age, due to the court moving to Madrid.

A last recurring theme that still remains unresolved stems from the royal gardens of the *Alcázar.* Marías (1983, IV: 75) expressed scepticism about the plan on the poster by Giorgio Vasari el Joven in the "Palazzo et giardino del Re à Toledo ogni

[12] 1605-1606.AMT. Archivo Secreto. Cajón 4, legajo 2, núm. 81.

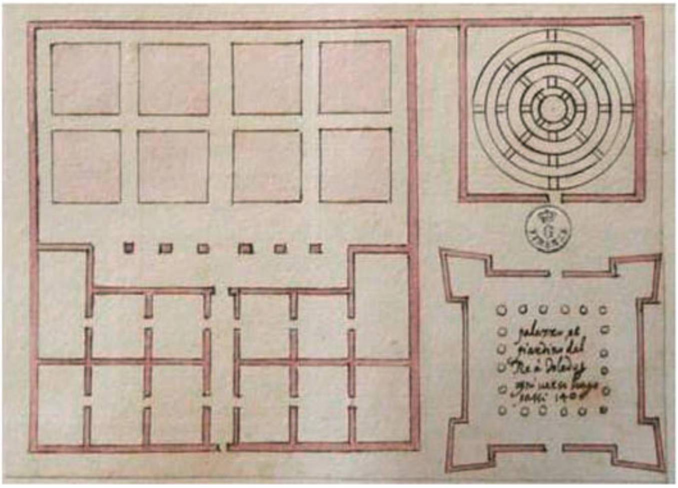


Fig. 4 Giorgio Vasari el Joven "Palazzo et giardino del Re à Toledo ogni verso luego passi 140". Gabinetto Disegni e Stampe degli Ufizzi GDSU no. 4762

verso luego passi 140" (c. 1595. GDSU nº 4762), edited by Virginia Stefanelli (1970: 206). The links between the Italian and Tuscan court and Spain have been researched and, although the young Vasari was never on the Peninsula, he may indeed have had access to the plans and projects of several Spanish buildings (Guerrero 2008: 98). This plan might be understood as, if not completed works, a project related to the stated intention of Philip II to lay out gardens in the Alcazar (Fig. 4). Juan Herrera, in a document dated 1586[13] (García Diego 1977: doc. 4), guaranteed irrigation to the king through recourse to Juanelo's device:

> …water also for some recreation garden that his Majesty shall be gracious enough to order in the place that has been stipulated (…) and will give orders as to how the garden of the said water can be served and have it whenever he should desire it for the garden and some fountains.

Or through the traditional Toledo water tank system :

> …and for gardens, should they be constructed … there shall be four aljibes that are in the said Alcázar that can fit more than one hundred and twenty thousand pitchers, should His Majesty desire to make a garden.

[13]1586, marzo, 6. AGS (Archivo General de Simancas). Casas y Sitios Reales, leg. 271, fol. 210-213v.

4 The European and Spanish Context: The Circulation of Water Treatises During the Renaissance

Water models and devices in Latin countries were resumed during the Renaissance, thanks to the prevailing interest in controlling water. The splendid study by Ferretti conveys how the Florentine cities participated in the “reproduction of this type of machine that the European West had known at the end of the thirteenth century,” but within the traditional scope of the “*machinatio* of the Roman world that survived over the centuries, and also from Muslim culture” (Ferretti 2016: 30–31).

Certainly, experimentation and the empirical constitute part of the development of water-lifting machinery in the sphere of gardening and private spaces, as, in this context, the widespread taste for automatic systems and musical organs enabled the perfect interaction between water and movement (Ferretti 2016: 32), observed both in treatises (Giovanni Sanminiati) and in their practical application (Villa d’Este, Villa Patrolino).

Water systems were redefined during Humanism, when, with Leonardo da Vinci at the head, art, science and technology formed one single body of knowledge. Da Vinci was not able to complete his “libro dell’acqua” (Book on Water), but, together with the works of Brunelleschi, Francesco di Giorgio Martini and Taccola, among others, a huge advance was achieved in the technology of the water-raising wheel. The drawings printed in the Italian and Spanish treatises achieved wide circulation and reaching an interested public (García Tapia 1996: 17–22; Gómez López 2017a, b).

Specifically, the city of Toledo was a reference point for Taccola and Francesco de Giorgio, who proposed solutions for raising water based on the Roman past. Taccola referred to the syphon system of the Roman aqueduct (Galluzzi 2012: 196; Zanetti 2017), and Giorgio Martini proposed the solutions of the Vitrubio aqueduct in an illustration in his O*pusculum*, identifying “plunger pumps moved by means of cams operated by a hydraulic wheel placed at the valley floor” to supply Toledo (Galluzzi 2012: 200; Zanetti 2017).

On the other hand, Leonardo’s scientific and technical teachings did not go ignored in Spain: the best-known example is that of Lastanosa, the author of *Los 21 Libros de los Ingenios y de las Máquinas* (*The 21 Books of Mills and Machines*) (García Tapia 1996). The general concern that interested Leonardo, Lastanosa, and the sixteenth-century Spanish inventors, such as Francisco Lobato and Jerónimo Ayanz, was the hydraulic water-lifting machine, together with the water mills (García Tapia 1996), solutions that were formulated theoretically in the well-known “theatres of machines” (Gómez López 2017a).

In any case, we must not forget that the Andalusian texts on agronomy—precisely, those in which the references to hydraulic engineering can be found—were written without the presence of the Latin sources, which were also to be found in medieval Spain (Vitruvius and Frontino); consequently, two traditions coexisted during that period: the Latin and the Muslim, which were not coincidental, but from common Hellenistic roots, and that were later to merge.

5 The Early Modern Age Alternatives for the Supply of Water: The First Renaissance Proposals

The attempt to raise water and overcome a 100-m difference in height between the river and the city was a story of successive failures. In 1485, still under the Catholic Monarchs, the raising of water to the Plaza de Zocodover[14] was already under consideration. Furthermore, as from the beginning of the 1500s, the cathedral chapter and the town hall obtained a licence "so that the water of the river Tagus could skilfully be raised to this city, and distributed through the piping system right through it, building fountains wherever needed."[15]

The opening of fountains in the city's nerve centres, the squares of Zocodover and Town Hall, appears to be the common denominator in these first attempts, as is also the case with the attempt documented in 1527 that sought to raise water for two fountains.[16] The title "water masters" identifying the professionals in charge of these tasks appears in a 1527 list of materials, alongside "iron, copper and lead for the carts" to raise water to the "Reales Alcázares," the royal residence.[17] This news must correspond to the artifice backed in 1526 by the chamberlain of Charles I of Spain, Henry III of Nassau-Breda and his wife, the second Marchioness of Zenete, who was supported by the Emperor himself: "the royal faculty (…) to raise water from the river and fashion the necessary buildings and fountains"[18] in a more clearly expressed form to "raise the water of the River Tagus and make two fountains."[19]

The German specialist Quentin and his assistant, Adrian, were commissioned for this task (cfr. Sánchez 1984: 75).[20] The system was put into operation in 1528 by "a foreigner, the servant of the Count of Nasao and, after having cost the city dear, the water rose from the first mills next to this Alcantara bridge to the Alcaçar" (Pisa 1605: 23).

It seems that the weaknesses in the mechanism and the flooding of the river served to destroy this ingenious device:

> …for the river having carried off the tower and factory where the artifice was in the water, (…) since no type of metal was sufficient for the pipes, however much reinforced, to be able to resist the fury of the water. (Pisa 1605: 23)

It is confirmed that steel had been brought from the north of Spain: "[F]or this they took from the town of Mondragon a lot of *raya* (mineral dust) which is made into steel." The description of the mechanism, "some wooden sledgehammers like fulling mills, that shook the water and enclosed it, in such a way that pure impetus

[14] 1485. Zocodover. AMT. Archivo Secreto. Caja 6, Leg 2, num. 4 Pieza 1.
[15] AMT. Archivo Secreto. Caja 6, Leg 2, num. 4.
[16] AMT. Archivo Secreto. Caja 6, Leg 2, num. 4, Pieza 2.
[17] 1527. Papeles tocantes al arbitrio del agua desde el río a los Reales Alcázares AMT. Archivo Secreto. Caja 6, Leg 2, num. 4, Pieza 3.
[18] 1526. AMT. Archivo Secreto. Caja 6, Leg 2, num. 4, Pieza 2.
[19] 1526, julio, 7. AMT. Archivo Secreto. Caja 6, Leg 2, num. 4, Pieza 2.
[20] AMT. Actas 1562, fol. 24v.

would make it run up the pipes," evokes the design that Isacchi (1579: 126–128) was to produce a century later, inspired by the tradition of the mills on the River Po. Due to its exterior similarities, Escosura (1888: 18) considered that, instead of mallets, there should be wooden pumps (not bronze) moved by levers. Escosura explained to Ctesibio, via Vitrubio, that eventual breakages were due to the air pressure in the pumps and the impact of the water in the pipes. However, due both to the German origin of the engineer and the description by Pisa, the Toledo device relates to the dike-based water pump elevation systems that appeared in the fifteenth century in Germany and Central Europe (Nuremberg, Aubsburg, Konstanz), and were even combined with waterwheels, as in Bremen (Ewbank 1876: 294), subsequently promoted by Charles, the emperor himself.

Reports on other contemporary attempts to raise water are imprecise, in some cases, even amateurish. The case of the clergyman Sebastián Navarro, in 1553,[21] is worth a mention here, alongside that of Luis de Fox, a poorly identified character, possibly in the service of the king at El Escorial or possibly a disciple of Turriano, and probably the only author of the famous engineer's models, as the royal decree of 1564 would suggest. This decree orders the financier of the works on the Alcázar de Toledo to pay "Luis de Fox, our servant … for the costs he has incurred in order to make certain models to raise the water to that city" (Llaguno 1829, II: 77). However, the likelihood is that these models were never put into practice and were related to the patent that the engineer Luis Fois (most likely the same person) had obtained in 1563 to "remove and raise water from the rivers to high places, by subjection."[22]

The project subsequently presented in 1561 at the request of the Crown may be the most interesting during this period prior to Juanelo's. This project once again questioned the feasibility of adopting the mill next to the Alcantara Bridge as an extraction point.[23] The authors, Juan de Coten and Jorge de Ulrique (*maestre* Jorge), were also involved in different channelling works for Aranjuez, as well as in raising water up to Madrid's Alcázar (Llaguno 1829, II: 77; García Tapia 1990: 272). The presence of Dutch experts, called "plumber engineers," at the royal sites for the regional projects of companies commissioned by the Spanish monarchs, Charles I and Phillip II, is primarily explained by the entry of the Netherlands into the Spanish empire (1555). A royal document dated 1562 refers to the way in which "Coten and Maestre Jorge, Flemish, our servants, tried to make certain machines to raise the water to that city" (Escosura 1888: 18).

The water level measurements "of the water that has to come to the Alcázar, which if it would reach would be a great thing" most likely refer to this waterwheel. These works were undertaken in 1562 by Luis de Vega (Cervera Vera 1996: doc. 3), another outstanding professional employed in creating the royal surroundings with experience regarding the waters of the Tagus in Aranjuez.

[21]AMT. Archivo Secreto. Caja 6, Leg 2, num. 4, Pieza 2.
[22]AGS. Cámara de Castilla, Libro de Cédulas, 141, fol. 38. Cfr. García Tapia, 2008, 45.
[23]AMT. Archivo Secreto. Caja 6 Leg 2 num. 4 Pieza 2.

Although one author does attribute this device to a different project (Zanetti 2017: 358–359), it appears that Coten and Maestre Jorge's device is referred to in a 1561 document in which the town hall of Toledo makes mention of "the *yngenieros*" or engineers appointed by Phillip II, when explaining a series of problems to the royal scribe, mainly the excessive diameter of the channelling while, for the first time, considering the construction of two different mechanisms (Cervera Vera 1996: doc. 2).

The city was clearly concerned about obtaining water from a project that derived from the Crown's initiative, in service of which the experts were hired by Royal Decree on October 4, 1561. This document contains several points of interest: the fact that the city of Toledo would cover the payments to the people expressly termed "engineers" (which would not be the case with Turriano); the report that the town hall issued and brought to the attention of the king, detailing the errors detected in the calculations of the channel diameters; the great height to which the water was to be raised; and the alternative proposal to install two devices. The document also mentions the amounts that the king would use: one of the devices would serve the *alcázar* and another the city. Also detailed is the anticipated town hall decision in favour of having two waterwheels, very similar to the scheme that the city later adopted with Turriano.

In the two best known projects, those of 1526 and 1561, the use of pre-existing water-bearing structures is striking, specifically the mills of Barranchuelo, next to the Alcántara Bridge, as a water collection point. These same medieval Toledan structures and techniques would also once again be used by Turriano. The watermill leased for the 1561 project would eventually be purchased in order to undertake the Turriano project. While failing to achieve a successful device, this perfectly defines its place among the historic mills of Barranchuelo.

In this period prior to Turriano's intervention, the reference to the royal fortress was also reiterated as a point to which the water might rise, a logical reflection of the crown's involvement in the projects.[24] In the same vein, all of the evidence appears to indicate that the proposal was based on the 1561 project by the Flemish masters.

6 Juanelo's Device

In 1564, Turriano, later nicknamed Juanelo, presented a project to the king and the town council of Toledo to raise water from the river to the site of the *alcázar* (Cervera Vera 1996: doc. 13). A few years after the court moved to Madrid, Turriano embarked on his project. From 1565 onwards (Pisa 1605: 23), decrees

[24]AGS. Obras y Bosques. Lib. 3, fol. 211. Transcrita por Llaguno, 1829, 246.

were issued to “raise water from the river to *los Alcázares*,” from whence its distribution to the city squares is defined as “shared out between three fountains for the squares of Çocodover, the main square, and the one of the Town Hall.”[25]

Once the device had gone into operation in 1569, Juanelo began constructing another, adjacent to the first, in order to supply both the fortress and the city. This was completed in 1581 (Jufre García 2008: 13–18). However, with the death of Juanelo, and later his son, “the essence of the movement of the machine” was lost (Jufre García 2008: 19). Turriano left neither drawings nor plans and took great care not to talk about his invention in order to stave off competitors and the threat of plagiarism. Only Morales (1575) had conversations with Juanelo about the machinery. In 1605 and 1624, the first and second devices respectively stopped working, despite all of the efforts of the engineer Juan Fernández del Castillo, who even drafted a project based on the irrecoverable device.

After several years of research, Reti (1968) published the guidelines for Juanelo’s mechanism and made a model of the device consisting of 24 towers of buckets and a large waterwheel in the river at the location of both the dam and a number of pre-existing structures.

The wheel moved 24 buckets via an iron chain, raising the water 14 m in height to a first tank. From there, the machinery became more complex (the portion that was considered the true invention), due to the continuous, circular movement of the drive wheel before the transition to another swinging, rectilinear one thanks to the straps and propulsion device that moved in a jagged direction, in keeping with the terrain’s profile. The swinging bucket towers poured water from one to another to achieve successive increases in elevation, thanks to the vertical swinging mechanism, which, accordingly, moved the buckets up and down. In addition, there was a pause in the system to enable the water to be emptied from the buckets.[26] Reti’s research represented the culmination of a process of progressively greater interest in the figure of Turriano that had first begun in 1879, when Luis de la Escosura y Morrogh was commissioned by the Town Hall to study the city’s water supply. The result of his studies was a report published in 1888 that, years later, Theodor Bech was to read and translate into German, a translation that eventually triggered curiosity in historians of science and technology.

Following the contributions of Reti, the artifice of Turriano was subject to the attentions of Spanish historiography. Scholars have concurred in confirming a series of antecedents to the water machine in the “Theatres of Machines,” as also indicated in the recent, well-studied work by Jufre García (2008), who identified the “Valturio scissors” or “scissors of Nuremberg” by Valturium, author of *De Re Militari* (1462), whose Book XII displays a picture with a structure indicated for storming fortresses. Recently, Shulman (2017: 153) updated the state of play, inclining towards Reti’s vertical model theory, which was also outlined in García Tapia’s hypothesis (García Tapia 1990).

[25]AMT. Archivo Secreto.Caja 6 Leg 2 num. 4 Pieza 2.
[26]Recreation in http://www.juaneloturriano.com/noticias/2014/03/17/video [last access 29/01/2018].

In line with the historiography, we may add a series of considerations. The first point is that, due to the device's size, its location and the consequent visibility, Turriano's watermill played a key role, not only in Toledo's sixteenth century water system, but also in the iconography of the city itself, determining the succession of descriptions and views that serve to illustrate the historical evolution of this contraption. The literature of the Golden Age praised the work to the point of making it famous internationally and simply contemplating this device became reason enough to visit Toledo.

The waterwheel emerges as one of the key features in Hoefnagel's and Arroyo Palomeque's bird's-eye views, as well as part of the iconography of the nineteenth century prior to the device getting demolished.

In its time, this machine reflected the high technical standards reached in Spain in the mid-sixteenth century. However, it did not cease to be fully contextualized in Renaissance treatises and was, simultaneously, heir to the knowledge of medieval times. Neither was it, surprisingly, anything new, as, while pioneering in the raising of water on the Iberian Peninsula, a hydraulic water-lifting system with a similar wheeled movement had already been built at an earlier date in the city of Nuremberg in Germany. Nonetheless, the Spanish system was indeed built earlier than both the water supply system in London, built in 1582, and the Samaritaine in Paris, dating to 1608.

One would have to connect this with Salomon de Caus, considering Crespo's appreciation of the advancement and virtues of Turriano's mechanism, as the engineer was, first and foremost, a clockmaker, an art that "involved the production of gears and transmission mechanisms of forces based on pulleys and wheels, a basic principle of Renaissance machinery" (Crespo Delgado 2014: 15).

As for the inheritance of medieval knowledge, the lifting wheel of the well-known device traces its antecedents to the great waterwheels already mentioned and as depicted in the nineteenth century photographs that still detail the supports belonging to the original mechanism. The debate still remains open as regards Balbás's idea that these hydraulic mechanisms may have served as a precedent and model for Turriano's complex device and that they may have been built in the same place as the waterwheel described by the Muslim, al-Edrisi, in the twelfth century (Torres Balbás 1942: 463). There is also obvious certainty as regards the incorporation of an *azud* or dam, a medieval mill, with its water-powered wheels acting as the point of intake for the water.

The swinging bucket structure based on the lifting wheel of Juanelo's device might be seen as the first antecedent of the unpressurised water elevation system through recourse to the bucket systems that, according to González Tascón (1987: 469), reach back to the thirteenth century under the influence of al-Jazari and his *Book of Knowledge on Waterwheels*.

Juanelo's machine, the most surprising expression of sixteenth century hydraulic engineering, scarcely got mentioned in subsequent treatises, with one of the few exceptions being the distant evocation of such contraptions represented in the work of Ramelli (1588: eng. 95, 96), *Le diverse et artificiose machine*. However, we must not consider that this device was simply ignored, as the spread of this technology required due assimilation.

In practice, the Phillip III commissions given to the military engineer Pedro de Zubiaurre on the occasion of the court's transfer to Valladolid demonstrate the importance of Juanelo's work as a model (García Tapia 1990). However, there were already more sophisticated and modern methods for raising water, such as using pressure to generate force, reflecting the reason for the success of a system very similar to that of Turriano's: Marly's device, developed in 1681 by Rannequin Sualen, a Flemish technician, who was thus able to supply water from the Seine to the fountains and gardens of Versailles. The piston pumps offered greater power, and this new feature was tried out by Fernandez when planning for the recovery of Turriano's device. The main difference between this and the great French invention was the recourse to pressure as a source of force. The weight of the Flemish tradition in Marly's case also requires consideration.

Flemish engineering took on a prominent role in the hydraulics of the Spanish Renaissance, through backing from the crown, as evident in the complex Aranjuez system, which made its own contribution through Turriano's contemporary proposal. In any case, Turriano's device was a victim of its own complexity, and hence its survival was possible only to a limited degree, but at least it gave rise to its study and application through focus on a number of the features that made up its system, as is the case with the later treatises mentioned above.

7 Final Remarks

The truth is that the solution produced by Turriano's artifice soon came to an end as a result of economic problems, and thus almost became a mere anecdote in the city's history.

With the end of Juanelo's waterwheel and Juan Fernández del Castillo's restoration attempts (Jufre García 2008), the city's hydraulic water supply mechanism was no longer in usage. However, the perpetual need to quench the thirst of Toledo, as well as the memory of the artifice, especially during the eighteenth century, gave rise to proposals for systems to supply the city. More than twenty projects were presented before the Town Hall[27]—the first in 1679, followed by others in 1692, 1695 and 1714 (Mora del Pozo 1984), but all failed due to the stringent conditions demanded by the corporation, among other reasons.

The inability to obtain water in Toledo attracted attention in the eighteenth century, with a bent towards hydraulic solutions accompanying the printing of new texts such as the Treatise of Ardemans, *Fluences of the earth and the underground course of the waters* (Madrid, 1724), which described methods for capturing groundwater, its collection by wells and its transportation or channelling towards cities. This work also covered the "method of manufacturing ponds, *aljibes*, *norias* and wells" (Blasco Esquivias 2014: 275), areas and structures that were, nonetheless, well-known and under implementation in the city by the Tagus.

[27]AMT CAJA 6 LEG 2 Nº 4.

It would seem that the eighteenth century treatises on hydraulics failed to contribute any new features or solutions to Toledo. In 1830, a report from the Academy of Fine Arts in Madrid, *On the transportation of water to the fountains: construction of aqueducts, wells, cisterns and ponds*, in many ways confirmed the continuity of traditional water storage and supply systems.

The early years of the nineteenth century brought one last project based on recourse to the inherited infrastructures. Specifically, the usage of dams, especially that of the *Corregidor* or chief magistrate, was proposed for supplying the city. The proposal was put forward by the engineer Vallejo (1833), an outstanding mathematician of his time and the author of *Adiciones*, featuring additions to the geometry of Benito Bails.

Water management in Toledo during the early modern age was based on the continuity of the infrastructures and systems originating from the Roman and Taifa periods, which, as they were well preserved and had been fully repaired or converted, still remained in use. In fact, many of these lasted through to the 20th century. This link with the city's hydraulic past even emerged in newly created devices and industries, which were based on the medieval mills, such as Turriano's spectacular device of the sixteenth century and the Weapons Factory of the eighteenth century.

Toledo was thus able to maintain crops and gardens, both in the surrounding urban environment (orchards and *cigarrales*) and also the heart of the city, through the usage of *azudas* and *norias*, pipelines, *aljibes* and wells. We are thus able to revise the picture of the dry city, an image built up by travellers and artists who merged the ideas of the broken waterwheel, the arid rock and the thirst of the townspeople.

Toledo was a city that was able to satisfy both its recreational and domestic needs (washing, irrigation, sanitation), but not its need for drinking water, which confirms the reality of the secular thirst of Toledo, with the supply of drinking water correspondingly becoming the main goal of hydraulic management in Toledo during the early modern age. On the one hand, Toledo was the object of attention both for treatise writers (especially Taccola and Martini) and European engineers. The centuries of modernity were marked by successive attempts and failures to raise water from the river to the city by Spanish, Flemish, British, and French professionals alike, with the exception of the Turriano device, which did function, even if only for a few decades. The distribution of drinking water would, in fact, not be achieved until the nineteenth century, already into modern times.

In any case, we should not forget that Muslim science and technology provided the necessary link for the logical transmission and development of the Greco-Roman tradition and the most notable advances attributable to the Andalusian world lie in their empirical studies on the ideal conditions for improving plant growth, especially as directed towards gardens. The confluence of the Hispano-Moresque footprint with the new features of the Renaissance was a hallmark of the Spanish garden during the early modern age and, in the Toledo case, was expressed in the gardens that took shape in cigarrales (country houses), orchards and intramural areas.

In short, it is this confluence of medieval tradition and modern treatise by both European and Spanish engineers and theorists that synthesizes some of the fundamental issues of hydraulic engineering in Toledo between the sixteenth and nineteenth centuries.

References

Aranda F. et al. 1997. *El sistema hidráulico romano de abastecimiento a Toledo,* Toledo: Instituto Provincial de Investigaciones y estudios toledanos.

Blasco Esquivias, B. "Toledo y Madrid: sistemas de captación y uso del agua para servicio doméstico en la Edad Moderna". In: Lozano, M.M. y Méndez, H. (Eds.), *Patrimonio cultural vinculado con el agua: paisaje, urbanismo, arte, ingeniería y turismo*. Cáceres: Editora Regional de Extremadura, 2014.

Briz, J. y Simó, P. 1755. *Curso Ydrographico y Corográphico de los ríos Tajo y Guadiela.* España, Servicio Geografico del Ejército.

Cabanes, F. J. de. 1829. *Memoria que tiene por objeto manifestar la posibilidad y facilidad de hacer navegable el río Tajo desde Aranjuez hasta el Atlántico, las ventajas de esta empresa, y las concesiones hechas a la misma para realizar la navegación*. Madrid: Miguel de Burgos.

Carduchi, L. 1641. *Chorographia del rio Tajo : año de 1641*. 2008. M. García Ruipérez (Ed.). Toledo: Ayuntamiento de Toledo.

Cervera Vera, L. 1996. *Documentos biográficos de Juanelo Turriano.* Madrid: Fundación Juanelo Turriano.

Crespo Delgado, D. 2014. "Juanelo Turriano: ingenio y fama", In: A. Cámara et B. Revuelta (Coord.), *Ingenieros del Renacimiento.* Madrid: Fundación Juanelo Turriano. pp. 9–23.

Crespo Delgado, D. 2017 "Miguel Sánchez Taramas y Benito Bails: dos tratados de ingeniería hidráulica de la España de la Ilustración", In: A. Cámara et B. Revuelta (Coord.), *La palabra y la imagen: tratados de ingeniería entre los siglos XVI y XVIII,* Madrid: Fundación Juanelo Turriano.pp. 123–144.

Escosura y Morrogh, L. de la. 1888. *El artificio de Juanelo y el puente de Julio César.* Ed. 2012. Valladolid: Maxtor, 2012.

Ewbank, T. 1876. *A Descriptive and Historical Account of Hydraulic and Other Machines for Raising Water.* New York: Scribner.

Fernández Casado, C. 2008. *Acueductos romanos en España.* Madrid: Colegio de Ingenieros de Caminos, Canales y Puertos.

Ferretti, E. 2016. *Acquedotti e fontane del Rinascimento in Toscana*. Firenze: L. S. Olschki Editore.

Galluzzi, P. 2012. "From Brunelleschi to Leonardo". In: R. Zwilling (Ed.), *Natural Sciences and Human Thought*. Berlin: Springer Science & Business Media. pp. 193–202.

García Diego, J. A. 1977. "Cinco documentos relativos a Juanelo Turriano", *Toletum,* 8:245–284.

García Mercadal, J. 1999. *Viajes de extranjeros por España y Portugal.* Salamanca: Junta de Castilla y León.

García Tapia, N. 1990. *Ingeniería y Arquitectura en el Renacimiento Español*. Valladolid: Universidad de Valladolid, Secretariado de Publicaciones.

García Tapia, N. 1996. "Ingeniería del agua en los códices de Leonardo y en los manuscritos españoles del siglo XVI", *Ingeniería del agua,* Vol. 3. (2): 17–38.

Guerrero, J. M. 2008. "El plano de Vasari de la catedral de Sevilla". In: M. C. Álvarez (Ed.) *La catedral gótica Magna Hispalensis: Los primeros años.* Sevilla: Avla Hernán Ruiz. pp. 89–121.

Gómez López, C. 2017a. "... *Sia in guerra che in pace*. Los teatros de máquinas, una escenografía de la técnica, entre utilidad y el placer". In: A. Cámara et B. Revuelta (Eds.), *La palabra y la imagen. Tratados de ingeniería entre los siglos XVI y XVIII*. Madrid: Fundación Juanelo Turriano, pp. 39–54.
Gómez López, C. 2017b. "La retórica del ingenio. Imágenes de invención, entre el arte militar y la escenografía". www.drammaturgia.it http://drammaturgia.fupress.net/saggi/saggio.php?id=6971] (last access: 2 Feb 2018).
González Tascón, I.1987. *Fábricas hidráulicas españolas*. Madrid: MOPU-Turner.
Hurtado de Toledo, L. 1576. "Memorial de algunas cosas notables que tiene la imperial ciudad de Toledo". In: C. Viñas & R. Paz (Ed. 1963) *Relaciones Histórico geográficas de Felipe II. Reino de Toledo.* vol. III. Madrid: CSIC.
Isacchi, G. B. 1579. *Inventioni de Gio. Battista Isacchi da Reggio, nelle quali si manifestano varii secreti & utili avili a persne de guerra, e per i tempi di piacere*. Parma, 1579.
Jufre García, F.X. 2008. *El artificio de Juanelo Turriano para elevar agua al Alcázar de Toledo (s. XVI). Modelo con escaleras de Valturio.* Lleida: Milenio.
Laborde, A. 1809. *Itinéraire descriptif de L'Espagne, et tableau élémentaire des différentes branches de l'administration et de l'industrie de ce royaume.* Paris: H. Nicolle.
Llaguno y Amirola, E. 1829. *Noticias de los arquitectos y arquitectura de España desde su restauración.* Madrid: Imprenta Real.
López Gómez, A. et al. 1998. "Felipe II y el Tajo". In: J. Martínez Millán, J. (Ed.), *Europa y la monarquía católica: Congreso Internacional Felipe II, Europa dividida, la monarquía católica de Felipe II.* Madrid: Universidad Autónoma de Madrid. Vol. 2, pp. 501–525.
Macías, J.M. y Segura, C. 1999. *Historia del abastecimiento y usos del agua en la ciudad de Toledo*. Toledo: Confederación Hidrográfica del Tajo.
Madoz, P. 1849. *Diccionario geográfico-estadístico-histórico de España y sus posesiones de ultramar*. Vol. XIV. Madrid: Establecimiento tipográfico de P. Madoz y L. Sagasti.
Marías, F. 1983. *La arquitectura del Renacimiento en Toledo (1541–1631).* vol. IV. Madrid: CSIC.
Marineo Sículo, L. 1530. *De las cosas memorables de España*. Alcalá de Henares: Miguel de Eguía.
Merlos Romero, M. 1998. *Aranjuez y Felipe II: idea y forma de un Real Sitio*. Madrid: Consejería de Educación y Cultura de la Comunidad de Madrid.
Merlos Romero, M. 2001. "El palacio arzobispal de Toledo, su entorno urbano en la Edad Media". In: J. Passini (cord.) *La ciudad medieval: de la casa al tejido urbano: Actas del primer curso de historia y urbanismo medieval 2001. Universidad de Castilla - La Mancha.* Toledo: UCLM, pp. 241–268.
Mora del Pozo, G. 1984. "Los intentos de subida del agua del Tajo a Toledo en el siglo XVIII", *Anales Toledanos*, XIX: 169–199.
Morales, A. de. 1575. *Las Antigüedades de las ciudades de España. Edición crítica del manuscrito.* (Ed. 2012). Madrid: Real Academia de la Historia.
Palomo, J. et Fernández, M.P. 2006–07. "Los molinos hidráulicos en la Antigüedad", *Espacio, Tiempo y Forma*. Serie II, 19-20, pp. 499–524.
Pisa, F. de. 1605. *Descripción de la Imperial Ciudad de Toledo, I Historia de sus antigüedades, i grandeza, i cosas memorables.* Toledo: Pedro Rodríguez.
Perla, A. and Soto Caba, V. 2015. "The *jardines de crucero*: a possible study scenario for the gardens of Toledo". In: A. Duarte (Ed.), *Courtyards and Monastic Enclosures*, Évora: CHAIA/CIUHCT. pp. 77–96.
Ramelli, A. 1588. *Le diverse et artificiose machine.* Paris: Ramelli.
Reti, L.1968. "El artificio de Juanelo en Toledo: Su historia y su técnica", *Provincias*, separata.
Román de la Higuera, J. 1700. *Historia Eclesiástica de la Imperial Ciudad de Toledo*. Toledo.
Shulman, C. 2017. *A tale of three thirsty cities: the innovative water supply systems of Toledo, London and Paris in the second half of the sixteenth century*. Leiden: Brill.

Soto Caba, V. and Perla, A. 2015. “Vulnerable images: Toledo, the arid city and its hidden gardens”. In: A. Duarte (Ed.), *Gardens and Tourism. For and beyond economic profit*. Évora: CHAIA/CIUHCT. pp. 27–46.

Soto Caba, V. and Perla, A. 2016. “De la vida entre jardines a los solares yermos. En torno a una construcción de la imagen de Toledo”. In: J. Calatrava, F. García, D. Arredondo. (Eds.) *La cultura y la ciudad.* Granada: Ediciones de la Universidad de Granada. pp. 651–657.

Stefanelli, V. 1970. *La città ideale: piante di chiese [palazzi e ville] di Toscana e d’Italia*. Roma: Officina Edizioni.

Torres Balbás, L. 1942. “La Albolafia de Córdoba y la gran noria toledana”, *Al-Andalus*, VII: 461–469.

Vallejo, J. M. 1833. *Tratado sobre el movimiento y aplicaciones de las aguas, 3: en el cual se manifiesta por métodos sencillos, claros y exactos, cuanto pertenece a su conducción, distribución y elevación…* Madrid: Miguel de Burgos.

Vázquez González, A. y Morollón Hernández, P. *Los cigarrales de Toledo: origen, evolución y situación actual. Informe histórico.* (inédito) Ayuntamiento de Toledo, 2005. Copia depositada en el Archivo Municipal de Toledo (AMT).

Vegue and Goldoni, A. 1927. “Los cigarrales de Toledo en el Siglo de Oro”, *Revistas de las Españas*. no. 12: 508–518.

Zanetti, C. 2017. *Janello Torriani and the Spanish Empire: A Vitruvian Artisan at the Dawn of the Scientific Revolution.*

Water Supply Management in Seville, 1248–1800

Manuel F. Fernández Chaves

Abstract
This work aims to provide a general overview of the water supply of the city of Seville from the Christian conquest in 1248 through to the nineteenth century. It focuses especially on the managing of the running water delivered by two aqueducts, one inherited from the Almohad caliphs and the second built in the sixteenth century. The institutional conflicts that took place between the king and the city government over water management represent another key line of study in conjunction with the means and structures for distributing water and the tensions that arose between this public good and private interests.

1 Usage and Consumption of Water: General Conditions[1]

Seville was formerly one of the largest and most populated cities in al-Andalus becoming, in the twelfth century the capital of the Almohad Empire on the Iberian Peninsula. Hitherto, the means of the city's water supply had traditionally relied on

[1]Our knowledge of the history of urban water supply systems in the Middle and Modern Ages has grown considerably in recent years, especially following the works of María Isabel del Val Valdivieso (2003), (2008), (2015) and Segura Graíño (2003), as well as others, as regards different cities across the country. In this chapter, we present a summary of the general history of the main

M. F. Fernández Chaves (✉)
Department of Early Modern History, Facultad de Geografía e Historia, Universidad de Sevilla, Sevilla, Spain
e-mail: mfernandez6@us.es

A. Duarte Rodrigues and C. Toribio Marín (eds.), *The History of Water Management in the Iberian Peninsula*, Trends in the History of Science,
https://doi.org/10.1007/978-3-030-34061-2_3

drawing water from wells and fetching water from the Guadalquivir River. However, this also represented the main artery of communication between the city and the Atlantic and the Mediterranean, and intensive usage by ships and vessels had left its waters in an insalubrious state. Within this context, and as part of his mandate project, the Almohad Caliph Abu Yacub Yusuf undertook the urban transformation of the city, including the construction of shipyards, a major new mosque (later restructured into the Cathedral) located within the Alcázar precinct and coexisting with the older place of worship (later transformed into the Church of El Salvador), the building of a pontoon bridge and, among other works, the reconstruction of the Roman aqueduct. Beginning in 1172, the last would begin playing a crucial role in providing the city with running water for the first time in centuries. This aqueduct was supplied by springs in the nearby town of Alcalá de Guadaíra (17 km away) and comprised three sections: an underground tunnel system, an open channel, and, finally, an elevated section that led to a large storage facility adjoining the city wall.

Most of the water carried by this aqueduct was dedicated to the irrigation of two palace complexes. The first, located outside of the city walls, was known as the Gardens of al-Buhaira and of the King ("Huerta del Rey") in Christian times and was supplied by a branch of the main aqueduct that split off just before the elevated section. The second spanned the grounds of the Alcázar inside of the city walls. However, little is known about how the Caliph came to possess the near totality of the running water supplied by the restored aqueduct. It would, in any case, only remain in the Caliph's hands for less than a century, with the city falling to King Ferdinand III of Castile in 1248. His son and successor, Alfonso X, regulated the city's water supply in such a way that a newly constituted council was attributed to a newly constituted council, responsibility for repairing and maintaining the aqueduct; known in the Christian sources as the "Caños de Carmona". The rent received from leasing the nine mills located along the water course was put towards these expenses. In return, the council was able to administer the water that reached the fountains inside of the city. Nevertheless, the Christian rulers reserved most of the water for their own use and enjoyment, as had their Muslim predecessors, and thus no great change in the water distribution system was brought about in this period (Fernández Chaves, 2011, 28–37; Valor Piechotta & Romero Gutiérrez, 1995).

The city council took on the heavy burden of maintaining the entire supply system from its own revenues, in an obligation that would only become steadily more difficult as the number of water system beneficiaries increased in conjunction

water supply systems in the city of Seville from the thirteenth century to the eighteenth century within the framework of setting out a bibliographic and knowledge-based overview, as exhaustive as possible, and including a large body of documentary references previously worked on within the scope of the references cited throughout.

with the scale of the installed network of pipes, drains and fountains. The aqueduct was itself difficult to maintain for several different reasons: in the underground section, calcareous formations produced blockages that emerged along the tunnels walls; this was coupled with by human activities in which people, as well as making use of the wells connected to the surface to draw drinking and irrigation water, would also use them to dispose of all sorts of debris and refuse. Along the open surface channel, this problem multiplied, due to the constant predatory activities of farmers, millers and landowners interested in using the water from the aqueduct for their own purposes. The channel also served as a place for watering livestock and was, indeed, spanned by a number of small bridges that enabled the passage of herds of cattle, as the channel interrupted the paths of various drovers. The mills located along the channel held back water in order to generate greater power for their wheels, thus causing losses of streamflow and even partial cuts to supply. Although the channel was supposedly protected by ditches and a wooden fence, these measures simply did not prevent access, whether by cattle herds or people extracting water for drinking or irrigation, or even the occasional building of walls to divert this artificial rill into their private estates, as well as the soiling of the water supply through the disposal of waste and refuse along the channel. All of these activities resulted in clear and purposeful damage to the infrastructure, adding to the natural deterioration of the materials themselves, whether caused by the passage of time or the erosive action of water, thus making constant maintenance work necessary (Fernández Chaves, 2011, 57–132).

The Islamic origins of this channel are reflected in its route, as, instead of going directly to the city, it traces a broad northerly curve before heading into the city by way of the open shrine that still survives today, known as the "Cruz del Campo", located next to a small chapel. This route correspondingly took advantage of the changes in the physical topography, thus contributing to maintaining a constant and accessible current on which to locate the water mills, which totalled fourteen in the Almohad period. From the shrine onwards, the aqueduct surface section turned westwards, before passing another mill (known as "de la Cruz," in keeping with the nearby landmark) from which a branch broke off to supply the aforementioned Huerta del Rey, which became a private property in the fifteenth century. Then, the channel began rising over the increasingly high arches, built to maintain the hydrostatic load, before leading into a storage tank adjoining the city wall next to one of the city's most important gates: Puerta de Carmona (Fernández Chaves, 2011, 133–146) (Fig. 1).

Indeed, the council work to keep the aqueduct in good condition was an ungrateful task. As time passed, the city appointed a bailiff to be in charge of making rounds, earning his salary from part of the fines collected as a result of his reporting misuse. His work was difficult, as he had to face up to powerful landowners, millers, drovers, water carriers, washerwomen, etc. His rounds were complemented by the inspections made by the city's waterworks superintendent and the master builder, although they did not always inspect the entire aqueduct, focusing mainly on the surface channel and the elevated section, and neglecting the cleaning and repair of the more difficult-to-access underground tunnel system. In

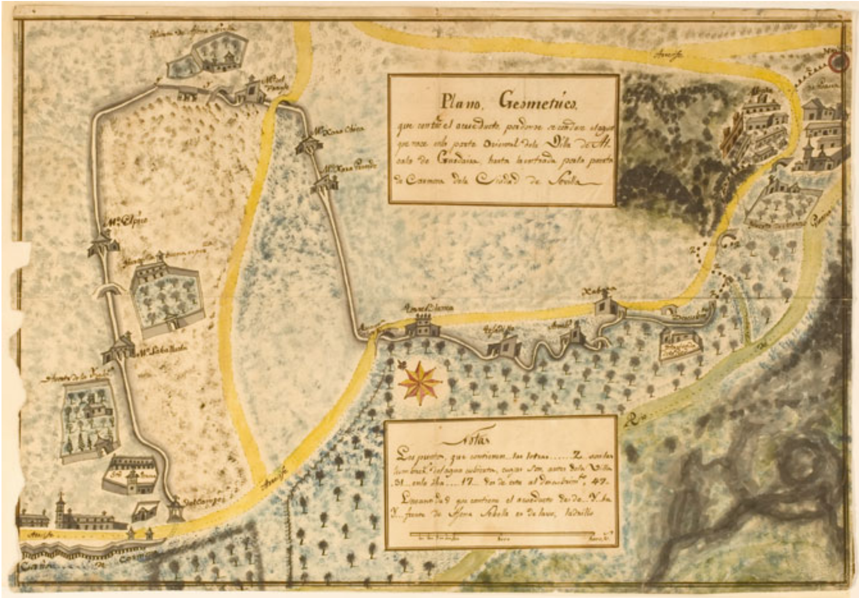


Fig. 1 Map of “Caños de Carmona” drawn by Acisclo Burgueño, seventeenth century. © ICAS-SAHP, Municipal Archive of Seville, Pl. I-3-24

theory, the mill tenants held responsibility for cleaning the conduits by which they were supplied, but they certainly did not always fulfil this obligation. Additionally, these problems became aggravated in times of drought when the flow of the springs naturally tailed off, with such times only deepening the rivalries over consumption of this running water and the abuses, fraud and water diversion taking their greatest toll on the water available, and therefore correspondingly exacerbating the situation in the city and the Alcázar (Fernández Chaves, 2011).

2 From the Middle Ages to the Renaissance

During the fourteenth century, the aqueduct water supply was less consumed by the general population than it was used for the irrigation of the fertile working gardens that the new Christian settlers continued to maintain. The city was the capital of an extensive economic area, strengthened by its productive hinterland (primarily wheat, wine and olive oil) and played an important role as an inland port able to connect the African, Mediterranean and Atlantic regions (Morales Padrón, 1989; Otte, 1996, 2008). However, its location was also on the border with the Kingdom of Granada and, on many an occasion, it was afflicted by the internal conflicts that were ongoing among the nobility. Undoubtedly, the fifteenth century constituted the period in which these three facets developed most forcibly, specifically, the economic and demographic growth of the city, its role as a centre for military operations against the Kingdom of Granada and the scene of rivalries among the nobility and struggles with the monarchy over political power. Urban growth also unleashed greater ambitions among the distinguished nobles and lords of the city over appropriating a proportion of the running water owned by the crown in order to supply their personal entourages and irrigate their own private gardens and newly built fountains. The only way of gaining access to the city's water supply was to receive a royal concession attributing a given amount of water, the unit of measurement for which was the "water straw", a hole with the diameter of a straw stalk opened up in the water distribution pipes. In the fifteenth century, the monarchy began to relinquish its rights over water in favour of its most faithful supporters in the nobility. During this century, distinguished households were supplied with more water than the city itself, which, after being gratified by the regent Ferdinand of Antequera at the beginning of the century, was thereon denied access to a majority share of the supply. With the concessions then extended, especially by Henry IV and the Catholic Monarchs, the list of private households in possession of running water expanded greatly. Between the late fourteenth century and the first third of the fifteenth century, while the references are not fully clear, but it does seem that some private estates already had access to the water supplies formerly delivered to the palaces of Islamic origin as was the case of the residence of the Dukes of Béjar (Fernández García, 2011; Fernández Chaves, 2012b). Some sources, for instance a manuscript held in the Municipal Archive of Seville, indicate that certain Jewish families held access to the city's water supply for a long period of time. This was subsequently confirmed by many of the private owners that took over the Jewish properties in the wake of the 1391 riots and the expulsion order of 1492, as they obtained access to the water hitherto enjoyed by the properties' former inhabitants (Fernández Chaves, 2010, 2012b). In the second half of the fifteenth century, the purchase and sale of water increased, with access to running water becoming more widespread for several reasons:

– Having running water in palaces and houses became essential for those deemed of a higher social status.
– Noble households divided up their large water concessions and granted access to their relatives and servants, in the image of the King, as was the case of the Duke of Medina Sidonia (Fernández Chaves, 2010), or for sold or leased their supply to palaces or industrial purposes, such as tanning and dyeing.
– The confiscation of properties belonging to expelled Jews and *conversos* fleeing the Inquisition, which began in 1478, left behind empty buildings already supplied with running water that became the object of the ambition and speculation of buyers at public auctions (Fernández Chaves, 2012b).

By the end of the century, thanks to these new concessions and incipient water sales, a notable transformation took place in the palaces, which had, in the meantime, multiplied across the city, with recreational patios and gardens being built on a greater scale and complexity than in the past (Fernández García, 2011). However, in parallel, true urbanistic operations began to take shape in which emptied properties were bought and merged to create new palace compounds, as is the paradigmatic case with the Casa de Pilatos of the Dukes of Medinaceli, which remains magnificently preserved today (Lleó Cañal, 2017; Aranda Bernal, 2011). In other cases, the residences were demolished so as to found convents, as was the case with the founding of the Madre de Dios convent, which the Catholic Monarchs also generously endowed with running water (Fernández Chaves, 2012a). Water from fonts and fountains had already become an indispensable feature in the religious and palatial spaces, the role of running water in the urban revolution of these times also being widely interlinked with the acceptance of the Renaissance canons for the architectural language of interior design (Lleó Cañal, 2012, 2017; Aranda Bernal, 2005, 2011; Fernández García, 2011; Fernández Chaves, 2010, 2012b).

As regards the water arriving from public conduits dependent upon the city council, the monarchy stepped in with a solution for the water shortage in the fountains existing at the beginning of the fifteenth century, even while the ultimate goal appears to have been promoting the city's prestige by means of its association with running water. This suggestion receives support from the observation that, following the concessions made to the city at the beginning of the fifteenth century by the regent Ferdinand of Antequera, the city's water supply would barely see any further growth. Among the reasons that we may correspondingly put forward is the fact, referenced above, that many of the noble households stood in for the lack of public fountains through the distribution of their own surplus supplies, in addition to the fact that wells would continue to endure for a long period as one of the main components of the daily water supply.

On the council's request, the regent Ferdinand endowed the prisons of the city, the main square of San Francisco and the convent of the same name with running water. These three sites were adjoining and occupied a central space in urban life; they were also just a short distance from the church of El Salvador, which had already benefitted from the supply of water since Islamic times. This strengthened the axis that ran from the Alcázar and the Cathedral to San Francisco Square and the El Salvador cross, thereby crossing the most representative political and economic zone of the city: the Alcázar, the seat of the King's power, the Cathedral, the main commercial addresses, the most popular and prestigious convent in the city, the royal prison and the plaza itself, which constituted a key meeting and social place, hosting all kinds of activity and the intermingling of many of the city's characters, from gentlemen, merchants, scribes and clerics to water carriers, slaves, fishmongers and all kinds of profession.

The story thus far presented begins to define the historical profile of the city's water management: the aqueduct was in the hands of the city council, which spent significant sums on its maintenance, and for which revenues from the rented water mills did not always suffice. Simultaneously, most of the running water was actually in private hands, resulting in water fraud and theft as the result of increasing access for other interested parties that correspondingly impacted the rest of the participants in the supply network, and especially the King, as the Alcázar stood at the very end of the distribution line and particularly suffered from the depletion of the water supply carried through the aqueduct (Fernández Chaves, 2011 and 2012b).

As also mentioned above, the water distribution would take an important turn during the reign of the Catholic Monarchs as a result of the significant reforms that they promoted in the city. Among other matters, they imposed their royal authority over the nobility, who had hitherto not only been the true owners of the city, but had also often engaged in murderous confrontations. In Seville, the new monarchs founded the first Tribunal of the Holy Office of the Inquisition, which reported to the Kings of Castile on the verdicts for the large number of *conversos* living in the city. They also reinforced the Alcázar's authority over managing the city's water supply and its general role in defending the running water system, as it was, indeed, then recognised as the system's main beneficiary. However, they also put into practice a concessionary policy that helped to balance the predominant position of the noble households. The Catholic Monarchs now placed all of their attention on the city's convents, especially the newly established institutions founded in the wake of the religious reforms. By the end of their reign, a certain balance had been achieved between the convents and social elites in such a way that both the amount of running water existing in the city and the number of existing conduits had multiplied (Fernández Chaves, 2012a).

All of the above facets only reinforced the idea that running water was a private good, serving to transform and raise the prestige of the domestic, convent and palatial environments to which it was supplied and that reproduced, albeit on a smaller scale, the layouts of fountains and gardens of which the Alcázar itself was the largest and most accomplished example. The known examples still existing today are Casa de Pilatos, the palace of the Dukes of Medinaceli (Lleó Cañal, 2017), and the homes of other distinguished households, such as the Pinelo family (Falcón Márquez, 2002). That the vast majority of the water remained in private hands did not mean that there was any liberal sense in the way in which the bulk of the population enjoyed the water that nobles, convents and magnates supplied by opening their pipes and small fountains so as to discharge their surplus water into the public domain as a sign of their grandeur and generosity. As the sixteenth century unfolded, many private owners also opted to let water carriers take away such water in exchange for small sums (García-Baquero López, 2006). The great majority of the population, which grew steadily throughout the sixteenth century, was therefore able to access drinking water in three ways:

1. Using river water, which was heavily contaminated by the port and the industrial activities located on its banks (such as wool washers, gunpowder mills, etc.).
2. Using wells that were very common throughout the city.
3. Using water from fountains either directly or through the intermediary of water carriers.

In addition, sharp increases in the volumes of running water inside of the city would lead to the transformation of the simple exchanges of water and properties among the dignitaries and magnates of the fourteenth and fifteenth centuries through the emergence of a formal water market, which then grew exponentially throughout the sixteenth century. This became feasible for three precise and very strongly interconnected factors:

1. The lack of any adequate system for correctly measuring water quantities.
2. Ongoing conflicts over jurisdictions that prevented the appropriate regulation of the aqueduct.
3. The interest of private participants in boosting their own supplies thereby enabling them to repeatedly retail quantities of water well in excess of their original concessions. This was particularly true of the convents, which, protected by church jurisdiction, systematically took advantage of their privileges.

The sixteenth century saw the emergence of an interesting paradox according to which running water, which had formerly been promoted by notions and actions of royal liberality and distributive justice, became a mercantile good, thus breaking the balance that the aforementioned justice had pursued. The Seville water market also suffered from the price inflation that afflicted Spain as a whole, and that increased still further in the second half of the century (González Mariscal, 2015). The water straw measure had come to cost the astronomical figure of 1000 ducats prior to the 1580s, when it rose to 1200 ducats (the daily salary of a bricklayer was 102.3 maravedís, with 1000 ducats being equivalent to 375,000 maravedís). Such exorbitant prices drove an extremely powerful water market in which demand always exceeded supply, underpinnig the maintenance of these high prices. This also logically led to situations in which fraudulent practices aimed at expanding the amount of water to which each user had access did nothing but multiply as the seventeenth century advanced.

The response of the city to the exponential urban growth of the sixteenth century, during which the population rose from 45,000 to 120,000 inhabitants due to the discovery of the Americas and the city's role as the main commercial and financial centre of the kingdom, was to focus on providing guarantees for the supply of public and private fountains and to ensure their proper functioning. New pipes were installed, not only for private use, but also for the city itself, as the old conduit had become too small, with a new facility having to be built in order to cope with serving the growing multitudes (Fernández Chaves, 2011, 155–62).

In addition, promoted by King Philip II, the decision was made to acquire a source near the city in order to create an *ex-novo* supply system. The underground conduits would not only take water into the northern city section, that most neglected by the existing system, but would also supply the public fountains in a new recreational space created for the city's inhabitants, which from 1574 would become known as "Alameda de Hércules" still in existence today (Albardonedo Freire, 1998, 135–65, 2002, 191–208). This supply system was managed entirely by the city, with large sums invested in its construction and maintenance. Indeed, the city devoted as much or, at times, even more attention to the Alameda conduits than it did to those of Caños (Fernández Chaves, 2012a). This was a citizen space, where the most distinguished members of Seville society would meet and where a complex Renaissance artistic program was fostered (Lleó Cañal, 2012;

Albardonedo Freire, 2002; Solís de los Santos, 2012). This also became a model that was subsequently copied in distant American cities (Luque Azcona, 2015; Paya, 2014), although it was not itself the first of this kind on the Iberian Peninsula (Fernández Chaves, 2015). Its particular urbanistic connotations set it apart from the rest, and water played a crucial role in its configuration and usage (Albardonedo Freire, 2015; Fernández Chaves, 2007a, 2015; Torres García, 2017), as documented by several paintings that depict the fountains and trees as the focal features around which citizen sociability was structured (Cabra Loredo, 1998, 206–11). Despite undergoing two bankruptcies of the monarchy, in 1575 and 1596, and the tremendous corresponding increases in tax during those years, the city was awash with opulence. Not only did it carry out this urban restructuring, but the city also fully repaired the Caños, the main water deposit and the Alcázar conduit, among other redevelopment works (Fernández Chaves, 2012a, 186–88).

The city's policy on water became more complex and ambitious as the sixteenth century advanced, while the activities of the Alcázar developed in parallel. The King's palace encountered increasing difficulties in ensuring a regular water supply, due to its positioning as the final beneficiary of the aqueduct, and correspondingly suffered from losses in streamflow (due to droughts, breakages or diversions) to a greater extent than other users. This prompted the wardens of the Alcázar and their aides (Gil, 2009; Márquez Redondo, 2010a; Fernández Chaves, 2012a, 106–123, 174–193) to fight for jurisdiction over managing the aqueduct. They began insistently to demand that the city make the necessary repairs to the aqueduct, sending their own master builders to check on the structure and to identify the repairs and improvements required. Additionally, during the sixteenth century, they set up the parallel figure of a bailiff to visit and monitor the Caños, an individual who not only scrutinised the activities of council bailiffs, but also handed out fines, thus generating a conflict of power between the council and the Alcázar. This conflict would, in turn, further hinder the correct management of the water supply, greatly to the benefit of those taking advantage of this situation, either by to illegally expanding their own water concessions or stealing from the aqueduct with complete impunity (Fernández Chaves, 2012a).

The city tried to restore order over water distribution by establishing a system of equivalence that sought to put an end to the abuses and outrages committed by many distinguished households and convents. Among the most recurrent problems were the theft of water from the main springs by a mill owned by the Cartuja convent in Alcalá de Guadaíra, the systematic diversion of water for irrigating the Huerta del Rey and the continuous bleeding of the surface channel. The mills located on this channel made a habit of retaining water in order to gain greater power for their grinding wheels, thus triggering partial cuts in supply downstream. An attempt was made to solve this problem by converting the channel and the mills into the so-called "bucket" type, which functions by retaining larger amounts of water, but for much shorter stand-by times. This would also have enabled the city to raise the rent on the mills and guarantee higher revenue flows, but the Alcázar deemed this solution also not to be in its own best interest.

The Alcázar wardens began to demand the concession of "private jurisdiction" and absolute knowledge of all matters related to the city's water management. The city, on the other hand, had decided to undertake its own policy without any input from the Alcázar wardens. King Philip II imposed his authority upon this situation and called upon collaboration from the court judges, the maximum judicial authority of the crown both in the city and in the legal district of the Kingdom of Seville. However, the deliberations of the joint commissions upon which the Alcázar wardens also sat were never seen through to implementation. This was undoubtedly due to pressures from certain private interested parties, especially powerful noblemen and convent representatives, but also many members of the city government, who had their own interests in maintaining an irregular water market and a legal situation that was never very strong (Fernández Chaves, 2012a).

Finally, we would note that the sixteenth century also saw improvements to the city's drainage and evacuation systems. The sewers were not primarily designed to evacuate waste waters but rather to drain rainwater when the river overflowed in order to prevent flooding. They did, however, also serve to expel surplus water with a system of currents stronger than those collecting rainwater run-off (Fernández Chaves, 2007b, 2011, 175–82).

3 The Seventeenth Century

During the first half of the seventeenth century, the abovementioned problems with the city water distribution system only worsened. The Alcázar, which was supplied by the large conduit that ran atop the city wall from the main Puerta de Carmona storage site to the palace compound, was, in 1629, forced to build a new pipeline due to over usage of the old rill. The number of private users of this supply had, indeed, greatly multiplied, with people obtaining access either through concessions or by having purchased rights. However, the water supply was also being exploited by the tanning and dyeing industries located along its course, while thieves and fraudulent schemes continued to surreptitiously drain water. The new Alcázar pipeline would also soon become colonised by illegal users, activity that the fines and the authority of the wardens were unable to do anything to halt (Fernández Chaves, 2011, 158–160; Amores Carredano, 2011). As a result, the Court considered it appropriate to re-grant the Alcázar private jurisdiction over the water supply, its rents and royalties. This measure came into effect in 1603 and was expanded in the 1620s by the founding of a guard of halberdiers to act as the warden's escort and as a dissuasive force. This turn of events was first put into practice by the Duke of Lerma, and then extended by his successor, the Count-Duke of Olivares, who had previously been the Alcázar warden and knew the situation well (Fernández Chaves 2012a, 197–215). It would, however, mark the beginning of a century of discord with the city: agreements were forced through, whether by the monarchy or by powerful water usurpers such as the Dukes of Medinaceli, while disagreements were frequent, fuelled by the eternal conflicts over jurisdiction typical of the Old Regime.

Considering that this was the position faced by the leading water beneficiary, we may safely assume that such complaints and actions between individuals and against the city were generalised, just as the thefts and water scams proved detrimental to everyone. The confrontation between the Dukes of Medinaceli (the owners of the Huerta del Rey) and the city and the Alcázar was particularly bitter. The city and the Alcázar joined forces to attempt to put an end to the massive theft of water that constituted the norm in the early decades of the seventeenth century. Even after clashes and deaths, the situation was never favourably resolved, neither to the satisfaction of the interests of the municipal corporation or to that of the Alcázar wardens, who had to watch as the Huerta del Rey increased the amount of water that it accessed in order to intensify its milling and irrigation activities (Fernández Chaves, 2011, 126–132 and 2012a, 213–216).

It was not until after the fall of the Count-Duke of Olivares, and with his nephew Luis de Haro taking his position in 1643, that the Court designed a new project for full cooperation with the city in another attempt to bring order to the chaos produced by the legal and illegal diversions of the water supply. From his uncle, Luis de Haro then inherited the position of Alcázar warden and set about instituting important reforms. He appointed a Court judge, who would be assisted by Sebastián de Ruesta, foreman of the Alcázar, and his brother, a senior aide in the Casa de la Contratación, to design a suitable and precise measurement and equivalence table that would clearly define the multiples and submultiples of the water straw. The ultimate purpose was establishing a rational distribution matrix for dividing the water that could not be subject to manipulation by the biased interpretations of one pipe master or another. This project turned out to be successful, and was subsequently complemented by an updating of the Alcázar archives with the amount of water originally granted to each concession and to each subsequent partition through successive sales, in a historical reconstruction of the concessions and subsequent sales of water ongoing since the fifteenth century. This did manage to bring the situation under stricter control (Fernández Chaves, 2011, 37–55, 2012a, 246–263). However, the water market continued to maintain high prices, with a water straw still costing 1000 ducats, despite the then-prevailing generalised situation of economic crisis and social and political hardship. This then led the city to lease maintenance of both the aqueduct, or sections of it, and the Alameda to various bidders, who were generally foremen in the city's works or other institutions. The bidding for repair contracts lowered the prices, but jeopardised the scope for achieving an appropriate level of maintenance, thus leading to situations of abandonment and deterioration. These especially afflicted the most remote parts of the infrastructure, such as the mine and the underground section (Fernández Chaves, 2012a, 2017) (Fig. 2).

The supply of water therefore remained a crucial issue for the city and the aqueduct and the network of conduits continued to be under monitoring and repair throughout the final quarter of the century, albeit with all of the limitations detailed above. The weakening of monarchical power would lead to renewed but intermittent competition between the city and the Alcázar. The former attempted to singlehandedly manage usage and control of the aqueduct, establishing itself (in

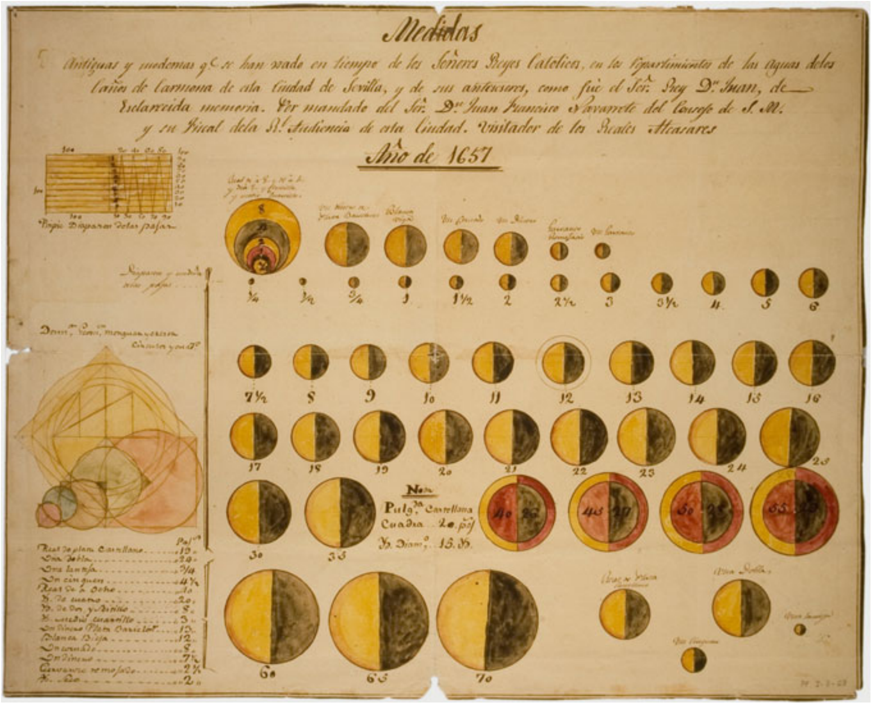


Fig. 2 Illustration of the measures deployed for water dispensation from the "Caños de Carmona" 1657. © ICAS-SAHP, Archivo Municipal de Sevilla, Pl. I-3-67

place of the Alcázar) as the authority responsible for the permits necessary to transfer water from one pipeline to another, a procedure in which water could easily be diverted by those keen to increase their water supply through fraudulent means. The city's position was motivated by the interests of certain individuals who held connections within the council, to such an extent that, by the end of the seventeenth century, many of the improvements made in the middle of the century had been undone. This situation would, indeed, last until the turn of the century, when new initiatives would be taken. However, these were themselves cut short by the onset of the War of Succession, following which a clear change in the water management system did finally take place (Fernández Chaves, 2012a, 263–285).

4 Changes and Continuities in the Eighteenth Century

During the eighteenth century, the urban water supply system continued growing but only at a much slower pace than in the three previous centuries (Fernández Chaves, 2012a, 95–102). This does not, however, imply that there was no ambitious policy, as, in fact, the concepts of utility to the King and to the common good, both in urban planning in general and in the use of water in particular, significantly impacted on the Seville of this period (Ollero Lobato, 2015). Of particular interest to us here, on the political level, is the fate of the royal water concessions, which had mainly benefited the city's distinguished households and convents in previous centuries. Now, they were almost exclusively sought to provide running water to the royal factories built following orders to intensify the industrialisation and rearmament of the Monarchy. The imposing new tobacco factory, alongside those producing saltpetre, artillery and quicksilver, as well as some convents and the military barracks set up in that century (Fernández Chaves, 2009 and 2012a, 98), became the main beneficiaries of these concessions.

As regards water management, the eighteenth century would see the recovery of cooperation between the city and the King's ministers, previously initiated by Luis de Haro in the 1652 reform process, again with the aim of preventing fraud and water theft, both from the aqueduct and from the urban pipe system. In the 1700s, the Alcázar warden would also become the presiding officer of the Court. This implied that the longstanding prerogatives of the Alcázar had become reinforced by the judicial power of the high judges (as King Philip II had once attempted) and that they would combine to fiercely defend the King's water and combat the main water thieves, especially the ecclesiastical institutions that possessed estates adjacent to the aqueduct. The warden Francisco de Bruna (Romero Murube, 1997; Márquez Redondo, 2010a, 2010b, II, 97–110) was particularly active in this area and worked in harmony with the city's representatives.

Among the most noteworthy eighteenth century initiatives taken by the city were the increase in the number of fountains on the Alameda and the near-complete rebuild of their supply system. The walkway was completed with two new columns, which remain in place today (Fernández Chaves, 2007a, 2012a), and with the fountains rising from three to six in number. Moreover, the works included an expensive refurbishment of the pipes supplying the northeast of the city. This serves as confirmation, firstly, that the water supply system was always considered as capable of expansion and improvement, even if priority was, in this case, attributed to an area of leisure and recreation, rather than areas experiencing deficient water supplies and, secondly that, from the municipal point of view, the Alameda constituted one of the city's landmarks. This justified its constant care in terms of water supply, as it continued to provide one of the main social spaces in the modern city (Bejarano Pellicer, 2015) in a model that had already become common across the rest of the Hispanic world (Luque Azcona, 2015; Recio Mir, 2015). Other recreational areas would subsequently emerge outside of the city walls and were also endowed with water and fountains (Ollero Lobato, 2004) (Fig. 3).

Furthermore, the city continued in its struggle against the ongoing frauds while expanding the aqueduct. On the long list of complaints made and actions taken, it is worth highlighting the importance paid to maintenance and curation of the underground section of the aqueduct, especially when suspicions arose that a mill belonging to the Cartuja convent of Alcalá de Guadaíra might be draining water from the very source of the spring in a problem that had been brewing since the

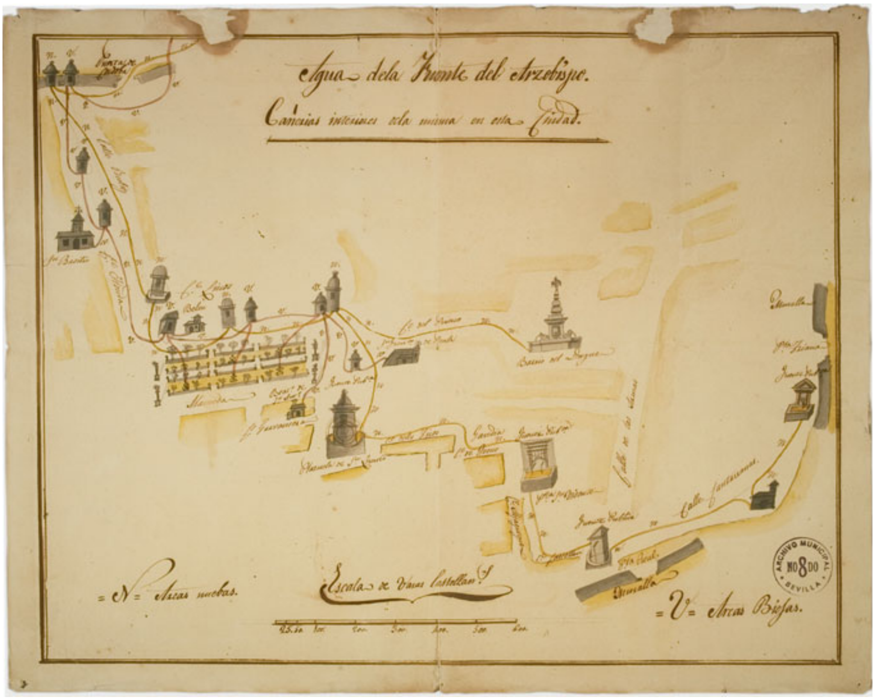


Fig. 3 Map of the 18th century "Fuente del Arzobispo" water supply on the Alameda. © ICAS-SAHP, Archivo Municipal de Sevilla, Pl. I-3-63

sixteenth century, as already noted above. Although periodic visits to these sites had already been made by the highest civil authorities of the city, the aides and the presiding officers of the Court, and with discussions having been held between the pipe foremen of all of the institutions involved to ascertain whether or not they were unduly draining water from the aqueduct, the Cartuja was still allowed to quietly continue running its mill and irrigating its surrounding lands. In addition to the protection of the spring, the eighteenth century saw the consolidation of the city's interest in expanding the volume of water carried by the Caños aqueduct, primarily through improvement of the incidence of repairs and the addition of more water resources to the system. Indeed, in times of scarcity, the lack of water became truly dramatic and, as already detailed, substantially exacerbated by widespread water theft throughout the system (Fernández Chaves, 2012a, 304–330, 2017; Márquez Redondo, 2010b, II, 897–909).

In addition to these actions, the city advanced with the renewal of the urban environment through redeveloping certain areas. Such was the case with the central sector, known as the "Don Pedro Ponce", where new fountains served to structure the public space while supplying running water to neighbouring residents. Similar initiatives would see the installation of fountains in "Laguna de la Pajería", a peripheral area between the Cathedral and the port, home both to the still-surviving bawdyhouses and to a large gypsy community. The city also welcomed the private initiatives implemented by several wealthy merchants, including Prudencio de Molviedro, who completed the redevelopment of the aforementioned area, building large palaces and providing public and private running water (Ollero Lobato, 2012; Fernández Chaves, 2012a). Another merchant and member of the municipal council, Pedro Pumarejo, contributed to redeveloping a section in the northern sector of the city, installing an eminently artisanal and agricultural population, and creating sumptuous palaces and a plaza with running water, thus transforming the surrounding urban fabric and complementing the nearby Alameda fountains.

5 Conclusions

The water supply and its administration in Seville displayed several constants during the Early Modern period. The first stemmed from the importance of the monarchy whether in terms of protecting the installations of infrastructures or facilitating their remodelling, not always successfully, but in such a way as the great system transformations would ultimately depend, all the way from the design and construction of the Alameda de Hércules and the reforms undertaken to its management, leading to its judicialisation through the intervention of Court judges. Another constant encapsulates the predatory activities of noble households and convents, especially the latter, which were sheltered by church jurisdiction and committed outright supply system robberies. A third derives from the competition between the often antagonistic models of supply envisaged by the city and the Alcázar. Despite sharing the same basic interest, the abundant and appropriate supply of water, they were frequently at odds, due to the independent criteria that two institutions both applied. The fourth and final constant was the generalised privatisation of water compared to the very limited public supply, although this did not prevent water from getting to many interested parties in one way or another. All of these factors contributed to the management of the water supply systems that evolved in the most populated city of Castile up until 1620, and remained central planks in the political strategies for water until deep into the nineteenth century. The case of Seville holds particular interest, as much of the supply system was maintained according to ideas of royal benevolence and distributive justice, even while the urban and socioeconomic realities evolved quite differently. The creation of an alternative supply system, such as that of the Alameda, also underlined the shortage of water arriving from the Caños, caused not so much by its flow volumes as by its management model, and became emblematic of the political and urban management of the city, as its waters were granted gracefully by the town council. From our perspective, the management models of these urban water distribution facilities and infrastructures signified much more than the technology that conditioned them, playing decisive roles in the evolution and development of the welfare of both the city and its inhabitants.

Bibliography

Albardonedo Freire, A. 1998. "Las trazas y la construcción de la Alameda de Hércules", *Laboratorio de Arte*, 11: 135–166.

Albardonedo Freire, A. 2002. *El urbanismo en Sevilla durante el reinado de Felipe II*. Seville: Guadalquivir.

Albardonedo Freire, A. 2015. "La alameda, un jardín público de árboles y agua. Origen y evolución del concepto", *Anuario de Estudios Americanos*, 72 (2): 421–452.

Amores Carredano, F. 2011. "Los usos industriales del agua (siglos XIII-XVIII)". In: *El agua y Sevilla. Abastecimiento y saneamiento*. Seville: Emasesa Metropolitana, 103–119.

Aranda Bernal, A. 2005. "Una Mendoza en la Sevilla del siglo XV. El patrocinio artístico de Catalina de Ribera", *Atrio. Revista de Historia del Arte*, 10–11: 5-16.

Aranda Bernal, A. 2011. "El origen de la Casa de Pilatos de Sevilla. 1483–1505", *Atrio. Revista de Historia del Arte*, 17: 133-172.

Bejarano Pellicer, C. 2015. Música y alameda en la Edad Moderna. El caso de la sevillana alameda de Hércules en el siglo XVIII, Anuario de Estudios Americanos, 72-2: 545–576.

Cabra Loredo, M. D. 1998. *Iconografía de Sevilla*. *Vol. I, 1400–1650*. Madrid: Ediciones el Viso.

Del Val Valdivieso, M. I. 2003. *Agua y poder en la Castilla bajomedieval. El papel del agua en el ejercicio del poder concejil a fines de la Edad Media*. Valladolid: Junta de Castilla y León.

Del Val Valdivieso, M. I., & Villanueva Zubizarreta, O. 2008. *Musulmanes y cristianos frente al agua en las ciudades medievales*. Santander: PubliCan, Ediciones de la Universidad de Castilla-La Mancha.

Del Val Valdivieso, M. I. 2015. *La percepción del agua en la Edad Media.* Sant Vicent del Raspeig: Universitat d'Alacant.

Falcón Márquez, T. 2002. *La casa de los Pinelo a la luz de nuevas aportaciones documentales*. Seville: Real Academia sevillana de Buenas Letras.

Fernández Chaves, M. F. 2007a. "El agua en la Alameda de los Hércules en el siglo XVIII: gestión de un recurso para la organización del espacio", *Archivo Hispalense*, vol. 90 (273–275): 77–111.

Fernández Chaves, M. F. 2007b. "Hábitos de la naturaleza y costumbres de la ninfa "indolencia" en Sevilla: Río y husillos". In: F. Núñez Roldán (Coord.), *Ocio y Vida Cotidiana en el mundo hispánico en la Edad Moderna*. Seville: Universidad de Sevilla, 755–767.

Fernández Chaves, M. F. 2009. "De la *caritas* a la *utilitas.* Usos públicos del agua en la Sevilla del siglo XVIII. Fábricas y cuarteles". In: O. Rey Castelao, R. J. López (Eds.), *El mundo urbano en el siglo de la Ilustración, II*. Betanzos: Xunta de Galicia, 113–124.

Fernández Chaves, M. F. 2010. "La competencia por la honra en torno al agua en la Sevilla Bajomedieval. Rey, ciudad, nobles y conventos". In: B. Arízaga Bolumburu, J. Á. Solórzano Telechea (Eds.), *Construir la ciudad en la Edad Media*. Logroño: Instituto de Estudios Riojanos, 621–640.

Fernández Chaves, M. F. 2011. *Los Caños de Carmona y el abastecimiento de agua en la Sevilla moderna.* Seville: Emasesa Metropolitana.

Fernández Chaves, M. F. 2012a. *Política y administración del abastecimiento de agua en Sevilla durante la Edad Moderna*. Seville: Diputación Provincial de Sevilla.

Fernández Chaves, M. F. 2012b. "El papel de nobles y conversos en la difusión del agua de pie en la Sevilla del siglo XV". In: M. I. del Val Valdivieso, J. A. Bonachía Hernando (Coords.), *Agua y sociedad en la Edad Media hispana*. Granada: Universidad de Granada, pp. 323–357.

Fernández Chaves, M. F. 2015. "Las alamedas en la España moderna", *Anuario de Estudios Americanos*, vol. 77 (2): 453–486.

Fernández Chaves, M. F. 2017. "La mina de agua de los Caños de Carmona: alcances y límites de su gestión durante el siglo XVIII". In: F. Mantecón Campos *et alii* (Coords.), *Actas de las XI jornadas de Historia y patrimonio de la Provincia de Sevilla. El patrimonio subterráneo (natural o artificial) en la provincia de Sevilla.* Seville: Diputación de Sevilla, 75–94.

Fernández García, R. 2011. “El agua doméstica. Casas y jardines (siglos XVI-XVIII). In: *El agua y Sevilla. Abastecimiento y saneamiento*. Seville: Emasesa Metropolitana, pp. 141–177.

García-Baquero López, G. 2006. *Sevilla y la provisión de alimentos en el siglo XVI. abastecimiento y regulación del mercado por el concejo municipal en la Sevilla del siglo XVI*. Seville: Diputación de Sevilla.

Gil, J. 2009. *El exilio portugués en Sevilla. De los Braganza a Magallanes*. Seville: Fundación Cajasol.

González Mariscal, M. 2015. “Inflación y niveles de vida en Sevilla durante la revolución de los precios”, *Revista de Historia Económica-Journal of Iberian and Latin American Economic History*, vol. 33 (3): 353–386.

Lleó Cañal. V. 2012. *Nueva Roma. Mitología y humanismo en el Renacimiento sevillano*. Madrid: Centro de Estudios Europa Hispánica.

Lleó Cañal. V. 2017. *La casa de Pilatos. Biografía de un palacio sevillano*. Seville: Editorial Universidad de Sevilla.

Luque Azcona, Emilio. 2015. “Conformación y características de las alamedas y paseos en ciudades de Hispanoamérica”, *Anuario de Estudios Americanos*, 72 (2): 487–513.

Márquez Redondo, A. G. 2010a. *Los alcaides del Alcázar de Sevilla*. Seville: Patronato del Real Alcázar de Sevilla.

Márquez Redondo, A. G. 2010b. *El Ayuntamiento de Sevilla en el siglo XVIII*. Seville: ICAS. Two volumes.

Morales Padrón, F. 1989. *Historia de Sevilla. La ciudad del Quinientos.* Seville: Universidad de Sevilla.

Ollero Lobato, F. 2004. *Cultura artística y arquitectura en la Sevilla de la Ilustración (1775–1808).* Seville: Caja San Fernando.

Ollero Lobato, F. 2012. *El barrio de la Laguna de Sevilla. Diseño urbano, razón y burguesía en el siglo de las Luces*. Seville: Universidad de Sevilla.

Ollero Lobato, F. 2015. “Ciudad e Ilustración. Transformaciones urbanas en Sevilla (1767–1823)”, *Cuadernos Dieciochistas*, 16: 215-217.

Otte, E. 1996. *Sevilla y sus mercaderes a fines de la Edad Media.* Seville: Universidad de Sevilla.

Otte, E. 2008. *Sevilla, siglo XVI. Materiales para su historia económica*. Seville: Centro de Estudios Andaluces.

Paya, L. 2014. Les alamédas de l'Empire Espagnol durant la Renaissance: un ensemble singulier et cohérent de promenades arborées, Le Verger-Bouquet, 5: 1–19.

Recio Mir, Á. 2015. “Alamedas, paseos y carruajes. Función y significación social en España y América (siglos XVI-XIX)”, *Anuario de Estudios Americanos*, 72 (2): 515–543.

Romero Murube, J. 1997. *Francisco de Bruna y Ahumada.* Seville: Colegio Oficial de Aparejadores y Arquitectos Técnicos de Sevilla.

Segura Graíño, C. 2003. *Agua y sistemas hidráulicos en la Edad Media Hispana*. Madrid: Laya.

Solís de los Santos, J. 2012. “El trasfondo humanista de la Alameda de Sevilla”, *Calamvs Renascens*, 13: 75–138.

Torres García, M. 2017. *Seville: through the urban void*. New York: Routledge.

Valor Piechotta, M., Romero Gutiérrez, V. 1995. “El abastecimiento de agua”. In: M. Valor Piechotta (Coord.), *El último siglo de la Sevilla islámica. 1147–1248*. Seville: Universidad de Sevilla.

Water for Madrid: The Problems of Water Supply in a Pre-industrial Capital

Fernando Arroyo Ilera and Concepción Camarero Bullón

Abstract

The water supply to Madrid has been a subject of special interest ever since Felipe II located his capital in the town. In the case of Madrid, water not only represented a necessary element for city life, which therefore had to be managed and distributed in the best possible way, but also an authentic precondition for the city's existence as there was no river and no other alternative stable water supply. Hence, there was a need to seek out, force and even invent other sources of water supply. Therefore, more than management, we find in Madrid a case of creation and water governance, essential to enabling the city to expand from village to town and, from there, to becoming the national capital. In this study, we make some brief references to the water policies of the Habsburgs and the Spanish Bourbons, devoted to the management of water as a factor for transport and irrigation, even while it remained essential for the supply and life of the city. We focus on all of the urban supply projects for drinking, washing and cleaning water that took place in the seventeenth and eighteenth centuries.

1 Introduction

Between the seventeenth and nineteenth centuries, the water supply in Madrid constituted one of the core problems faced by the state authorities and city leaders, and dealing with it was a necessary step for the capital on its way to developing into its current urban agglomeration. In the case of Madrid, as in other European cities,

F. A. Ilera · C. C. Bullón (✉)
Department of Geography, Facultad de Filosofía y Letras,
Universidad Autónoma de Madrid, Madrid, Spain
e-mail: concepcion.camarero@uam.es

A. Duarte Rodrigues and C. Toribio Marín (eds.), *The History of Water Management in the Iberian Peninsula*, Trends in the History of Science,
https://doi.org/10.1007/978-3-030-34061-2_4

water was not only an essential element of the life of its inhabitants, that required managing and distributing in the best possible way, but also a precondition for the existence of a city that had not previously existed as such. Indeed, other large European courts, established prior to that of Spain, were located in already established cities, and were correspondingly well connected and equipped with everything needed for the Court and its inhabitants. In these cases, the conversion of the city into a capital was the spur and the main driver of both urban development and the consolidation of the state itself. None of this held for Madrid, hitherto a small town that was difficult to supply suitably. In Madrid, there was neither a city for the Court nor water for the city. From this point of view, we may state that locating the headquarters of the Court and the future capital in Madrid was a genuine "geographical error" by the Crown (Pérez Boldo and Arroyo Ilera, 2003–2004), at least from the structural point of view and from the perspective that we hold today of just what a state's capital city should be.

In contrast to the centrality that defines Madrid today, the banks of the Manzanares on which the city was established were originally a marginal location in the communications hub from *Caesar Augusta* to *Emerita*, where two well established urban centres, *Toletum* and *Complutum* had also existed since Roman times. Until 1085, Madrid has been a simple castle in the Toledo defensive system, and certainly not as famous as the writer Moratín would claim centuries later, with a modest *town and country* community around it. The fortunes of this small enclave on the banks of the Manzanares stemmed from the result of a political decision that failed to take into account the region's structural deficiencies, which clearly not only advised against such a move, but also subsequently made it necessary to attempt to shape such an unsuitable geography so as to allow for the emergence, development and consolidation of a great capital city.

These changes, as regards the water supply, represent the core theme of discussion in this present study, but without ever forgetting the reasons that led Felipe II, 'The Prudent', to make this noted "error", if, indeed, such was the case. Why locate the Court in a place that does not meet the conditions necessary for a capital city, generating a host of problems that found no definitive solution through to the construction of the Queen Isabel II Canal that currently still supplies Madrid with its water?

2 Madrid, Town and Court: The Natural Conditions

In 1787, Eugenio Larruga correctly observed that large cities, especially those hosting capitals, must be "close to the sea or on wide rivers, as the Courts will then abound in all that is necessary and attractive for human life" (Larruga, 1797, 32). Years later, as if in confirmation of the reasoning of this Aragonese chronicler, Konvitz noted (op. cit. Ringrose, 1985, 336): "[U]ntil the railways reduced the cost of land transport over long distances, the needs of a town of more than 10,000 inhabitants could only be fulfilled by waterways". Contrary to such claims, Madrid, between the sixteenth and eighteenth centuries, amply overcame these limits, in that it lacked both a wide river and any proximity to the sea. The city therefore represents the exception that confirms the rule, as it had to be supplied almost exclusively by land. The Manzanares River, due both to its scant flow and its watercourse running below the base level of old Madrid, was not up to the task of fulfilling any of the essential functions that rivers played in pre-industrial times: the supply of drinking water, a means for river transport and the irrigation of the market gardens along its banks. Castro Núñez described the situation thus in a work that is otherwise dedicated to extolling the virtues of Madrid as a court: "Madrid lacks […]: a river to bathe it, market gardens near it, enjoyable outings that make more pleasant the work of courtiers" (Fig. 1).

The shortcomings of the Manzanares in solving urban water supply related issues became increasingly evident over the course of the seventeenth century, giving rise to various sayings and songs, which, aside from their burlesque and ironic meanings, serve as direct evidence of the unfit nature of the river. Thus, the writer Tirso de Molina compared the Manzanares to a school, because "you have vacations in the summer and course only in the winter," and Calderón de la Barca, another writer, praising the Florida walkway but with only one objection: "[I]n terms of a river there lacks only the river, this being an old objection;" meanwhile, a German ambassador commented that the Manzanares was better than all of the

Fig. 1 Plan of Madrid (*Plano geométrico de Madrid*). Tomás López, 1785 (Biblioteca digital hispánica, Biblioteca Nacional)

other rivers of Europe "in being navigable by cart and on horseback" (op. cit. Palacio Atard, 1998, 119).

The same perceptions remained into the nineteenth century, when Fernández de los Ríos referred to the Manzanares as that simple "apprentice of a river that waters Madrid". (op. cit. Thomas, 1988, 404). Around the same time, Mesonero Romanos (1861, 39), in *El antiguo Madrid*, summarized the disadvantages that the scarcity of the river's waters caused the capital: "[L]acking were just two vital circumstances, the abundance of water […] and the speed of its communications with other provinces."

Hence, why, when the shortcomings in the water supply were so evident, did Felipe II establish his capital in this town? Alternatively, as Fernández de los Ríos (1868, 30) asked: "What attracted him to Madrid? Its location amid a continuous series of ragged hills, a huge obstacle to it becoming a convenient capital? What led him to the decision?"

All of this leads us to consider that, back in the sixteenth century, these deficiencies were not as obvious as they would subsequently become and that other, different advantages must have existed that are able to explain the royal decision. In this respect, other authors, such as Cabrera de Córdoba (1998, I. 218), have discussed the issue in very different terms: "[Madrid] *had the potential to find a city which would be well supplied for its maintenance by its abundant environs, good water, admirable weather, pleasant air*". Such a perception or belief was also reflected in the very coat of arms of the original city—"I was built over water,"—as well as in the description made in the 1575 work *Relaciones* by Felipe II: "It has the most numerous and best sources and the best water until now seen" (Viñas Mey and Paz, 1949). Cervantes himself, in *Licenciado Vidriera*, pointed to this positive and favourable vision of Madrid's environment in comparison to Valladolid at precisely the time when the two cities were disputing the Court's location: "That's not what I'm asking, but which is the better place: Valladolid or Madrid?" And he answered, "Madrid, for the highest and the lowest; Valladolid, for the parts in the middle." "I don't understand," said the questioner. And he replied, "In Madrid, the top and the bottom; in Valladolid, the part between." That is, as we would say today, Madrid's environmental setting and Valladolid's buildings, streets and houses, typical of a city.

It is interesting to note that what Cabrera considered as advantages here, *abundance, good water*, etc., were, for Mesonero and other authors, among Madrid's deficiencies. No doubt this is because the waters that the sixteenth century chronicler described were different, or perhaps of another type, location and condition, than those that nineteenth century chroniclers did not find. For some, the lack of a river affecteds the city, whereas, for others, good water and provisions were rather to be valued as a facet of the entire region and not only in terms of the town of Madrid itself.

3 The Court in Madrid: Countryside and City

The decision by Felipe II to establish his capital in Madrid has already been analysed on numerous occasions (Alvar, 1985 and 1989), but almost always from the current perspective of a completely consolidated capital amidst a search for the history of its current political configuration. However, in 1561, under other historical circumstances, and, above all, with a different concept of geographical space and what a political capital was, this was not the problem but rather merely preliminary issues regarding whether the Court would or should settle there or continue to be transient, simply questions as to where the ministers and their Monarch should reside and whether or not they needed to share a common base. In the strictest sense, we might say that there was no such move and still less of any kind of definitive relocation, but rather the beginnings of a settlement that was then consolidated over time.

We might recall that the Spanish Court was still itinerant at a time when most European courts had established a fixed base, although the Court in Spain did move in increasingly smaller circles: Segovia, Valladolid, Toledo, Seville, Burgos, etc. Of this group, Madrid was the city preferred by the last of the Castilian Trastámaras family, by Cisneros, by Carlos I, and even by Felipe II, as Prince of Asturias, in 1551. It did have an *Alcázar*, including a rebuilt ancient fortress that only very poorly served as a royal residence. The city was not the hamlet that it is sometimes claimed to be, but rather a city of medium scale, hardly comparable to its possible competitors in keeping with its smaller population and ongoing activities, and yet with the advantage of being free of the bishopric of Toledo. As Cristóbal Pérez de Herrera declared in 1597, when the capital was beginning to take shape as such, Madrid lacked only "*a river, a cathedral, a city wall, and the title of city*" (Cámara, 1999, 64).

In our view, Felipe II chose a space more than a place, primarily seeking a residence according to his political wishes, and his conception of the monarchy, as well as his hunting interests, rather than a city in which to establish his capital. Nevertheless, it is still hard to imagine that such desires and interests led to Madrid being identified as the ideal place in the sixteenth century. The decision would seem more favourable were we to extend our view and consider not only the city, but also its surroundings; thus the region of Madrid, but also the region between the Tagus and Guadarrama Rivers. Royal attention, it seems, was not restricted to a single point, but instead extended to all of the space around that point. For this reason, we must not seek geographical reasons for the decision in a specific and concrete "location," as in a certain city, but rather in the factors surrounding the "situation," that is, the broader lines characterizing a given area, which, in the case of the lands and environs of Madrid, included its position south of the Sierra de Guadarrama, "beyond the mountains" (Gutiérrez Nieto, 1983), facing the most promising regions of the Kingdom of Castile: the New, the Andalusian and, above all, American Castile, in contrast to the old Castile on "this side of the mountains," which was increasingly being abandoned and forgotten.

Using a phrase from contemporary times, we might say that Madrid was simply in the right place at the right time. While it is true that its *Alcázar* fell short as a royal residence, it was less so as a centre for official and bureaucratic business. In this broad space, where, to a greater or lesser extent, the province and region of Madrid would form over time, successive royal residences would be sited: the *Royal Sites*, on which stood the authentic royal headquarters.

Felipe II bought a *Country House* from the Vargas family with exactly this idea of residing both close to and far from the city at the same time. Therefore, Madrid, more than a capital, was, for many years, simply the *town* separated from the *Court*, with the former having little or nothing to do with the latter's location. In addition, the Crown had long since owned a small property in the *El Pardo* mountains, an area greatly appreciated for their hunting. To the east of the city, as if balancing the site of the *Alcázar* as regards Madrid, the Count-Duke of Olivares built another royal residence, in the seventeenth century, more open and landscaped than the primitive fortress and significantly called the Good Retreat (*Buen Retiro*).[1] Still further distant, yet within the aforementioned triangle, there were two fundamental enclaves in the political and territorial ordering of this space of power, both loaded with symbolism and meaning: *El Escorial* and *Aranjuez*, two principal and significant royal sites that were simultaneously similar and different. Both display the geographical sense of the mindset and policy of the King as also encountered on many other occasions (Kagan, 1986 and Arroyo, 1998).

However, the town and the court, the city and the royal sites, all functioned as an organic whole, thanks to the activity of courtiers, nobles, and officials, as well as the royal family, to the extent that the Casa de Campo, the Pardo, Aranjuez and El Escorial "ornamentally serve this town [Madrid] and increase its greatness," as Jerónimo de la Quintana noted. Hence, Felipe II emerges from this as the organizer not so much of a capital, but rather of a much broader environment that included the city, royal residences, gardens, forests, hunting grounds, etc. often interlinked by the walks, groves and canals that Chueca defined as "the most impressive building program of the Spanish Renaissance," with the stamp of the Habsburgs, before later being subject to improvements by the Bourbons (op. cit. Domínguez, 1983).

4 The Urban and Demographic Consequences of Madrid Becoming the Capital

In either case, this territorial whole integrated the different sites and royal enclaves around Madrid and formed part of the complex *city and countryside* relationships that led to the greatest structural tensions that pivoted around the city. It was the city that hosted the de facto seat of power and the symbol of the monarchy and that

[1]During the reign of Felipe II, this site was occupied by a Hieronymite Monastery and its orchards. It was to become a Royal Site under Felipe IV in the 17th century.

experienced the sharpest changes, whether of a demographic, social, economic or some other nature, driven by the political decisions made there.

In 1600, Madrid had about 90,000 inhabitants, far less than the estimated 200,000 of the London of that period or the 400,000 of Paris. However, this still reflected a considerable increase in comparison to the slightly over 20,000 that the town contained when Felipe II moved his court there. Thus, from the demographic point of view, problems did not stem from the actual volume of its population, but rather from the speed of its growth, an aspect with more serious consequences than the actual population size. Such rapid growth continued throughout the first half of the seventeenth century, with the population almost doubling by 1650, thereby maintaining a rate very similar to that of London, then considered as the European city experiencing the fastest rate of growth (Carbajo, 1987).

As was the case with these other European capitals, the Madrid population growth stemmed from the intense migration triggered by the attractiveness of the capital. Furthermore, and for the same reason, there was a substantial floating population, including temporary migrants, such as the sons and daughters of the middle and upper provincial classes, sent to Madrid for their education and to *prosper in Court* as the city expanded its reputation as the capital (Caro Baroja, 1969).

In this way, the Court turned the town into a capital but only with certain dependencies and constraints. In Madrid, in conjunction with a large homeless and uprooted population, which had to be sustained, albeit at a subsistence level, so as to avoid the risk of protests and riots—we may recall the Esquilache riot in 1766—, there was also an elite of privileged classes, families, institutions, corporations, etc. They might have been few in number, but nevertheless enjoyed high consumption capacities that required high living conditions, thus maintaining the growth and expansion of the city, especially through the significant efforts necessary to ensure the supply of provisions. Carlos de Simón Pontero, designer of a well-known navigation project for the River Tagus, to which we shall return below, stated: “The grain needed for the consumption of the Court, sees the entering of one million bushels of wheat and two million bushels of barley. In the same sense: to supply bread to Madrid—this from a news item from the era—has always been one of the most serious provisions occupying the attention of the Government, and had it not been for the piety of the Kings, some unfortunate event due to a lack of such necessary food would have occurred”.[2] By 1748, Madrid was importing goods each year amounting to 500 million reales, including “295,000 rams […] 11,000 cows, 60,000 kids, 6000 calves, 191,000 head of sow. […] 191,000 arrobas of oil, etc.” (Estrada, 1768, 84).

In the beginning, goods came from the nearby countryside, for example, wine from Villaverde, Getafe, Vicálvaro, Pozuelo and Carabanchel. However, by the middle of the eighteenth century, when consumption had already topped one million arrobas, wine was being sourced from many different places: Sacedón, Chillarón, Colmenar, Talavera, and with imports from La Mancha also beginning with

[2]Biblioteca Nacional, ms. 10,714.

some regularity. The same happened with fruits and vegetables, which were, at first, supplied by the small market gardens that existed on the riverbanks close to the city, as already mentioned in *Relaciones* (Arroyo, 1998 and Camarero, 2001 and 2005), but when the production of such sources began falling short, there emerged the need to resort to imports from further afield: "Vera de Plasencia, Ribera del Ebro, the two Castiles and from twenty to thirty leagues away," in a way that, as Núñez de Castro (1675) notes in his customary hyperbolic tone, "in the market square of Madrid, where all fruit is found, all is sold and still the privileges of Paradise seem to be enjoyed."

An essential chapter in this urban trade in provisions was that of the import of coal and firewood that Domínguez Ortiz cites as totalling about 2,000,000 arrobas annually in the eighteenth century. And Simón Pontero raises that figure to three million ats ("arrobas") of holm oak charcoal and a million of heather coke per year; this was, perhaps, somewhat exaggerated, given that he was himself interested, as we will see, in promoting the advantages of the river transport system that he was advocating. Additionally, in this case, the scope of the supply of provisions expanded gradually and steadily. First, this scope was understood as being within a radius of twenty leagues around Madrid, before this expanded to thirty leagues in 1769 and forty-three leagues in 1798 (Domínguez, 1986, 201). For his part, Simón Pontero states that its limits, in the middle of the eighteenth century, were set "to the East in the mountain range of Cuenca, to the West in the mountains of Oropesa or Toledo," corresponding to a circumference of some 21 leagues in diameter. According to all of these data, Bravo Lozano (1993, 50) has delimited the radius for the supply of energy to Madrid to an area of over 70,000 km^2 around the capital.

This form of provision incurred three types of negative effect for the environment: over-exploitation of the closest areas, the expansion of the scope for sourcing provisions driving reductions in the fertility of this same area, and an overexpansion in the cart-transport sector, which became a large and bloated trade. This represents a very different scenario from the large cities in the wetter parts of Europe to which Madrid is frequently and wrongly compared, which had a cheap and effective alternative transport system that allowed for improvements in the lands in nearby areas of influence. In such places, the demand for supplies stimulated increases in the productivity of such lands. This reflects the case of London, as studied by Fisher and Wrigley, where the city's expansion triggered agricultural changes that went hand in hand with the industrial revolution. In Madrid, by contrast, and perhaps because of the poor conditions of the environment and the lack of river transport, an *extension* of the area of supply took place instead of the *intensification* of production on the closest lands, which led to both the deforestation of the natural environment and the saturation of a transport system that was unable to transport heavy goods over long distances. Hence, and as Ringrose makes clear, the relatively infertile interior of Spain supplied a capital that was one of the largest cities in pre-industrial Europe, but which nevertheless still lacked direct access to maritime or river transport. This gave rise to a perverse duality that this historian expressed in the phrase, "Madrid forced the stagnation of its environment to maintain its own growth" (Ringrose, 1985, 29).

5 Water as a Solution

It is thus little wonder that, whereas the problem of Madrid was generated by the Crown in establishing the Court in a city devoid of a river and with scant water supply, it was that same Crown that would attempt to provide a solution, whether by rectifying its decision and moving the capital to another city or by means of various measures to improve the water endowment of Madrid, thereby combatting both the transport problems, through usage of waterways, and the loss of fertility, through expanding the extent of irrigation.

The Count of Aranda, in the eighteenth century, was one of the first to contemplate the seriousness of this situation: "Which court in all of Europe is worse situated to provide what is necessary or to obtain it?, neither the nature of its land can be worse nor the industry of its Government more neglected" (Arroyo and Camarero, 2003). A few years later, it was once again Larruga, describing the excellence that the Courts of Europe had bestowed upon themselves by being near large rivers, such as "the Po and the Tiber in Italy, the Vistula in Poland, the Danube and the Rhine in Germany, Seine and Garonne in France and the Thames in England", who said that, where nature had not provided this liquid element, it should be the hand of man that seeks its substitution: "…using glorious emulation to achieve these artificial rivers for the populations and Courts where the help of wide rivers has been denied. This was the case in the capital, Madrid, for its good temperament, climate, situation and centre of Spain, having been chosen for the Court and the residence of the Kings, it is feared, or has indeed already lost this greatness, basing it in another location, for the lack of coal and firewood, an experience that is being already felt, since long journeys must be endured to get these provisions" (Arroyo and Camarero, 2003). According to the same author, this waterway would extend the area of Madrid's energy supply to "the infinity of mountains which lie along the River Tagus and continue until the Portugal border," thus reducing pressure on the deforested woodlands in the immediate vicinity. In the same way, the watercourse would also increase the productivity of newly irrigated lands: "…the abundance of harvests […] that could be used for the supply of this Court, of wheat and barley, without suffering the shortages and high prices as were experienced in sterile years."

This was a clear choice, common to any project of what we would today call Territorial Planning, because that is effectively what it was, only belonging to the pre-industrial era. Firstly, *space* was considered *as distance*, which would imply improvements to the transport and communications network so as to be able to import goods from remote areas. The second consideration, *space as a resource*, aimed at increasing the productivity of the closest surrounding lands. While both solutions were tried, they returned nothing but very poor results due to the limitations imposed by the environment, which, however, according to their sphere of influence and the scale of the space acted upon, may be differentiated across three levels: intra-urban, suburban and regional (Pérez Boldo and Arroyo Ilera, 2003–2004, 198).

6 Water as a Means of Transportation and Communication

Recourse to water as a means of transport to improve communications for Madrid via the River Tagus and its tributaries reaches back to the sixteenth century (Arroyo and Camarero, 1989 and 2003, Arroyo, 2004a). The Tagus was a key element in these Spanish river navigation projects, the first of which was by the famous Italian engineer, Juan Bautista Antonelli who, in 1580, with the annexation of Portugal in mind, argued that the Tagus, then navigable from Abrantes to Lisbon, would also be navigable, with a few modifications, between Abrantes and Alcántara, and later, with further work, between Toledo and Alcántara. To demonstrate his thesis, he set out from Lisbon and travelled the entire extent of the river and its tributaries to Madrid in a small boat before then returning to the Portuguese capital (López, et al., 1998, 504).

In the following century, and again with the problems of Portugal as a backdrop, the issue was once more taken up, this time by Carducci and Martelli (López Gómez, 1998), who sought to re-establish the navigation of the River Tagus and its tributaries following their abandonmen at the beginning of the seventeenth century. However, it took the arrival of the eighteenth century for the third project, which is of greatest interest here, to emerge through the initiative of Carlos de Simón Pontero as a private endeavour backed by the launching of a *company of shares* (Arroyo and Camarero, 2003). Carlos de Simón Pontero was originally from Chillarón, a place close to the very river that he intended to navigate, and was Mayor of the House and Court of Ferdinand VI. He must have been well-placed economically, given his capacity to commission two experts, José Briz and Pedro Simó, to survey the course of the river and provide an account of its state and the works necessary to make it navigable (López Gómez, 1998, 125). This survey, carried out between July and December of 1755, resulted in a travel diary (Cabanes, 1829: doc. No. 135), which recorded the vicissitudes and course of the river and described its banks. This third attempt displays several essential differences with the projects of the previous centuries: firstly, this was a private undertaking by Carlos de Simón Pontero, and not a Crown initiative; the navigable zone focused on was the High Tagus—not explored in the previous surveys—and the core interest was now supplying the Court, and not communicating with Portugal. For the same reason, their journey took place overland, with brief incursions into the river to learn of possible means of supply; finally, in order to enable access to Madrid, the project also planned the Guadarrama and Manzanares canals (Arroyo and Camarero, 2003).

7 Water for Irrigation

The other option explored involved making use of the rivers close to the capital, especially the Jarama, to irrigate the drylands and increase their productivity by transforming them into market gardens. However, transforming drylands into irrigated farmland does not only pose technical problems, but also involves a series of practices, operations and changes in mentality, which, in this case, were rarely taken into account, ultimately leading to the failure of the project. In the case of Madrid, attempts to irrigate the drylands close to the capital also reached back to the sixteenth century, with Aranjuez at the centre and the Colmenar irrigation canal as the most representative example, in a process then organized directly by the Crown. But soon after, due to the capital's demographic expansion and the greater volume and faster supply of food correspondingly required, this area of irrigation was extended to the nearby plains of the Jarama, between Rivas and the vicinity of Toledo (Arroyo, 2002 and 2005) and the Henares, from Humanes to beyond Alcalá de Henares (Sánchez Peral, 2018).

The first of these interventions was the *Royal Irrigation Canal of Jarama* (*Real Acequia del Jarama*), designed in the sixteenth century, begun in the seventeenth, constructed in the eighteenth, improved in the nineteenth, and finally finished in the twentieth. Nowadays, it provides the main axis of the Las Vegas region and was the blueprint for all other similar interventions that were subsequently carried out. In the construction of the canal for the Jarama, its character as a public work coincided with the technical difficulties that were faced due to it being a hydraulic engineering project that had hardly ever been attempted before in such an unsuitable rural setting (Arroyo, 2005). In the eighteenth century, the works were directed by two well-known military engineers, Pedro Superviela and Sebastián de Feringán, but were not completed until the nineteenth century, following modification to the project by Pedro Delgado (Fig. 2).

Fig. 2 Plan of the initial project of the royal irrigation canal of the Jarama River (Plano *de la Real Zequia del Xarama.* Juan de la Clime, 1717) (Archivo General de Simancas)

Fig. 3 Plan of the initial project of an irrigation canal in the Henares Valley (*Mapa de la campiña de Guadalaxara y Alcalá*. Manuel de Navacerrada. Madrid, abril, 19 de 1770). (Archivo General de Simancas)

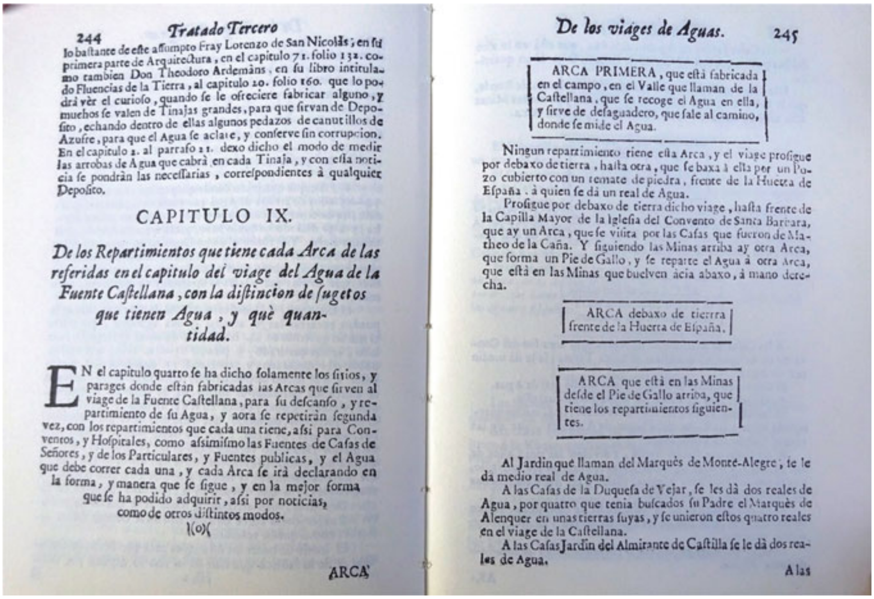
The Henares Valley represented another set of arable and irrigable lands capable of helping to meet the capital's needs. The corresponding irrigation canal was designed in the eighteenth century, as a complement to that of Jarama, but was not built until the following century. This itself would not have been possible without the initial 1770 project, made possible by the intervention of the Count of Aranda, that set out an irrigation and planning program for the whole territory. This furthermore included extending the area watered to the right-hand banks of the Jarama, between the Pesadilla and San Fernando villages, in a project that never came to fruition as originally envisaged (Sánchez Peral, 2018) (Fig. 3).

8 Supplying Water to the City

However, the area in which Madrid's deficiencies in terms of water were most clearly seen, in this unbecoming state capital and headquarters of the Crown, emerged out of the difficulties of achieving and maintaining an appropriate water supply, despite the image repeatedly reinforced by the chroniclers of the sixteenth century. As seen, the Manzanares was of little use for the urban supply, not only due to its lack of volume, but also because of its location, appreciably lower than the city's altitude. Other sources of supply thus had to be found simply to ensure that the city's population could drink, cook, clean, etc.

9 Kanats, Hygiene and Urban Sanitation

As is well known, these functions were indeed fulfilled, and long before the arrival of the Court, by the so-called *viajes de agua* or kanats, sloping subterraneous waterways referred to in the *Relaciones* of Felipe II, 1575: "In the pasture called San Hierónimo, there are five sources of singular artifice […] and these are the sources of Leganitos, Lavapiés, los Pilares Viejos, the sources of El Peral and of La Priora, in such abundance that there is more water than necessary for everything" (Viñas, 1949, 359–360). In 1561, the time that the Court established itself in Madrid, most of the water supply came from the *Alcubilla* kanat, with an approximate flow of 80 m^3/day (López Camacho et al., 1986, 30), enough for the town's 20,000 inhabitants, but completely inadequate for the growing needs of a city of over 60,000 inhabitants, as Madrid had already become by the beginning of the seventeenth century. In 1606, new captures were initiated to boost the available flow rate, giving rise to the kanats of *Alto Abroñigal* (1614), *Bajo Abroñigal* (1617) and *Castellana* (1614–1621), but without ever fully ensuring the supply. The system was supplemented by the numerous waterwheels that raised water from the river and the wells that existed in many houses, which did enable the city to be supplied but always with notable difficulties (Troll and Braun, 1974, Martínez Alfaro, 1977, Pinto Crespo et al., 2010) (Fig. 4).



244 *Tratado Tercero*

lo baſtante de eſte aſſumpto Fray Lorenzo de San Nicolàs, en ſu primera parte de Arquitectura, en el capitulo 71. folio 132. como tambien Don Theodoro Ardemàns, en ſu libro intitulado Fluencias de la Tierra, al capitulo 20. folio 160. que lo podrà vèr el curioſo, quando ſe le ofreciere fabricar alguno, y muchos ſe valen de Tinajas grandes, para que ſirvan de Depoſito, echando dentro de ellas algunos pedazos de canutillos de Azufre, para que el Agua ſe aclare, y conſerve ſin corrupcion. En el capitulo 2. al parrafo 21. dexo dicho el modo de medir las arrobas de Agua que cabrà en cada Tinaja, y con eſta noticia ſe pondràn las neceſſarias, correſpondientes à qualquier Depoſito.

CAPITULO IX.

De los Repartimientos que tiene cada Arca de las referidas en el capitulo del viage del Agua de la Fuente Caſtellana, con la diſtincion de ſugetos que tienen Agua, y què quantidad.

EN el capitulo quarto ſe ha dicho ſolamente los ſitios, y parages donde eſtàn fabricadas las Arcas que ſirven al viage de la Fuente Caſtellana, para ſu deſcanſo, y repartimiento de ſu Agua, y aora ſe repetiràn ſegunda vez, con los repartimientos que cada una tiene, aſsi para Conventos, y Hoſpitales, como aſsimiſmo las Fuentes de Caſas de Señores, y de los Particulares, y Fuentes publicas, y el Agua que debe correr cada una, y cada Arca ſe irà declarando en la forma, y manera que ſe ſigue, y en la mejor forma que ſe ha podido adquirir, aſsi por noticias, como de otros diſtintos modos.

ARCA

De los viages de Aguas. 245

ARCA PRIMERA, que eſtà fabricada en el campo, en el Valle que llaman de la Caſtellana, que ſe recoge el Agua en ella, y ſirve de deſaguadero, que ſale al camino, donde ſe mide el Agua.

Ningun repartimiento tiene eſta Arca, y el viage proſigue por debaxo de tierra, haſta otra, que ſe baxa à eſta por un Pozo cubierto con un remate de piedra, frente de la Huerta de Eſpaña, à quien ſe dà un real de Agua.

Proſigue por debaxo de tierra dicho viage, haſta frente de la Capilla Mayor de la Igleſia del Convento de Santa Barbara, que ay un Arca, que ſe viſita por las Caſas que fueron de Matheo de la Caña. Y ſiguiendo las Minas arriba ay otra Arca, que forma un Pie de Gallo, y ſe reparte el Agua à otra Arca, que eſtà en las Minas que buelven àcia abaxo, à mano derecha.

ARCA debaxo de tierra frente de la Huerta de Eſpaña.

ARCA que eſtà en las Minas deſde el Pie de Gallo arriba, que tiene los repartimientos ſiguientes.

Al Jardin què llaman del Marquès de Monte-Alegre, ſe le dà medio real de Agua.

A las Caſas de la Duqueſa de Vejar, ſe les dà dos reales de Agua, por quatro que tenia buſcados ſu Padre el Marquès de Alenquer en unas tierras ſuyas, y ſe unieron eſtos quatro reales en el viage de la Caſtellana.

A las Caſas Jardìn del Almirante de Caſtilla ſe le dà dos reales de Agua.

A las

Fig. 4 Juan Claudio Aznar de Polanco, *Tratado de los quatro elementos, origen y nacimiento de las aguas y fuentes de Madrid y sus viages subterráneos*. Madrid, 1727. Double page where the description of the *Viaje de Agua de Fuente Castellana* (water journey of Fuente Castellana) begins

In the early eighteenth century, the Madrid population broke the 100,000 mark. It was at this point that the water supply became perceived as being excessively deficient, because, along with drinking water consumption, other needs were also now becoming apparent for which the kanats were clearly insufficient. Moreover, the new century and the arrival of the new dynasty brought other hygiene and cultural practices into usage, both at the personal and the communal levels, only serving to increase the demand for water. In addition, some galleries experienced subsidence when building work, resulting from the city's continued growth, was carried out above them. All of this illustrated the inadequacies of a modern city built on a drilled surface of galleries (Macías and Segura, 2000). In addition, the contamination of the water running through these galleries, due to wastewaters and leakages from domestic septic tanks, affected the health of residents and forced the water supply issue to be dealt with from the hygiene and sanitation perspective (Pinto Crespo et al., 2015).

The problem was by no means new and had attracted the attentions of locals and foreigners alike, pretty much ever since the installation of the Court. In 1594, Camilo Borghese, the future Paul V, visited Madrid as *apostolic nuncio*, and left with an unfortunate image of the capital: "There is a broad street which would be beautiful if it were not for the mud and filth which mars it. The houses are bad and ugly and almost all made of mud and among other imperfections have neither doorsteps nor closets; in consequence of which, all perform their necessities in chamber pots which they afterwards throw into the street, something that afterwards creates an insupportable odour." Other foreign visitors conveyed similar impressions throughout the seventeenth century. In 1623, Sir Richard Wynn, following a trip to Spain, recounted his views of the capital thus: "There were so many things emptied in the street, that did almost poison us; for the usual custom there is, that at eleven at night everyone empties those things in the street, and by ten the next day, it is so dried up, as if there were no such thing." In 1664, the French Ambassador François Bertaut described the following: "The streets are for the most part wide, but I do not think that anyone has ever removed a single cart-load of mud from them, so much of it is there everywhere, and so infected because of dung thrown onto them" (Thomas, 1988, 81–82) (Figs. 5 and 6).

Thus, the scant provision of drinking water, population growth and increasing demands for hygiene and sanitation made the prevailing situation unsustainable. By the middle of the eighteenth century, Madrid had a population bordering on 150,000 inhabitants (Camarero, 2001), with drinking water supplied thanks to the four previously described *viajes de agua*, which that provided an average flow of 800 m^3 and the provision of 5.3 l/inh./day, somewhat higher than the average of a

Fig. 5 Archaeological remains, preserved at the Opera metro station, of the big fountain called "Caños del Peral", built in 1565, by the architect Juan Bautista de Toledo, which supplied water to the palace and part of the population of Madrid

Fig. 6 The water came through a *viaje de agua*. *Photo* C. Camarero Bullón

century before. However, by the end of the century, the population reached 200,000, and new captures for each of these *viajes de agua* became necessary so as to increase their respective water supply capacities. In 1741, the *La Alcubilla* kanat was expanded and, three years later, works began to improve *La Castellana*; in 1756, a new branch, called the *Viaje de los Gremios* (the Guildsmen's Kanat), was opened. In 1771, it was the turn of *Bajo Abrogiñal* and, in 1796, of *Alto Abrogiñal* to undergo renovation (López Camacho, 1986, 39).

Simultaneously, the problems around the lack of hygiene and poor sanitation were addressed with numerous legal provisions, such as the *Pregón General mandado guardar por los Alcaldes de la Casa y Corte de Su Majestad* (General Instructional Speech addressed to the Mayors of the House and Court of his Majesty) of March 15th, 1613, which prohibited the throwing of water or filth through windows at night. Just three and a half months later, a public announcement again prohibited the throwing of wastewater from homes into the street and included other rules stipulating the cleaning and sweeping of the streets, including cleaning the facades of houses and the corresponding half of the street with water (Cervera, 1975, 150). Numerous edicts in the same general direction were made throughout the seventeenth century, for example, the *Condiciones con las cuales se ha de rematar la limpieza y el empedrado de todas las plaças y calles de esta villa de Madrid* (Conditions with which to finish the cleaning and cobbling of all squares and streets of this city of Madrid) of 1620, and the *Ordenanzas municipales* (Municipal Ordinances) of 1639, 1659, 1660, and 1719.

In 1735, the architect José Alonso de Arce planned the construction of Madrid's first sewage system. He proposed a main gallery, or "royal mine", running through the city's subsoil from the beginning of Alcalá Street to the current Isabel II Square, where it connected with a branch mine network. From there, it continued to Manzanares along another secondary gallery. The drains and sinks of neighbouring houses would be linked with the public network, thus preventing their waste and filth from entering the street. However, nothing got done until 1750, when Antonio de Ulloa, following a trip to Paris to learn about the city's sanitation system, once again raised the idea of sewers, which had been abandoned since the time of Arce. Two years later, another report was published, this time by Pedro Bort, also arising from his travels through France and the Netherlands, that, in addition to the drainage system, included the concepts of paving and lighting. Finally, the project by Pedro del Campo and Veneras is also worth mentioning as it contained various recommendations for improvements to the city's cleaning and sanitation systems (López Gómez, 1988, 37–38).

10 Project Writers, Arbitristas and Engineers

For all of the success of these regulations and projects, much more water was still needed than the *viajes de agua* could ever supply. It was therefore necessary to bring in water from other basins along an appropriate canal system, giving rise to the numerous projects that would later serve as precedents for the work of Bravo Murillo (Arroyo, 2004b, Fernández et al., 2016).

The original idea to transfer water to Madrid from neighbouring basins dates back to the reign of Juan II, and also featured both in the plans of Antonelli and the later project by the Grunemberg brothers, even while their goals were both different and misguided, ranging from the transportation of goods to the irrigation of farming lands close to the city without, of course, discounting for the improvements made to the urban supply. The issue was that each of these goals reflected different approaches to solving the problem. Everyone wanted more water for Madrid, but why and for what? Were the three uses mentioned here compatible? For some, from a perspective that we might describe as mercantile, water would serve to facilitate the trade, transport and supply of goods; others, adopting a physiocratic approach, considered that the problem derived from the poor fertility of the dry lands in the vicinity of Madrid and that water should thus be applied to boosting their fertility; and, finally, a third, more environmental group, began to evaluate the usefulness of water itself, not as a means of transport or irrigation, but for drinking, cleaning, sanitizing and improving the city.

Furthermore, out of this triple dilemma, various actors intervened according to very different arguments; from the most highly qualified engineers and architects to utopian project writers and *arbitristas*. The latter group were right in their objectives, but lacked the expertise to implement them, while the former, with better technical training, were always more conservative in selecting their objectives.

In this latter group, we may, on the one hand, include those projects proposed by a number of individuals from different backgrounds and interests and, on the other hand, studies carried out by military engineers under the command of the Crown at the end of the century of the Enlightenment. For the former group, which arose in the first half of the eighteenth century, the list begins with the project of Andrés Martí (1737), a characteristic representative of the group of *arbitristas* and project writers, who presented himself as a *Captain of a Galiot (galley boat)* and proposed building a canal, about two kilometers in length, from a dam in the Jarama River, just above Pesadilla, as far as Manzanares, and from Puente Verde to Soto de Luzón, located between Madrid and Vallecas. He then sought to irrigate the area traversed by the canal spanning an area of 80,000 bushels of production. He also proposed devoting an area amounting to some 13,000 bushels to the cultivation of vegetables, legumes, forage and alfalfa, for consumption in Madrid. The irrigation would beautify the areas crossed by the canal, for which the building of five walkways was proposed, 55–60 ft wide, trimmed with groves, in Fuencarral, Fuente Castellana, Alcalá, Fuente del Berro and Vallecas. In addition, the canal would allow for other exploitations of its banks, such as mills, fuller mills, etc., and improve the hygiene of Madrid. The project came in for a great deal of criticism, particularly from Arce and Colonel Sicre, with the latter making a devastating remark: that the project proposed to draw its water 300 ft below the site to which it sought to conduct it.

Similar in terms of its ambiguity and imprecision was another project, drafted in the same year by Vicente Alonso Torralba, entitled *Spanish efforts making clear the way to clean the streets of Madrid*, which did not even say where the diversion dam was to be built, even while containing some original ideas that, nonetheless, did not extend any further than simple speculation. As Sicre observed: "[I]t proposes to make a deposit of the greatest size that can be made in the heights of Foncarral (sic) […] from which […] it distributes the water in three parts: a small part for the land between Puente Verde with the remainder going to Manzanares; another main part going east, to water the whole of the greater portion of land, with what remains introduced into Manzanares at Soto de Luzón; and the third part to be taken by means of the two, to be captured in two or more kanats […] for Madrid's wells and to make drinking ponds for cattle." That is, Torralba, in the first instance, imagined an urban distribution network, although with a highly arbitrary distribution. It did, however, contain a clear correlation between urban cleaning and the diversion of the Jarama, which is, indeed, its most notable contribution.

In the same year of 1738, Joaquín Casses put forward a similar project, also without a plan for levelling and repeating many of the previous proposals, *Tridente Scéptico de España* (Skeptical Trident in Spain), which, in Sicre's view, "is enlivened with the prettiness of a fable". Additionally, and in the same sense, though rather more thoughtful than the previous cases, we might cite the project of the Mayor of Viñuelas to build a dam on the River Jarama, at the height of Galápagos, in order to direct the river's water towards the city, thus resurrecting the old projects of Martí and Torralba (López Camacho et al., 1986, 40).

Ultimately, in the mid-eighteenth century, the hygiene situation of the town and Court had become untenable, especially from the perspective of the new criteria of enlightened urban planning. The search for a solution was divided between those authors who had diagnosed the problem with precision, but, driven by a utopian spirit, were ignorant of how to solve it, while others, the engineers, who knew how to address the situation, only thought of water either in terms of navigation or for watering and irrigation. Thus, there were constant cleaning and reform projects, often with shared uses overlapping into arable land or garden irrigation, which necessarily required increases in the water supply as the water flow from the kanats was wholly insufficient for these functions.

Between 1766 and 1773, the intervention of the Count of Aranda, President of the Council of Castile, would become key to solving the problem. Aranda, aware that the problem had to be dealt with from its very roots, commissioned a project from the military corps of engineers, who had considerable experience in channelling rivers. The man chosen was Colonel Jorge Sicre y Béjar, under whose command were fifty officers of that Corps; this choice well illustrates the importance that the Crown attributed to the water supply issue in the capital. In 1768, Sicre drew up a detailed project for diverting the Jarama River to Madrid. His essential argument, reached after detailed analysis of the situation, was that it was not necessary to take water from the Jarama, and that doing so from the Guadalix would be enough. Upstream, there was no irrigated land, and thus Sicre, always conservative in terms of his targets, thought that this was the appropriate route for his canal. However, in compliance with his commission, he prepared a double project, one that could be adapted to either of the two proposed solutions or, indeed, to both simultaneously.

In addition, in the event that the decision fell to taking water from the Jarama, this should be done at its confluence with the Lozoya River, the only place that met the two fundamental requirements: the required quota, *a hundred and fifteen feet higher than the door of Santa Barbara*, and sufficient flow rates, only possible after the confluence of both rivers. Upstream, there was an insufficient flow, whereas downstream, the loss of height and quota was too rapid. Therefore, the point chosen by Sicre was the so-called "strait of the Gueza tables, half a league to the northwest of Uzeda and nine from Madrid. […] But as I went ahead I saw that forming a reservoir on the river Guadalix could be achieved with the aim of taking water to Madrid without the expense of bringing it from the Jarama, so far away." Faithful to this aim, Sicre actually produced two interlinked projects: the first between Jarama and Guadalix; the second, from the latter river to Madrid.[3]

A few years later, in 1786, it was Juan de Villanueva who modified and expanded Sicre's project to carry water as far as the reservoir of El Retiro from a large dam in the Salto del Hervidero on the Guadalix River, from whence the water

[3]General Archive of Simancas, Guerra Moderna, leg. 3519. A copy from 1844 exists in the Madrid Town Archives (Archivo de Villa), leg. 4-5-4.

would then be transferred to Madrid by means of a canal, a plan that was similar both to Sicre's and that subsequently followed by Rafo and Ribera. Other projects at the end of the century and in the early nineteenth century included those of the Uceda Canal, built by Pedro de Echauz, whose heir sold the operating rights to Francisco Cabarrús in 1790; that of José Mariano Vallejo in 1818; and that of Francisco Javier Barra in 1832, all of these being predecessors of the Isabel II Canal (López Camacho et al., 1986 and López Gómez, 1996).

At the same time, we must take into account improvements to the city's sanitation. Carlos III, having just ascended to the throne, commissioned Sabatini with the drafting of a comprehensive plan for paving, sewerage, cleaning, lighting, etc., called the *Instrucción*, enacted in 1761, known by the name of its promoter, the King, and destined to be much more successful than its predecessors. In relation to public cleaning, it improved the waste collection system, placing the obligation on all carriers entering the city with goods to leave with waste and transport it to the assigned tips. One system of canals for rainwater and another to carry residual waste to appropriate wells were established, alongside a ban on throwing filth out of windows, as had hitherto always been done. The *Instrucción* stated that solid waste was to go into septic tanks, to be built on the urban perimeter. In 1765, there were almost 13,000 such tanks, which remained in operation until well into the nineteenth century: they were cleaned at night and their waste removed in foul-smelling wagons that people referred to as «Sabatini's chocolate carts» (López Gómez, 1988, 209). Nevertheless, all of this could only work properly with an increase in the water supply as Sabatini had himself predicted.

The results, which constituted a real turnaround in the opinions of both locals and visitors as regards the city's ambience, soon became clear. In 1764, the Marquis of San Leonardo could not repress his astonishment about "*what was always regarded as an impossible enterprise, that is, that in the most general parades one can already walk without the risk of splashes of a low quality*" (Cervera, 1975, 174–176). Among foreigners, Peyron, who visited Madrid between 1772 and 1773, was amazed at the fact that "almost all the streets of this town are straight, wide, clean and well paved" (López Gómez, 1988, 208); and the most tellingly positive, a paragraph from Beaumarchais, who was aware of the causes of the city's new environmental conditions: "[S]ince the stubborn determination of the reigning Prince to clean the city of Madrid has beaten the obstinacy of the Spaniards to remain in filth, this city has become one of the smartest that I have ever seen" (Thomas, 1988, 83).

The railway and the Isabel II Canal (1851) provided the definitive solution to the problem; the former in that the city became accessible from anywhere in the country, and the latter in that it permitted an allocation of water similar to any other European capital, even while Madrid was still neither on a river nor close to the coast. The "geographical error" committed by the Crown to set the capital in an area unsuited to such an enterprise had finally been "rectified" through the efforts of the Crown itself, or, perhaps more accurately, by those of the state. And, henceforth, Madrid went from being responsible for the "stagnation of its environment", as Ringrose had proposed, to being "the breakwater of Spain" and the core element in the geographical and political articulation of the entire country, as the poet Antonio Machado noted.

References

Alvar Ezquerra, A. 1985. *Felipe II, la Corte y Madrid en 1561*. Madrid: CSIC.

Alvar Ezquerra, A. 1989. *El nacimiento de una capital europea. Madrid entre1561 y 1606*. Madrid: Turner.

Arroyo Ilera, F. 1998. *Agua, paisaje y sociedad en el siglo XVI, según las Relaciones Topográficas de Felipe II*. Madrid: Ed. del Umbral.

Arroyo Ilera, F. 2002. «Orígenes y antecedentes de la Real Acequia del Jarama», *Estudios Geográficos*, 248–249: 409–442.

Arroyo Ilera, F. 2004a. «Marinas y riberas interiores: notas para una geografía histórica del Tajo en los siglos XVI y XVIII», *Cuadernos de Geografía,* 73/74: 233–258.

Arroyo Ilera, F. 2004b. «Arbitrismo, población e higiene en el abastecimiento hídrico de Madrid en el siglo XVIII», *Boletín de la Asociación de Geógrafos Españoles.* 37: 257–278.

Arroyo Ilera, F. 2005. «Ilustración y Riegos: la Real Acequia del Jarama en el siglo XVIII», *Estudios Geográficos*, 25: 5–41.

Arroyo Ilera, F. y Camarero Bullón, C. 1989. «Proyectos ilustrados de navegación fluvial». En *Los paisajes del agua.* Valencia: Universidades de Valencia y Alicante, 347–369.

Arroyo Ilera, F. y Camarero Bullón, C. 2003. «La Compañía de navegación del Tajo en el siglo XVIII y el proyectos de Carlos de Simón Pontero». En *Historia, Clima y Paisaje.* Valencia: Universidades de Valencia, Alicante y Autónoma de Madrid, 75–98.

Bravo Lozano, J. 1993. *Montes para Madrid. El abastecimiento de carbón vegetal a la Villa y Corte entre los siglos XVII y XVIII.* Madrid: Caja de Madrid.

Cabanes, F. 1829. *Memoria que tiene por objeto manifestar la posibilidad de hacer navegable el río Tajo desde Aranjuez hasta el Atlántico*. Madrid: Imprenta Miguel de Burgos.

Cabrera *de Córdoba, L. 1998. Historia de Felipe II.* Valladolid, Junta de Castilla y León.

Cámara, A. 1999. "Madrid en el espejo de la Corte". In *Madrid, Ciencia y Corte*. Madrid: Comunidad de Madrid, CSIC, UAH, 63–74.

Camarero Bullón, C. 2001. *Madrid y su provincia en el Catastro de Ensenada. I. La Villa y Corte.* Madrid: Ediciones del Umbral.

Camarero Bullón, C. 2005. *Madrid y su provincia en el Catastro de Ensenada. II. Los pueblos* Madrid: Ediciones del Umbral.

Carbajo Isla, M. F. 1987. *La población de Madrid desde finales del siglo XVI hasta mediados del siglo XIX*. Madrid: Siglo XXI.

Caro Baroja, J. 1969. *La hora navarra del siglo XVIII* (personas, familias, negocios e ideas). Pamplona. Comunidad Foral de Navarra.

Cervera Vera, L. 1975. «Francisco de Sabatini sus normas para el saneamiento de Madrid». *Anales del Instituto de Estudios Madrileños*, XI: 140–155.

Domínguez Ortiz, A. 1983. «Los primeros Borbones españoles y los Reales Sitios». In *El real sitio de Aranjuez y el arte cortesano del siglo XVIII*. Madrid: Comunidad de Madrid y Patrimonio Nacional.

Domínguez Ortiz, A. D. 1986. *Sociedad y Estado en el siglos XVIII español.* Barcelona: Ariel.

Estrada, J. A. de. 1768. *Población general de España*. Madrid: imprenta de Andrés Ramírez.

Fernández de los Ríos, A. 1868 (1975). *El futuro Madrid*. Ed. Facsimil. Barcelona: Los Libros de la Frontera.

Fernández Izquierdo, F. *et alii*. 2016. *La presa de El Vado y el Canal del Jarama*. Madrid. Fundación Canal. Canal de Isabel II.

Gutiérrez Nieto, J. I. 1983. «En torno al problema del establecimiento de la capitalidad de la monarquía hispánica en Madrid». *Revista de Occidente,* 27–28: 52–65.
Kagan, R. L. (dir). 1986. *Las ciudades del Siglo de Oro. Las vistas españolas de Anton van den Wyngaerde.* Madrid. El Viso.
Larruga, E. 1797. *Memorias políticas y económicas…* Ed. facsímil. Gobierno de Ara-gón. Vol. II, Tomo VI. fol. 32 y ss.
López Camacho, B. et alii. 1986. *Antecedentes del canal de Isabel II: viajes de agua y proyectos de canales*. Madrid: Canal de Isabel II.
López Gómez, A. 1988. «Madrid a mediados del siglos XVIII». In *Planimetría Gene-ral de Madrid*. Madrid: Tabapress, pp. 17–40.
López Gómez, A. 1996. «Un canal madrileño caso olvidado: el de Cabarrús en el río Lozoya». In *Boletín de la Real Academia de la Historia*, III, 393–442.
López Gómez, A. 1998. «La navegación por el Tajo: el reconocimiento de Carduchi de 1641 y otros proyectos». *Real Academia de la Historia.* Madrid.
López Gómez, A. et. al. 1998. «Felipe II y el Tajo». In Martínez Millán, J. (dir): Felipe II (1527–1598). En *Europa y la Monarquía Católica*. Madrid: Ed. Parteluz. vol. II: 501–525.
Macías, J. Mª. y Segura, C. (Coords.). 2000. *Historia del abastecimiento y usos del agua en la Villa de Madrid*. Madrid: Conf. Hidrográfica Tajo y Canal Isabel II.
Martínez Alfaro, P. 1977. «Historia de los abastecimientos de agua a Madrid", *Anales del Instituto de Estudios Madrileños*, XIV: 29–52.
Mesonero Romanos, R. 1861 (1976). *El antiguo Madrid. Paseos históricos, anecdóticos por las calles de esta villa*. Ed. facsimil. Madrid: Ediciones Ábaco.
Núñez de Castro, A. 1675. *Sólo Madrid es Corte*. Madrid: Roque Rico de Miranda. Ed. facsímil. Valencia: Librerías París-Valencia.
Palalacio Atard, V. 1998. *La alimentación de Madrid en el siglo XVIII.* Madrid: Real Academia de la Historia.
Pérez Boldo, A. and Arroyo Ilera, F. 2003–2004. *Madrid: Agua, Corte y Capital en los Siglos XVI al XVIII. Boletín de la R.S.G.*, CXXXIX-CXL: 175-210.
Pinto Crespo, V. *et al*. (dir.). 2010. *Los viajes de agua de Madrid durante el Antiguo Régimen*. Madrid: Fundación Canal. Canal de Isabel II.
Pinto Crespo, V. *et al*. (dir.) 2015. *Historia del Saneamiento de Madrid*. Madrid: Fundación Canal.
Ringrose, D. R. 1985. *Madrid y la economía española 1560–1850.* Madrid: Alianza Editorial.
Sánchez Peral, J. L. 2018. *El canal del Henares. Estudios de un proyecto de regadío en la Campiña del Henares.* Doctoral Thesis (UAM).
Troll, C. y Braun, C. 1974. «El abastecimiento de agua de la ciudad por medio de qanates a lo largo de la historia (Madrid)». *Geográphica*. 1–4: 235–314.
Thomas, H. 1988. *Madrid. Una antología para el viajero.* Madrid: Grijalbo.
Viñas Mey, C. y Paz, R. 1949. *Relaciones de los pueblos de España ordenadas por Felipe II.* Madrid. CSIC. Provincia de Madrid.

Thirsting for Efficiency: Technological and Transaction-Cost Explanations for the Municipalisation of Water Supplies

Álvaro Ferreira da Silva

Abstract

This chapter advances two main explanations for the waterworks' municipalisation trend after the late nineteenth century. On the one hand, the importance of abundant water in sustaining the technological innovation behind the new sewerage system. On the other hand, the difficulties in designing a proper regulatory framework for private firms in the water industry motivated by the high transaction costs in designing and enforcing contracts. Paradoxically, this argument is based on the study of a European city where private ownership and operation subsisted until the late twentieth century. Asking why Lisbon failed the municipalisation trend flips the conventional question on the reasons for increasing public ownership in water supplies. In a similar way to the deployment of counterfactual arguments for dealing with research questions, asking why municipalisation did not occur is similarly relevant, and perhaps even more illuminating in explaining the municipalisation movement.

1 Introduction

Large transport, sanitation and energy infrastructure projects changed the way of life during the nineteenth century. Railways by the mid-nineteenth century, gas and then later electricity in the late nineteenth and early twentieth centuries, water supply in the second half of the nineteenth century, all began creating the networked city and the spaces within it that characterise modern life (Tarr and Dupuy 1988). These different infrastructure projects started out and flourished as private

Á. F. da Silva (✉)
Nova SBE (Nova School of Business and Economics), Carcavelos, Portugal
e-mail: alvaro.silva@novasbe.pt

A. Duarte Rodrigues and C. Toribio Marín (eds.), *The History of Water Management in the Iberian Peninsula*, Trends in the History of Science,
https://doi.org/10.1007/978-3-030-34061-2_5

initiatives, challenging, from their inception, the very roots that the classical liberal economy had been building up. At the same time that Ricardo, Say and Stuart Mill were extolling the benefits of competition and the smooth adjustment of atomistic production and consumption, these infrastructures were creating monopolistic operations that not only had potential impacts on consumer welfare, but also large and wide-reaching externalities. These new infrastructure projects were calling into question the assumption that economic policy should be based on distant and benevolent state oversight of private initiative, with management models that would not be radically different from those of past business enterprises.

Railways shaped managerial and corporate finance models (Chandler 1979). Their capital intensity required the creation of more and larger joint-stock companies than any other previous business venture, hence the need to resort to capital markets to finance their construction. Long railway lines and the consolidation of different lines into unified networks created the first complex managerial organisations, foretelling the large multidivisional manufacturing firms to come. Capital intensity remained a shared characteristic with other infrastructure projects.

These large transport, sanitation and energy infrastructure projects relied on stand-alone operations in a specific city or country. However, from the outset, many depended on foreign sources of capital to develop these new ventures in distant locations—peripheral European countries, colonial regions or newly independent countries overseas. New patterns of direct foreign investment and multinationals emerged: free-standing companies (Wilkins 1988), consortia of investors, investment trusts, and dual-board firms (Silva 2014) created a panoply of organisational conduits to channel technology, capital, and management to these stand-alone firms in faraway locations (Lopes et al. 2018).

These infrastructures also shared another characteristic: they required long implementation phases at a time when capital investment in specific assets was at its height. It was during this implementation phase that investment in technology and knowledge became embodied in railway, energy, and sanitation solutions (Casson 1998).

Although this chapter focuses on the establishment of water supply networks, they inevitably shared many characteristics with other infrastructure projects of that period. They did not incur the managerial complexity of railways, but their peculiar economics and managerial challenges were nevertheless similar. Emphasising this lineage puts the water industry into perspective.

A sanitary transformation was in progress across European and North American cities during the second half of the nineteenth century (see Silva 2006 for an overview). Health problems had plagued these cities for many centuries, but they became aggravated when urban growth escalated following the onset of industrialisation. The solution of the problems of epidemic outbreaks in the urban context and the improvement of general living conditions resulted from technological innovations in sanitary equipment (Stine and Tarr 1998). In the nineteenth century, technological innovations in sanitation depended on the introduction of modern water supply and sewerage networks. This chapter argues that technological integration between water provision and sewerage is essential to understanding the municipalisation movement of the late nineteenth century, when public utilities' ownership and management was widely transferred to local public entities (for an overview of the municipalisation trend, see Robson 1935, Falkus 1977, Jacobson and Tarr 1996, and Kellett 1978; for the specific case of water supply, see Millward 2005: 41 ff, Troesken and Geddes 2003, Hassan 1985).

This chapter goes on to argue that improved health conditions also stemmed from organisational innovation in the way that sanitation technology was, in the meanwhile, mastered and synthesised into a solution planned for each specific city in conjunction with its operation management. Thus, the second argument of this chapter addresses the importance of incentives to firms that will ensure they might recover their investments in capital-intensive networks.

The literature on the modernisation of methods of water supply discusses the reasons that public companies took over waterworks from the late nineteenth century onward (see the section "Private or public ownership of water utilities" below). The current scholarship on the municipalisation trend proposes different reasons, but this chapter advances two main explanations: the importance that abundant water had to sustaining the technological innovations behind the new sewerage networks; and a transaction-costs explanation deriving from the difficulties in designing a proper regulatory framework for private enterprises.

The chapter addresses these issues and maintains this conversation with the literature on the municipalisation of water supply from an unusual perspective. Rather than actual municipalisation, it instead discusses the reasons that the water supply remained under private management in Lisbon for more than one century. Studying these reasons holds interest for understanding the specific case of the Portuguese capital city at a time when municipalisation was already widespread. However, the case is first and foremost relevant as a counter-argument for elucidating just why municipalisation occurred in other contexts. In this regard, the conversation with the literature on municipalisation (Sect. 5 below) takes on a particular approach. Instead of looking at cases in which municipalisation occurred, this chapter flips the argument and considers an instance when municipalisation did not happen.

The relevance of explaining the late nineteenth century trend towards municipalisation lies in dealing with a historical conundrum on the private-public relationship over time. This also illuminates current debates around the private and public ownership of water.

2 The Creation of the Water Supply and Sewerage Networks

The sanitary transformation contained two interrelated components. On the one hand, the modern water supply, characterised by water piped into households, relying on centralised and automated water distribution (Tarr 1985). On the other hand, modern sewerage, relying on the introduction of the water carriage system for waste disposal and also based on automated, centralised and capital-intensive systems that deployed water for sewage drainage and disposal (Melosi 1994; Tarr 1984 and 1988). The implementation of these two separate but interrelated services spanned different chronologies (Tarr and Konvitz 1987), with the first cities involved having already implemented a piped water supply to households by the early nineteenth century.

Contrastingly, the water-carriage system for sewage disposal, as a basis for these new sewerage services, emerged only during the second half of the nineteenth century, particularly in the closing decades. This divergent chronology generated consequences for the welfare and mortality of urban inhabitants. Indeed, expanding the water supply without proper sewerage services was responsible for increasing the mortality rate, as water sources steadily became more polluted (Tarr 1996: 8–9).

The interrelationship between water supply and sewerage services stems from the importance of water as an input for sewage drainage. In order to remove solid waste from the toilet flush and sewer pipes, the major technological innovation behind the modern sewerage system incorporated the usage of water as a draining and cleansing agent. This explains why both systems were interrelated in the sanitation system, which may be exemplified in the diagram set out in Fig. 1.

This integrated water and sewerage system depends on the effective functioning of either the water-supply network or the sewerage network. A universal and abundant water supply is critical for the sewerage network, based on the water

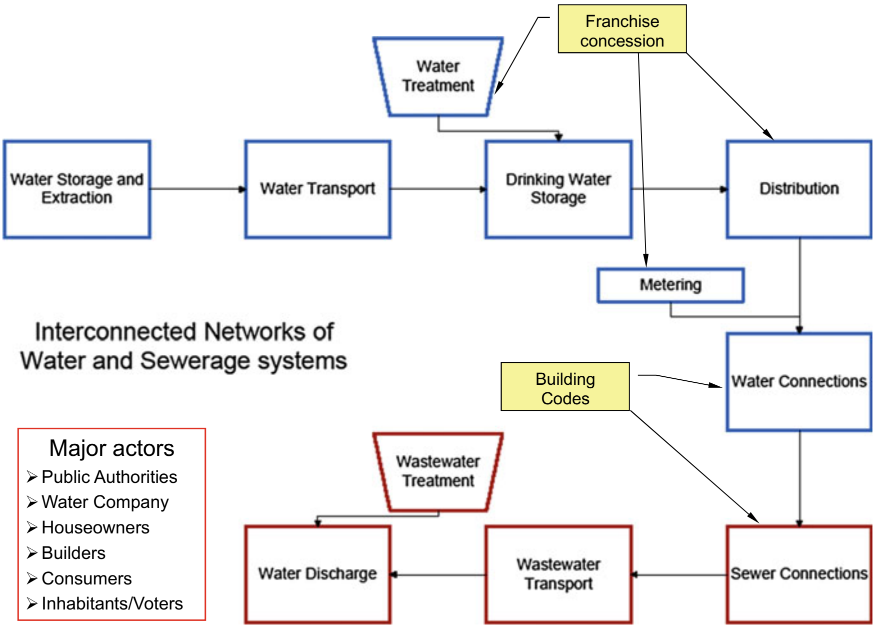


Fig. 1 Interconnected networks of water and sewerage systems

carriage technology. An efficient sewerage network should, furthermore, prevent toxic leakages of sewage from affecting the quality of the piped water. Its careful construction should preclude wastewater overflows whenever storm water drainage is combined with sewage and domestic water within the same sewerage network.

The two different but interrelated networks then interwove a web of contractual and regulatory instances. Each had different managerial and ownership solutions for constructing and running them. At the beginning of the modern water supply, the waterworks were usually private. Contrastingly, sewerage networks were constructed and run by public authorities at the local level. Two different managerial authorities supervised each of the networks, running different contracts with consumers and homeowners/tenants, developers/builders and business consumers. As the financing of sewerage networks was based on taxes, rather than on pricing its usage, inhabitants/citizens became another pole in the transactions associated with this interconnected system. Moreover, the regulatory web of norms and contractual guidelines connected the municipal authorities not only to private water companies, developers and builders, but also to homeowners and tenants.

Separating these interrelated networks between two managerial authorities was deemed an inappropriate solution by Edwin Chadwick, the British mid-nineteenth century reformer. He not only believed that water supply and sewerage represented closely interconnected problems, but also that they required similar technological and organisational solutions, and thus proposed that the same company might provide both ranges of services. Nowadays, it is indeed common for the same company to manage water supply and sewage disposal: Veolia Environment (the incarnation of the old Compagnie Générale des Eaux), Lyonnaise des Eaux, Biwater PLC, Thames Water, Severn Trent, AcquaAmerica, only a handful of names from an extensive list referring to other cases in which management consolidation took place.

In the late nineteenth century, new waterworks were ever more frequently managed by local councils, with the old, private waterworks having been taken over by municipal authorities. This consolidation of water and sewage network management under the same entity—in this case, public, municipal authorities—kept with the trend foreseen by Chadwick half a century earlier. The literature has offered several reasons for this municipalisation process. Before weighing these reasons, we first need to look at the specific economics of water supply, which may illuminate the organisational solutions conceived for its provision.

3 The Economics of Network Utilities and Water Supply

The modern water supply requires a fixed network in order to deliver its services. This networked dimension differentiates between modern waterworks, relying on centralised and automated water distribution, and localised and labour-intensive water supply, typical of the traditional provision by water peddlers who sold water door to door. Considering that this networked characteristic of water supply resembles other utilities, this characteristic similarly implies that coordination of every section of the system is essential to its efficiency. Partial investments in any point of the network only make sense whenever the performance and organisation of the entire system are efficient.

The second characteristic of the modern water supply infrastructure reflects the large amount of capital invested in waterworks (aqueducts, dams, pipes and reservoirs) (Cutler and Miller 2006). It is exemplary of an industry in which the sunk costs are very high, meaning that they cannot be swiftly recovered. The high capital costs prevent any rapid amortisation of the initial investment and exert considerable pressure on the subsequent profitability of the venture. Additionally, the limited cash flows in the first stages of operation generated from water sales are unable to amortise the capital costs, except after the passage of many years.

Investments in waterworks assets are also specific to water supply systems, and hardly transferable to any other economic activity. Waterworks incorporating aqueducts or pipes laid down under streets are almost entirely irrelevant to any purpose other than water supply. The specificity of this investment, the high sums of capital involved, and the concentration of the economic activity in supplying one single good prevent a smooth exit from the industry.

These investments also deploy long life-cycles, typically between 20 and 40 years, which makes it possible to postpone maintenance and replacement investments—and, consequently, to "underfund" such activities—for quite long periods of time.

Finally, and still furthermore, from the perspective of production, the modern water supply is a classic case of a natural monopoly in which a single firm may satisfy the entire local demand at lower total cost than any other combination of firms (Sharkey 1982). The network itself also represents an obvious case in which duplication raises the total costs of supplying a market.

These characteristics of the water supply as a network utility, with high sunk costs, non-redeployable assets and natural monopoly issues, are similar to those of other network industries during the nineteenth and early twentieth centuries. Some are even more greatly exacerbated in other utilities, as is the case with capital intensity and sunk costs. For instance, the electric power industry displayed a much higher intensity of initial capital costs, correspondingly making it harder to pay back capital remuneration over the initial years of operation from cash flows arising from sales (Silva and Bartolomé, forthcoming).

The water industry of this period also displayed certain other specific features when considered from the perspective of consumption. The first comes from its very character as a natural monopoly. A single firm supplying such a good or service might be tempted to abuse its market position through an inclination to levy higher prices.

Another feature within the consumption perspective derives from the positive externalities associated with water consumption. In dealing with nineteenth-century sanitary problems, continuous and abundant water consumption was essential to resolving urban health problems. The introduction of the water carriage system for waste disposal also created an automated, centralised and capital-intensive system through the building of sewers, whose performance depended upon the efficiency of their water supply (Hamlin 1992; Melosi 1994; Tarr 1979 and 1984). The deployment of water as a draining agent in the sewerage system implies that the price could not exclude the population from accessing water, considering its impact on resolving the leading nineteenth century city sanitary problems. In this sense, even if the scope existed for excluding someone from the consumption of piped water—a situation that differs from that which occurs with public goods, such as public lighting and defence, for instance—positive externalities act to potentially provide for the universal consumption of water.

As a rule, markets and private enterprises are much better adapted to supplying goods and services that are strictly private (which allows for the exclusion of any individual consumer). However, considering the positive externalities associated with the universal consumption of water, the public provision of water might therefore be perceived as a possible institutional solution.

4 Transaction Costs and Contracts

The superiority of private management in dealing with water supplies was taken for granted throughout most of the nineteenth century. The provision of water to cities was not considered fundamentally different from other economic activities, provided that several contractual conditions were agreed upon in order to deal with the specificity of the business (Falkus 1977: 140; Millward 1991: 99; Robson 1935: 304). Public administration might provide order, fight against fires, and maintain public spaces, but it should not intervene in other types of initiative. In Portugal, when the piped water supply became a theme of political discussion and decision, private management was also the solution envisioned, even though the arguments were much less insightful in their theoretical defence of the superiority of private undertakings. More critical were the references to the financial burden that any public water provision would create for state financial resources. A private company, able to raise capital by issuing shares to the public, appeared to offer the best prospect for improving the water supply, considering the capital intensity of modern waterworks. The emulation of the technological solutions implemented abroad extended to the governance and institutional model. The first governmental proposal for tendering bids to provide piped water to Lisbon states the importance of supplying water "in the same fashion as used in other European cities, where private companies are responsible for the introduction of new and modern habits in personal hygiene" (preamble to the December 22, 1852 law). The public provision of modern waterworks did not appear to be a solution in the mid-nineteenth century, in contrast to what was the case with the public construction and management of Lisbon's eighteenth-century aqueduct.

However, the production specificities associated with water supply, high sunk costs and the specificity of waterworks led private entrepreneurs to secure their property rights against opportunistic behaviours from the administrative body that granted the franchises. From the point of view of private investors, several dangers might emerge and had to be anticipated. They may be summarised in two instances. The first encapsulated the need to reward such a high and specific investment. The administrative guarantee of a minimum rate of return to the investment might have represented a solution to this problem, as was indeed usual in the railway transport sector. Another solution might have involved an extension in the limited franchise monopoly, securing property rights and giving the time for long-term strategies for recovering capital and profits, in keeping with the life-cycle of water networks. As the business was new and needed an extended period to mature, these concerns about capital return were also inescapable. In addition, the municipality represented one of the main clients for water supply. Thus, the company feared becoming a hostage, whether of the local administration or of decisions made by the central government. As the specific features of the assets prevented any exit from the business, strong incentives existed for trying to draft very detailed contracts that strove to cover any possible situation that might lead the firm into such a hostage position.

From the consumer's point of view, the private management of the water supply incurred two major shortcomings, even if they were susceptible to circumvention through contractual regulation. Firstly, a monopoly firm with a long-term contract raised the possibility of abuse of its market position, increasing prices or lowering the service standard. In a second instance, the introduction of piped water sought to boost the quantity and the quality of the water supplied, considering the positive externalities associated with the improvement of sanitary conditions. Therefore, the private operation of the water supply was to consider this general goal when developing the works intended to introduce larger quantities of water into the city and make the service available to the entire population. The franchise contracts tried to address the first problem through price regulation. In order to face the second problem, the contracts tried to secure the investments necessary to increase the quantity and quality of the water supplied in line with population growth, stipulating, for instance, a minimum quantity of water provision, whether in bulk terms or per capita.

The problem facing investors and the administration involved devising an institutional device that might balance different interests and powers. This tension between the investor and the consumer could be sidestepped by state ownership, which, furthermore, held the coercive power to finance the sunk capital without requiring the assurance of future returns from the utility. Alternatively, it might attempt to reconcile private ownership with the political power of consumers through the private franchise monopoly. In either case, the water supply networks would operate under the terms set by the state.

In the mid-nineteenth century, private operation under limited franchise monopoly constituted the most prevalent institutional alternative. This owed much to the then-contemporary experiences of railroad construction and operation, as well as to the theoretical principles associated with the work of Edwin Chadwick. He differentiated traditional market competition, "competition within the field," which assumed a large number of firms competing in the market, with his new concept of "competition for the field," based on competition between several bidders to gain the exclusive right to supply water to the entire local market (Demsetz 1968; Ekelund and Herbert 1990). This competitive bidding process would, in a certain way, replicate the social efficiency of "competition within the market." However, the efficiency of the competition-for-the-field approach ultimately depended on the contractual terms, the power of vested interests, and information on the industry.

The design of contracts is always imperfect, as is the information held on every possible issue as well. Institutional economics stresses the importance of bounded rationality, or the costs of acquiring and processing information, and opportunism, or the use of astuteness or fraud to distort outcomes to the benefit of one party. The problems associated with contracts for regulating water supply involved these two features. The regulation of the modern water supply has to deal with asset specificity on the part of the utility, bounded rationality on the part of the regulator and the concessionaire (incomplete and costly information about the options open to the utility and the prevailing forecasts) and opportunism by both parties. Regarding opportunist behaviour, private enterprise attempts to deliver those services that are the most profitable, rather than the most socially inclusive. The regulator's opportunism takes advantage of the costly investment in sunk and specific assets to threaten the company, reneging on contractual clauses or trying to renegotiate contracts in such a way that the utility fears becoming a hostage of the regulator. In summary, a network utility such as a modern water supply involves excessively high transaction costs.

This synthesis of the characteristics of water supply points out the reasons for the necessity of public regulation. In the late nineteenth century, public supply eventually became a realistic solution to the problems associated with providing such a good. The next section summarises the reasons for the trend towards municipalisation.

5 Private or Public Ownership of Water Utilities

The perception that the water industry had to choose a different tack in regard to economic activities than the usual market approach led to a strong movement towards public ownership of the water supply. Indeed, in the late nineteenth century, this trend towards municipalisation occurred in a number of different Western countries (for data on the USA, see Masten 2010; for Britain, see Millward 2000).

The timing and impact of regulation, firstly, and public ownership later has already been well documented (see Millward 2005: 36 ff). The explanations are, nevertheless, more contentious. The evolution from private to public ownership sometimes appears in almost whiggish tones as some inescapable trend towards social modernisation (Jacobson 2000). However, other instances stress ideological reasons while invoking the impact that progressive politics had on defending public control and ownership of waterworks (Hohenberg and Lees 1985: 317–8).

Abuses by private concessionaires, taking advantage of their monopolistic positions, constitute another reason sometimes put forward for including the integration of gas works in the same municipalisation trend (Moorhouse 1986; Millward and Ward 1993).

Other explanations for market failure also feature among the stated reasons for the advance of public waterworks after the late nineteenth century. The positive externalities deriving from universal water supply is one such factor, often emphasising the impact of clean drinking water in reducing epidemics (Melosi 2000; Spar and Bebenek 2009; Tarr 1996; Troesken 1999). Access to capital sources may also represent a case for market failure whenever private ventures lacked easy access to funding. In contrast, public authorities are generally better positioned to attract the confidence of investors, especially in the case of substantial investments (Cutler and Miller 2006; Hassan 1985; Melosi 2000). Finally, institutional reasons might prevent adequate private sector incentives for pursuing the long-term investments compatible with the life-cycle of waterworks. Therefore, regulatory failure over private enterprises (Millward 2005) or increasing regulatory pressure (Troesken 1997) might constitute powerful forces that lead to municipalisation just as much as market failure in capital access or externality issues.

The above explanations mobilise significant contributions to understanding how public policy addressed water supply in ways that are different from approaches to other ongoing market activities. However, as argued by Troesken and Geddes (2003), there is no clear evidence as to just why the public takeover of waterworks emerged as a better option than private management for dealing with the positive externalities of supplying quality drinking water. As they detail: "[A]lthough it is possible that subsidising private companies was politically unpopular and therefore unlikely, this suggests a contractual or political failure, not a market failure" (Troesken and Geddes 2003: 377).

The externalities argument proposed in the literature concerns the quality of water provided to city dwellers, emphasising the positive impact of modern water provision in decreasing mortality and improving urban health. However, this does not especially encapsulate how the water-carriage system of waste disposal of modern sewerage networks depended on water supply. The water carriage system was the technological innovation capable of solving the centuries-old problem of the disposal of sewage and domestic waters. The universal provision of water to city dwellers had positive externalities other than those usually associated with drinking water quality. The use of municipal ownership and control in order to obtain abundant and universal water supply for the modern sewerage system represented one major reason for the taking-over of private waterworks.

In addition, the explanations above fail to incorporate the difficulty in designing a regulatory framework for defending public interests and the positive effects of water supply under a private management regime. High sunk costs and non-redeployable assets rendered private companies vulnerable to administrative opportunism, as already mentioned above. Franchise contracts might stipulate clauses preventing administration authorities from engaging in opportunistic behaviours such as seizing control of the waterworks or imposing abusive rates. Such might also be the case for protecting consumers through imposing rate caps and standards of service. However, not only were the transaction costs quite high, the bargaining and other recurrent conflicts were also so intense that municipalisation may have emerged as the most efficient perceived solution for dealing with the difficulties in regulating private water supply (Troesken and Geddes 2003; Masten 2010).

The next section adopts the case of Lisbon for exploring the difficulties encountered in designing a regulatory framework for solving the peculiar economic characteristics of water supply, while defending public interest and consumers from abuse and ensuring the property rights of private companies.

6 Designing the Regulatory Framework

The growth and development of the Lisbon water supply has been addressed by several studies. Saraiva (2005), Schmidt (2011), and Saraiva et al. (2014) deal with the technological transformations in this supply and their relationships with the politics that prevailed in nineteenth and twentieth century Lisbon. Other research findings propose more economic and managerial perspectives for understanding why these technological changes took on certain specific institutional and regulatory forms (Silva and Matos 2004; Silva 2006 and 2007). The following paragraphs synthesise the main issues covered by these latter studies.

In Lisbon, the modernisation of the sanitation infrastructure follows the usual chronology: first, the transformation in the water supply, with the franchise tender settled in 1856; subsequently, the modernisation of the sewerage network, with the first plan approved in 1880, even though the actual construction works were delayed for years. The time lag between the technological transformation in the water supply and sewage disposal is similar to other cases and turns out to be not as large as those in certain metropolises, such as London or Paris.

The institutional models also bear similarities to other Western European and American cities: concession contracts signed with a private company for water provision and the public construction and management of the sewage network. The first joint-stock company for providing Lisbon with a water supply network was founded in 1857. Unlike other infrastructural projects in Portugal at that time (for instance, the railways or gasworks), the new Companhia das Águas de Lisboa (Lisbon Water Company) was a Portuguese firm, without any foreign capital involvement in meeting its statutory equity requirement of 1500 contos (ancient Portuguese currency equivalent to c. £350,000), thus, one of the largest limited liability companies in Portugal outside of the finance industry. Proposals from British financiers and engineers with considerable experience in similar works in other cities were thereby rejected, in favour of a domestic proposal, with a governance model prohibiting the concentration of capital into any one single shareholder. The undercapitalisation of the company and its lack of engineering experience delayed the project, and even led to the brief municipalisation of the waterworks between 1863 and 1867, before they were returned to a relaunched Lisbon Water Company, under new management and with greater financial and engineering muscle.

Notwithstanding these delays and all of the financial and technical difficulties, the waterworks remained under private management until 1975, when the concession contract came to an end within the context of the 1974 democratic revolution in Portugal. Throughout various decades, the private company was able to survive the project management strains of its early decades (1858–1880), the regulatory turmoil experienced in the same period, the economic consequences of World War I and the impact of the post-1919 inflationary surge (Amaral and Silva 2014).

The regulatory uncertainty of the initial decades is particularly interesting to this argument. The renegotiation of the tender clauses between the government and the private company lasted for a further two years after the tender decision in 1856, with the regulatory framework continuing to change systematically over the next four decades. The difficulties in designing contracts that secured the rights of both consumers and private investors, as well as providing assurances against opportunistic behaviours, whether undertaken by the administration or the private company, underlie the volatile contractual situation experienced immediately after the 1856 franchise tender (details in Silva and Matos 2004: Table 3).

This permanent series of negotiations was an experimental approach to designing a regulatory framework for water supply in a situation marked by uncertainty and recurrent conflicts between the municipality and the private company. For instance, the very first tender (1852) included almost no contractual conditions for participants in the competitive bidding process, setting only the period for the concession (20 years, remarkably short for waterworks investments) and the volume of water to be provided (also quite small). The next tender (1855) constitutes a turning point in water supply regulation, introducing the conditions usually established elsewhere for such water supply concessions, which had been absent from the previous tenders simply due to government inexperience in this type of agreement (see Silva and Matos 2004 for the influence of foreign entrepreneurs on the terms of the 1855 tender). For the first time, the terms of the bidding process incorporated the main items of any other contract in effect throughout the second half of the nineteenth century: price regulation (a water price cap) and a standard of service (the minimum volume of water per head to be provided by the company). This standard of service was to be maintained irrespective of any increase in the resident population, thus introducing a dynamic factor into regulating the minimum quantity of water per inhabitant. The bidding terms even included a clause precluding opportunistic behaviours by the franchised firm: for the final five years of the contract, the municipality had to act to control attempts by the firm to lower its standard of service and ensure its conformity. Finally, the contract stated that the municipality would receive any water needed for public service, except for the water used for cleaning sewer pipes.

Price regulation, combined with a predetermined service standard, was thus the regulatory method devised, and it correspondingly rejected the scope for having a rate-of-return alternative. Setting a maximum price sought to prevent the company from exploring its monopolistic position. The standard of service, defined by the minimum quantity of water for supply to the city, attempted to deal with the positive externalities inherent to water supply. A new contract in 1867, four years after the municipality took over managing the company (see Silva 2004 for details), increased the minimum quantity of water per head and per day by more than 60%, even though the clause requiring the maintenance of the service standard irrespective of the population increase disappeared. The implicit assumption was that the new quantity cap provided more than enough water for the population's needs, even in the case of growth. Such an increase in the previous minimum threshold constituted a strong argument deployed by the company to secure the concession in the wake of the 1864–1867 crisis. Abandoning the standard-of-service clause represented a significant change, as this left the administration without a contractual device for controlling the company's performance, despite its long contractual lifespan (99 years).

The new 1867 contract introduced a more important new feature: compulsory piping, stating that any new building erected in the city after 1872 was to have piped water. Compulsory piping was a means of shaping and maintaining a substantial consumer base (also becoming a rule in the first contract for the Oporto concession in 1882). From the company's perspective, this clause might constitute the corollary of price regulation. As the government did not guarantee the rate of return, enlarging the consumer basis by administrative, as opposed to market, means was critical to the company, due to the significant investments needed in the waterworks in order to modernise the water supply.

The new contractual clause imposing compulsory piping for any new building did not go unchallenged. The city council, trade associations, homeowners and builders stood up in resistance. The company applied the most effective weapon it had: it stated that, should the contractual clause fail to be applied, work on the new Alviela waterworks would stop. The ultimatum was successful, and the compulsory piping regulation received approval in 1880.

Finally, the 1867 contract also introduced a new institutional arrangement for providing public control over company operations. The 1855 clauses for the tender bid stipulated that the government and the municipality should have two representatives on the company's board. The substantial municipal assets (the former waterworks belonging to the Aqueduto das Águas Livres) that the Lisbon Water Company controlled for the duration of the concession justified the presence of these delegates. In 1867, an independent body—a control committee—with members appointed by the government and the municipality was set up to scrutinise company activities (construction of the waterworks, maintenance, operation, levels and quality of service). In order to deal with any disputes between the administration and the company, this also established an arbitration committee. Nevertheless, the activities of these two bodies left no documented traces.

These contracts and the other regulatory devices did not prevent future conflicts between the private concessionaire and the administration, mainly with the city council. The 1858 contract was very detailed when compared with the government's terms of reference for the 1852 contest. The 1867 contract became even more comprehensive. These contracts underwent discussion for years in a situation that was repeated for the contract signed between the municipality of Oporto and the French water supply concessionaire. However, either the municipal council or the company did not anticipate every possible situation that might appear in the prevailing relations, whether between the company and its customers or the company and the public administration. The perfect contract, one regulating the concession to the private company while capable of securing the business expectations of a new industry alongside the prospects for consumers, simply lay beyond their capacities.

The most important reasons for these conflicts between regulator and concessionaire have been explored elsewhere (Silva 2004, 2007). These recurrent disputes revolved around several issues: the abovementioned compulsory piping for any new building; the waterworks enforced by the concession and the works actually accomplished by the company; the quantity of water provided; the expropriation of private water sources by the company; the enforcement of rights of way; the company use of public resources such as streets; and the water consumed by the administration in addition to the free quota defined by the contracts.

At different times and in different ambiences, clashes between the municipality and the company would erupt. One of the most frequent reasons stemmed from calculating the water consumed by the public administration. According to the contract, the administration should receive a certain amount of water for free. Any excess would be charged at a reduced price (as a rule, half the average private consumer tariff). Up until World War I, public consumption represented about 60% of total water consumption in Lisbon. After accumulating several years of municipal debt owing to disagreements about the levels of public consumption required to be paid beyond the volume of water supplied for free, conflicts erupted. The accumulation of municipal debt compromised the company's operations and deeply stressed the relations between the private enterprise and the city council.

The public administration, on the one hand, had regulatory power over the company and, on the other hand, by far accounted for the largest share of total consumption. The peculiar relationship between the water company and the local administration explains the recurrence of the disputes between the company and the municipality, their bitterness, and even, at times, their virulence. The municipal administration being the company's largest customer and, simultaneously, its principal debtor effectively poisoned the relations between them. This peculiar relationship between client/regulator and utility constituted an additional motivation that consistently drove the former's desire to take over the private company. In addition to any public health reasons, which might arise from better, cheaper and extended water provision, the efforts that the municipality undertook to control the water supply at several points in time can only be explained by the intention to centralise, within the same body, the administration of a service that had the city council as its main consumer.

7 Why Was the Water Supply Not Municipalized in Lisbon?

The reasons for the recurrent conflicts between the administration and the concessionaire confirm the difficulty in designing an efficient regulatory framework and, therefore, sow potential ground for a municipal takeover. The most durable and serious conflict between the state and the company occurred between 1863 and 1867. However, for financial and technological reasons, the 1860s was simply too soon for municipalisation to take place. Firstly, the company would have had to engage in a lengthy judicial process with the municipality in order to receive compensation for the investments already made. Furthermore, urgent work was needed to modernize the water supply that extended far beyond the financial revenues of the municipal council. Resorting to financial markets would become an option after 1880, a period when the municipality made recourse to this channel to fund major works in Lisbon. However, this was not possible in the late 1860s (Silva 2004).

Secondly, the time was not yet right for technological reasons as well. Contrary to other interpretations of the driving impulse generated by positive externalities for municipalisation (see the references mentioned above, notably, Melosi 2000), the main impact of the modern water supply on improving the sanitary conditions arose via the role of water in the sewerage network. The water carriage sewer system did not appear to be a real technological solution in the Lisbon of the 1860s. At the time, every proposal for improving sewage disposal contemplated manual cleaning, without any recourse to water as a draining agent. Any defence of the water-carriage system as a new technology suitable for dealing with sewage problems was absent from the feasible solutions perceived at that time. Only in 1880 did the first project for installing a modern sewerage network become approved for Lisbon (Silva 2006). To sum up, the technological push for municipalisation simply did not exist in the 1860s.

In 1867, the best option for the government and the city council was to reach an agreement that would engage the private company in a programme of significant investments to solve the water scarcity problem in Lisbon. The 1867 concession contract resulted from this agreement. This was responsible for providing the private company with significant incentives to continue its activities for at least the current cycle of the waterworks' lifespan (about 40 years). This new contract also established the means for protecting the private company from future takeovers through providing a long-term economic base. The critical issue introduced was the compulsory connection to the company's water mains in the case of any new building, together with a tightening of the monopolistic supply (independent water-carriers selling water home to home were banned and the number of public fountains was frozen).

The specific economics of water supply are important for understanding how the Lisbon Water Company avoided municipalisation. Water supply depends on access to natural resources such as water sources, as diminishing resources are a logical result of the expansion of the network (Millward 2005: 52). The water supply had not experienced any corresponding trend towards cost reductions driven by technical progress, as other utilities had at the time (for instance, gas or electricity supply). In order to cope with the rising population and maintain the same standard of service, companies would have to increase investments in distant water sources, extend the pipe networks and potentially engage in more expensive water filtration and purification (see Millward 2005: 51 ff, for these economics). Indeed, to speak about economies of scale in water supply is misleading. What was important was the attainment of the network economies, backed up by the contiguity of potential consumers to the existing piping network.

From this perspective, private water companies critically had to secure a large number of consumers in those streets served by water mains. This represented the best approach to taking advantage of the economies of contiguity in the network and recovering the investment in the waterworks. The functioning of market mechanisms to attract consumers, on a one-to-one basis, would lead to the long-term recovery of investments. The price ceiling in the concession contract prevented any increase in the revenues. The rigid costs did not benefit from any trend towards decreasing due to technical or organizational innovations. This dilemma affected private companies across many cities (Millward 2000 and 2005: 26 ff; Troesken and Geddes 2003; Masten 2010), but was even more pressing in cities of low-income countries such as Portugal.

The solution would arrive with some corrective measure, which might evade the strict market constraints and enlarge the consumer base by administrative means. Compulsory piping was the administrative solution contractually introduced in 1867. From the perspective of the company, this clause constituted the corollary to price regulation. As the government did not guarantee the rate of return, enlarging the consumer base by administrative, and not by market, means was critical to the company, due to the significant investments required by the waterworks to collect water from Alviela. Compulsory piping provided the company with a means to support investment and to attain a comfortable economic and financial position after the 1880s. Every financial indicator aligned to the positive side: a rising number of consumers, the first profits, and the first distribution of dividends. Insulation from municipalisation thus resulted from providing this administrative means of enlarging the consumer base.

The importance of compulsory piping in the enlargement of the consumer base should not be exaggerated. In fact, without an adequate tariff policy, this administrative measure would have failed. The 1867 contract stipulated compulsory piping, but householders were not obliged to become customers and to consume piped water. They could have simply continued to rely on public fountains. As a result of compulsory piping, the number of consumers doubled from 1880 to the end of the century (Silva 2007: Table 8). However, the levels of water consumption per head and per day displayed a constant downwards trend through to the end of the century. Only when a new tariff with a double objective—a minimum level of water consumption and regressive tariffs—was introduced in the 1898 contract revision did water consumption per capita start to grow. The combination of compulsory piping and a new pricing framework fostered the conditions for securing a sizeable number of domestic consumers and a substantial increase in water consumption per household.

The other solution would be municipalisation, as argued by Millward (2005: 53–4): “A great deal of uncertainty therefore surrounded the operation of companies dealing on a one-to-one base with households, some of whom would be reluctant to make the necessary investments. A great attraction of municipal operation was that it involved the finance of water services to households by a water rate, that is, a price related not directly to the volume of household water consumption, but to the value of local property (…). By such a uniform levy, councils automatically enrolled all ratepayers on to the water undertakings’ books.” Even if tariffs were the pricing method, instead of the water rates based on property value as in Millward’s argument, municipalisation would use administrative means to enlarge the consumer base. After integrating water and sewerage networks under the same management, the administrative enforcement of a household connection to the municipal water network would be justified by the need to access the vital means for leveraging the technological advantage of the modern sewage disposal technique.

8 Conclusion

This chapter seeks to participate in the debate on the reasons for the municipalisation movement across late nineteenth century European and North-American cities. At a time when liberalism was influencing economic policies, and with the state retreating from direct intervention in economic activities (Sutcliffe 1982), the urban context became more than a laboratory for public management. The mass movement to take over water utilities, as well as the similar, although less intense, push in urban transportation and energy supply, represented more than separate experiments. “The urban variable” explained this propensity for increasing levels of state intervention in different fields of urban life, from utilities to the environment (Silva 1994; Silva and Sousa 2009). Urban agglomerations were, in different ways, catalysts of positive and negative externalities, demanding different types of public intervention. One of these was a clear trend for the public ownership and management of waterworks in the wake of several decades of arm’s length regulation.

Asking why Lisbon failed this trend towards water municipalisation reverses the initial question about the reasons for the municipalisation movement. Flipping the question is, nevertheless, similarly relevant, and perhaps even more illuminating. This may lead the argument through different but clearer perspectives, in a similar way to deploying counterfactual questions and arguments for dealing with research conundrums.

The absence of any water supply municipalisation in Lisbon did not result from any atavism regarding state intervention in urban affairs. This absence becomes even more surprising when one considers that late nineteenth-century Lisbon had experimented with urban planning through the expropriation of land (Silva 2004). This represents one of the most radical models of urban land management, with the municipality acting as a developer: firstly, expropriating large tracks of land, and then building public infrastructures on the ground prior to the sale of lots to builders.

In Lisbon, the absence of municipalisation stems from two main reasons, which thus also testify to why this occurred in other urban contexts: the technological integration between the water supply and sewerage networks and the high transaction costs posed by the regulatory regime for private water companies. These reasons were not unique in the sense of excluding the impact of other motives. The combination of social and political environments conducive to greater public intervention in urban affairs, as well as the financial and political autonomy of city councils, also played a role in nurturing conditions more favourable to municipalisation.

The literature on the evolution of sanitation technology has argued convincingly in favor of the interdependence between water supply and the technological solution for sewage disposal problems. This argument fails to appear in the debate on the reasons for municipalisation. When positive externalities are proposed, they emerge from the failure of private companies to provide adequate quality and socially inclusive piped water. The interconnection between water and sewerage was the most important source of positive externalities in the water supply and contributed to raising municipalisation as a potential solution for the shortcomings of private provision.

However, the externalities argument, based on the interconnection between water and sewerage networks, would not inexorably lead to municipalisation. An effective regulatory regime based on contractual agreements and constant overseeing by administrative bodies, similar to those existing in Lisbon following the 1867 contract, might attain the objectives of providing universal access to water, maintaining the profitability of the private undertakings, and preventing abuses of monopolist positions. In theory, public subsidies might also support access to private water provision by poor households. However, the efficiency of any regulatory regime for supervising private water companies turned out to be an illusion. Recurrent conflicts and bargaining manoeuvres, whether from the company or the municipal council, constantly contaminated relations between regulator and concessionaire.

Internalisation is a typical alternative to contracts when there are situations of high transaction costs and externalities (Coase 1937; Williamson 1975). Internalisation occurs whenever public ownership and management took over water supply networks. Consolidating the water supply and sewerage networks under public management would appear to solve the high transaction costs incurred in relations between private concessionaire and administration. Internalisation and consolidation under the same managerial authority would cope with the high transaction costs related to the regulation of the water component in the water and sewerage system.

Managerial consolidation under public ownership would also provide a solution to another issue besetting private water networks. The water supply did not have economies of scale, but rather economies of contiguity. Rapidly increasing the number of households connected to the water mains on any given road would represent the best mechanism for recovering capital investment and attaining an average rate of return for private investors. Concessionaire companies relied on the atomistic capture of consumers, based on one-to-one decisions to contract the piped water supply service. This atomistic process was slow, spread across the area served by the private concessionaire, and plagued by uncertainty. Municipal ownership of waterworks could mobilise administrative means for enforcing connections for every household to the water network. Other administrative apparatuses, such as building codes, the establishment of household water pipes and connections with the water and sewerage networks, could then also be mobilised to enforce standards and practices. Even while relying on tariffs (and not on taxes or rates), the public company might design a tariff regime based on a low, flat rate for domestic consumers with low consumption patterns and regressive tariffs for more affluent or business consumers. In this way, the desideratum of universal coverage could be rapidly attained, simultaneously permitting a more rapid amortisation of capital costs. Furthermore, the ultimate aspiration of enlarging the consumer base would also be accomplished.

In Lisbon, private management persisted, but based on an administrative device to recover sunk costs and insulate the company from municipalisation. Compulsory piping acted as an administrative solution to attaining a large consumer base, thus allowing the company to benefit from the economies of contiguity outlined above. This did not end the conflicts or the bargaining between the company and the administration. However, it strengthened the financial position of the company when finally implemented. The substantial increase in the volume of water after 1880 occurred in simultaneity with this implementation. The large volume of piped water flowing into the city encountered the administrative mechanism that created the consumer base that it needed.

References

Amaral, Luciano and Silva, Álvaro Ferreira da. 2014. "War Finance (Portugal)," in Daniel, Ute *et al.* (eds.), *1914-1918-online. International Encyclopedia of the First World War*. Berlin (https://encyclopedia.1914-1918-online.net/article/war_finance_portugal?version=1.0).

Casson, Mark. 1998. "An Economic Theory of the Free-Standing Company," in Mira Wilkins and Harm Schröter (eds.), *The Free-Standing Company in the World Economy, 1830–1996*. Oxford: Oxford University Press, 99–128.

Chandler Jr, Alfred D. 1979. *The Railroads, pioneers in modern management*. New York: Arno Press.

Coase, Ronald H. 1937. "The nature of the firm." *Economica*. 4(16): 386–405.

Cutler, David and Grant Miller. 2006. "Water, Water Everywhere: Municipal Finance and Water Supply in American Cities," in E. L. Glaeser and C. Goldin, *Corruption and Reform. Lessons from America's Economic History*. Chicago: The University of Chicago Press, 153–85.

Demsetz, Harold. 1968. "Why regulate utilities?" *The Journal of Law and Economics*, 11(April): 55–65.

Ekelund Jr., Robert E. and Robert F. Herbert. 1990. *A History of Economic Theory and Method*. New York: McGraw-Hill International Edition.

Falkus, Malcolm E. 1977. “The development of municipal trading in the nineteenth century.” *Business History*, 19(2): 134–161.
Hamlin, Christopher. 1992. “Edwin Chadwick and the engineers, 1842–1854: the systems and antisystems in the pipe-and-brick sewers war.” *Technology and Culture*, 33: 680–709.
Hassan, J. A. 1985. “The Growth and Impact of the British Water Industry in the Nineteenth Century.” *The Economic History Review*, 38(4): 531–47.
Hohenberg, Paul M., and Lees, Lynn Hollen. 1985. *The making of urban Europe, 1000–1950*. Cambridge (Mass.): Harvard University Press.
Jacobson, Charles D. 2000. *Ties that bind: economic and political dilemmas of urban utility*. Pittsburgh: University of Pittsburgh Press.
Jacobson, Charles D. and Joel A. Tarr. 1996. “No Single Path: Ownership and Financing of Infrastructure in the 19th and 20th Centuries,” in *Infrastructure Delivery: Private Initiative and the Public Good*. New York: World Bank Publications.
Kellett, J. R. 1978. “Municipal Socialism, Enterprise and Trading in the Victorian City.” *Urban History Yearbook*, 5: 36–45.
Lopes, Teresa Silva, Casson, M., and Jones, G. 2018. “Organizational Innovation in Multinational Enterprise: Internationalization Theory and Business History.” *Journal of International Business Studies*. https://doi.org/10.1057/s41267-018-0156-6.
Masten, Scott E. 2010. “Public Utility Ownership in 19th Century America: The “Aberrant” Case of Water.” *Journal of Law, Economics, & Organization*, 27(3): 604–54.
Melosi, Martin V. 1994. “Sanitary Services and Decision Making in Houston, 1876–1945.” *Journal of Urban History*, 20(3): 365–406.
Melosi, Martin V. 2000. *The Sanitary City: Urban Infrastructure in America from Colonial Times to the Present*. Baltimore: Johns Hopkins University Press.
Milward, Robert. 2000. “The political economy of urban utilities,” in Martin Daunton (ed.). *The Cambridge Urban History of Britain*, vol. 3. Cambridge: Cambridge University of Press, 315–350.
Millward, Robert. 1991. “Emergence of gas and water monopolies in nineteenth-century Britain: contested markets and public control.” in James Foreman-Peck (Ed.), *New perspectives on the late Victorian economy. Essays in quantitative economic history*. Cambridge: Cambridge University Press.
Millward, Robert. 2005. *Private and Public Enterprise in Europe. Energy, Telecommunications, and Transport, 1830–1990*. Cambridge: Cambridge University Press.
Millward, Robert and Robert Ward. 1993. “From Private to Public Ownership of Gas Undertakings in England and Wales, 1851–1947: Chronology, Incidence and Causes.” *Business History*, 35(3): 1–21.
Moorhouse, John C. 1986. *Electric Power: Deregulation and the Public Interest*. San Francisco: Pacific Institute for Public Policy Research.
Robson, William A. 1935. “The public utility services,” in H. J. Laski, & et. al. (Eds.), *A century of municipal progress, 1835–1935*. London: George Allen & Unwin Ltd.
Saraiva, Tiago. 2005. *Ciencia y ciudad: Madrid y Lisboa, 1851–1900*. Madrid: Centro Cultural del Conde Duque.
Saraiva, Tiago, Schmidt, Luísa, and Pato, João. 2014. “Lisbon Water Regimes: Politics, Environment, Technology and Capital (1850–2010).” *Flux* 3: 60–79.
Schmidt, Luísa, Saraiva, Tiago, and Pato, João. 2011. “In Search of the (hidden) Portuguese urban water conflicts: the Lisbon water story (1856–2006),” in Barraqué, B. *Urban Water Conflicts*. London: Taylor & Francis, 69–91.
Sharkey, W. W. 1982. *The Theory of Natural Monopoly*. Cambridge, Cambridge University Press.
Silva, Álvaro Ferreira da. 1994. “Modos de regulação da cidade: a mão visível na expansão urbana.” *Penélope* 13: 121–146.

Silva, Álvaro Ferreira da. 2004. "Running for money: municipal trade in Lisbon (1860–1910)," in A. Giuntini, P. Hertner e G. Núñez (eds.) *Urban Growth on Two Continents in the 19th and 20th Centuries. Technology, Networks, Finance and Public Regulation*. Granada: Editorial Comares, 85–116.

Silva, Álvaro Ferreira da. 2006. "Sanitary revolution and technology in nineteenth century Lisbon," in Michèle Merger *et al.* (eds.), *Les transferts technologiques dans l'espace méditerranéen. Perspectives historiques à long terme*, Paris: CNRS, 391–414.

Silva, Álvaro Ferreira da. 2007. "The peculiar customer: conflicts of power and the modern water supply system in Lisbon," in Denis Bocquet (ed.), *Réseaux techniques et réseaux de pouvoir dans les villes européennes (XIXe siècle-début XXe siècle)*, Rome: Éditions de l'École Française de Rome, 203–224.

Silva, Álvaro Ferreira da. 2014. "Organizational Innovation in Nineteenth-Century Railway Investment: Peripheral Countries in a Global Economy." *The Business History Review*, 88 (04): 709–736.

Silva, Álvaro Ferreira da and Bartolomé, Isabel. Forthcoming. "Electric Power Industry: Experiments in International Business," in *The Routledge Companion to Makers of Global Business*. New York: Routledge, 332–348.

Silva, Álvaro Ferreira da and Matos, Ana Cardoso de. 2004. "The networked city: managing power and water utilities in Portugal (1850s-1920s)," *Business and Economic History On-Line*, vol. 2 (http://w.thebhc.org/sites/default/files/daSilvaMatos_0.pdf).

Silva, Álvaro Ferreira da and Sousa, Luísa. 2009. "In search of the urban variable: Understanding the roots of urban planning in Portugal." *Métropoles* 6. (https://journals.openedition.org/metropoles/4029).

Spar, Debora and Bebenek, Krzysztof. 2009. "To the Tap: Public Versus Private Water Provision at the Turn of the Twentieth Century." *Business History Review* 83(4): 675–702.

Stine, Jeffrey K., and Tarr, Joel A. 1998. "At the intersection of histories: technology and the environment." *Technology and culture*, 39(4): 601–640.

Sutcliffe, Anthony. 1982. "The growth of public intervention in the British urban environment during the nineteenth century: a structural approach," in J. H. Johnson, & C. G. Pooley (eds.), *The structure of nineteenth-century cities*. London: Croom Helm, 107–124.

Tarr, Joel A. 1979. "The Separate Vs. Combined Sewer Problem: a Case Study in Urban Technology Design Choice." *Journal of Urban History*, 5: 308–39.

Tarr, Joel A. 1984. "Water and wastes: a retrospective assessment of wastewater technology in the United States, 1800–1932." *Technology and Culture*, 25: 226–264.

Tarr, Joel A. 1985. "Building the urban infrastructure in the nineteenth century: an introduction". *Essays in Public Works History* (14): 61–85.

Tarr, Joel A. 1988. "Sewerage and the development of the networked city in the United States, 1850–1930," in Joel A. Tarr and Gabriel Dupuy (Eds.), *Technology and the rise of the networked city in Europe and America*. Philadelphia: Temple University Press, 159–185.

Tarr, Joel A. 1996. *The search for the ultimate sink urban pollution in historical perspective*. Akron, Ohio: University of Akron Press.

Tarr, Joel, and Dupuy, Gabriel 1988. *Technology and the rise of the networked city in Europa and America*. Philadelphia: Temple University Press.

Tarr, Joel A., and Konvitz, Josef W. 1987. "Patterns in the development of the urban infrastructure," in H. Gillette Jr. and Z. L. Miller (eds.), *American urbanism: a historiographical review*: New York: Greenwood Press, 195–226.

Troesken, Werner. 1997. "The Sources of Public Ownership: Historical Evidence from the Gas Industry." *Journal of Law, Economics, and Organization* 13(1): 1–25.

Troesken, Werner. 1999. "Typhoid Rates and the Public Acquisition of Private Waterworks, 1880–1920." *Journal of Economic History* 59(4): 927–948.

Troesken, Werner and Geddes, Rick. 2003. "Municipalizing American Waterworks, 1897–1915." *Journal of Law, Economics, and Organization* 19(2), 373–400.

Wilkins, Mira 1988. "The free-standing company, 1870–1914: an important type of British foreign direct investment." *The Economic History Review, 2nd ser.*, 41(2): 259–282.

Williamson, Oliver E. 1975. *Markets and Hierarchies: Analysis and Antitrust Implications*. New York: Free Press.

Engineering, Geology and the Water Supply to Lisbon in the Second Half of the Nineteenth Century. Expertise and Innovation

José Manuel Brandão and Pedro Miguel Callapez

Abstract

Highlighting the city of Lisbon as a case study, this chapter focuses on the pioneering role of the earliest geologists who introduced Geology, its concepts and its methods as a key tool in the search for drinkable water. This paradigmatic change occurred in the 1850s, due to the work of Carlos Ribeiro, Chief Engineer of the Department of Mines in the Ministry of Public Works, and the first director of the Kingdom's Geological Commission, founded in 1857. Invited to submit his advice about the plans for the Lisbon water supply, Ribeiro was convinced that only detailed geological fieldwork could provide the knowledge for accurately predicting the occurrence of groundwater. For this purpose, he carried out detailed lithological and structural studies on the northern and eastern ranges of the city, subsequently becoming able both to redefine and map the main stratigraphic units and to characterize those with better quality aquifer properties. The knowledge and experience generated by this pioneering work was followed by several contributions by Nery Delgado, his right-hand man, and by their colleague, renowned geologist Paul Choffat. Taken together, these works may be considered as the true precursors of modern hydrogeological studies in Portugal.

J. M. Brandão (✉)
Institute for Contemporary History, NOVA School of Social Sciences and Humanities, NOVA University of Lisbon, Lisbon, Portugal
e-mail: josembrandao@gmail.com

P. M. Callapez
CITEUC, Earth Sciences Department, University of Coimbra, Coimbra, Portugal

A. Duarte Rodrigues and C. Toribio Marín (eds.), *The History of Water Management in the Iberian Peninsula*, Trends in the History of Science,
https://doi.org/10.1007/978-3-030-34061-2_6

1 Introduction

Considering the Portuguese context of the nineteenth and twentieth centuries, the water supply to Lisbon stands out as a paradigm, due both to its history and to the construction of technical monuments that brought together remarkable personalities who actively collaborated in a network of scientific and technological exchange. From an administrative point of view, the example of the Portuguese capital illustrates the coeval and international transition settings of financial liabilities for the management of water facilities, ranging from the traditional municipal sphere to the private sector, an example that also inspired other municipalities to adopt the same basis. This sort of water revolution happened broadly and simultaneously throughout Europe, with most countries advancing the construction of their water distribution and sewerage systems against the controversial debate backdrop of the municipalisation versus privatisation of these public services. This process was led by Great Britain, especially after Chadwick's important Report on Sanitary Conditions (1842) was published, and by France, with the "haussmannisation" of Paris.

While the functionalities of hydraulic engineering and industrial architecture were instrumental to the construction of the several structures that typify the city's supply system in the period under review, a new disciplinary field also began to impose itself as a strategic tool for deployment in the upstream phases of engineering works. The profile of Geology was raised by one of the most notable Portuguese pioneers in this field, the engineer Carlos Ribeiro (1813–1882),[1] head of the Department of Mines of the Ministry of Public Works, Commerce and Industry and, after August 1857, the director of the then-founded Geological Commission of the Kingdom. In historical praise, his right-hand man, Joaquim Filipe Nery Delgado (1835–1908),[2] also a military engineer, stated, "[I]t was this Man who had the glory

[1]Carlos Ribeiro studied artillery and military engineering at the Royal Navy Academy, the Army School, and, later on, at the Polytechnic Academy of Oporto. After 1845, he started working as a civil and mining engineer in the Public Works Company of Portugal and in the Farrobo and Damásio Company, concessionaire of the coal mines of Cape of Mondego and Buçaco. Between 1852 and 1857, Ribeiro was head of the Bureau of Mines, of the new Ministry of Public Works, Commerce and Industry. After this period, and until his death in 1882, he directed the Geological Commission of the Kingdom. His prior geological sketches formed the groundworks for the first complete geological map of Portugal (1:500,000), which was the primary goal of the Commission, published in 1876. As a researcher with multiple talents, Ribeiro left a huge amount of work in the applied areas of engineering, geology, hydrology and mining. His interest in prehistoric archaeology was also the focus of a famous controversy about the existence of humankind in Tertiary times. While on a mission to several European countries (1858), he became acquainted with the most prominent Earth Sciences experts of the time, starting regular scientific correspondence with many of them. Ribeiro was also a member of many Portuguese and foreign scientific societies and was distinguished with several national and international awards (Delgado 1905).

[2]A military engineer from the Polytechnic School of Lisbon and the Army School (1856), Nery Delgado joined the Geological Commission of the Kingdom in 1857, becoming its Director after the death of Carlos Ribeiro. His huge body of scientific work in the fields of Palaeozoic stratigraphy and palaeontology, applied geology and prehistoric archaeology was internationally recognized and recorded in many publications. Together with Ribeiro, he signed the first full

of being the first to recognize the stratigraphy of the country, and to determine the relative ages of the geological units before the organization of the Commission" (Delgado 1905: 21).

Thanks to his prestige and influence in this scientific field, Ribeiro was invited, on three separate occasions, to express his opinion on the projects that the Municipality of Lisbon and the Water Company had proposed to the Portuguese government. His suggestions and criticisms were based not only on his in-depth knowledge of the geological units and structures recognized in the Lisbon peninsula, but also on the expertise and work of several renowned European hydrologists. His opinions were not always taken in good faith; however, time proved their worth, clearly demonstrating the value of geological knowledge as a basis for the study of water for public consumption, and thereby ending the previously prevailing empiricism, hitherto in use for centuries.

Many authors have delved into the historiography of the Lisbon water supply from the eighteenth century to the twentieth century. These studies have focused on its primary hydraulic and mechanical infrastructures, such as the Águas Livres (Free Waters) Aqueduct (eighteenth century) and the Barbadinhos steam pumping station (1880), and on the economic aspects of the two Lisbon water concessionaires. In addition, there has also been some research into their management, their framework within national policies for the sector and the permanent tensions between the government and the stakeholders (e.g., Silva and Matos 2004; Costa and Vital 2005; Schmidt et al. 2005; Bruno and Inácio 2014; Saraiva et al. 2014; Pato 2016). Far from these domains, the present text instead intends to approach the historical application of geological knowledge as a means of revealing potential aquifers.

As it is unfeasible to cover all of the late nineteenth century projects in which Geology emerged as the guiding discipline in the search for and collection of water for public consumption, mostly undertaken by the tutelary members of the Geological Survey, Carlos Ribeiro, Nery Delgado and Paul Choffat (1849–1919),[3] the present contribution highlights the pioneering actions of the leading figure in achieving the huge desideratum that was the supply of drinkable water, in quality and quantity, to Lisbon, as had already been achieved in Europe's other main cities.

geological maps of the country (1:500,000), presented at international congresses, where he represented Portugal. Delgado was a member of several national and international scientific institutions and maintained a close correspondence with many well-known names from foreign institutes and universities (Choffat 1909).

[3]Born in Switzerland, Paul Choffat graduated in Chemistry and Natural Sciences from the University of Zurich. Following an invitation from Carlos Ribeiro, who met him in Paris during the International Geological Congress of 1878, he travelled to Portugal with the purpose of studying the local Mesozoic stratigraphy and palaeontology. Due to work and personal health issues, he remained in Portugal for nearly 40 years. During this period of intensive scientific research at the Geological Commission, he authored a vast bibliography, with extensive monographs on the Jurassic and Cretaceous formations. Besides stratigraphy and geological cartography, his work also included updated and rigorous studies in the fields of tectonics, hydrology, applied geology and mineral resources (Rocha et al. 2008). Choffat was an internationally reputed geologist, a member of several scientific societies and an authority on Mesozoic stratigraphy.

2 Historic Waterworks Predating the Concessions

One of the first major hydraulic works for supplying water to Lisbon was the *Olissipo* Roman dam, located about 10 km NW of the primeval city and built around the second century to exploit the Carenque stream springs (Almeida 1969; Quintela and Mascarenhas 2006). The dammed waters represented a volume of about 125,000 m^3, transported via an aqueduct that remained operational until around the mid-sixteenth century, with its reconstruction even being recommended by the painter and humanist Francisco de Holanda (1517–1585) as a means of dealing with the extreme water shortage that was then being experienced in the capital.

The outline of this precursory structure also served as the basis for the suggestions made by Leonardo Torriani (*c*. 1560-–1628), an Italian architect in the service of King Philip II of Portugal (Philip III of Spain), for the construction of a new aqueduct to transport spring water, known as the "Águas Livres" aqueduct, from the Carenque valley, northwest of Lisbon, to the city (Ribeiro 1867). However, given the substantial investment required, constructing the Águas Livres Aqueduct only began in 1731, during the reign of King João V, when the national financial distress that had previously prevailed found relief through the annual shipments of gold and diamonds from Brazil.

Built with the contributions of some of the most relevant names in Portuguese military engineering and architecture of the time, including Manuel da Maia (1677–1768) and Carlos Mardel (c. 1696–1763), this massive and majestic aqueduct (Fig. 1) underwent expansion during the second half of the nineteenth century in order to allow for capture and transport from more natural springs. The aqueduct was based on a complex water collection, adduction and distribution system, which covered a *continuum* of 58 km of underground and aerial galleries, built into the local limestone stonework and concluded in 1799.

With the help of gravity, the Carenque waters began flowing through the aqueduct in 1748, long before the conclusion of the Mãe d'Água das Amoreiras Reservoir, built in a topographic relief located near the city, where the water system ended. This was an enormous covered tank with a 5500 m^3 capacity, built to serve as a reservoir and act as a control site for distribution to a small network of magnificently decorated fountains within the city. It was finished in 1834 (Andrade 1851) and drew substantial criticism from the population of Lisbon, not only because of its delay, but also due to the poor quality of its waters. From then onwards, the city received about 1900 m^3 of water per day during the dry season. This caudal corresponded to a daily average of 15 L per habitant, a level of consumption that, although considered "good for the epoch" by some authors (Branco 1957: 6), was actually insufficient for the needs of a growing city.[4]

[4]According to Bruno and Inácio, this great hydraulic work "was not, in terms of a solution to the lack of water problem of Lisbon, an investment with any medium or long-term planning perspective" (2014: 10). This was subsequently reflected in the need to reinforce the capacity in the late nineteenth century.

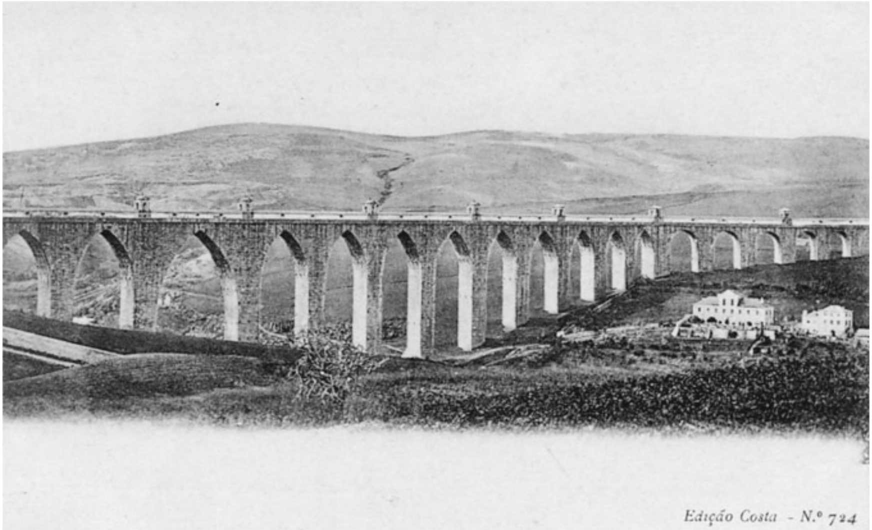


Fig. 1 Arches of the Águas Livres Aqueduct. Classified as a National Monument since 1910, this eighteenth century structure has long been considered an *ex-libris* of Lisbon. Postcard, *c.* 1900

Fig. 2 Water supply at a public fountain in Lisbon. *Photo* Joshua Benoliel, 1907. Municipal Photo Archive, Lisbon, JBN-1228

Only some public services, individuals holding contracts with the Municipality, or anyone who owned properties with springs adjoining the aqueduct received water directly from this structure (Andrade 1851). The rest of the urban population drew their supply freely from the fountains or bought water distributed by water carriers in 25 L barrels, an activity subject to City Council regulation (Ferreira 1981) (Fig. 2).

3 Pezerat's Proposals and Ribeiro's Opinion

In pursuit of the innovations brought about by the Industrial Revolution and their benefits, the Lisbon of the 1850s was struggling with various structural and planning problems stemming from a population growth of over 150,000 inhabitants. Furthermore, the absence of hygiene and sanitation along the public roads of this expanding urban area caused recurrent epidemiological outbreaks, specifically of typhus, cholera and yellow fever (Gomes 1866).

In response to this calamitous situation, the government was authorized to contract, through a public tender, a company able to guarantee an acceptable water supply to Lisbon (Decree from December 22, 1852). In the meantime, entrusted with the administration of Águas Livres, the Municipality appointed the engineer Pedro José Pezerat (1801–1872)[5] to carry out studies on how to solve the problem, correspondingly already foreseeing the possibility of a future commercialization of the service. Water was turning into a commodity everywhere.

Pezerat presented several solutions to the City Council, based on the studies that he had been conducting since 1846 (Pinto 1989). Part of his scrutiny focused on the "Bairro Oriental" (Eastern Quarter), one of the oldest urban nuclei of Lisbon, which was supplied by several natural springs, some of them collected by large fountains, such as Dentro and Lavadeiras in the inner city, or El Rei and Praia, located in the medieval quarter of Alfama, close to the Tagus River. He proposed to assemble all of these primary water sources through the construction of a large mine with a course running parallel to the river and the lower zones of the city. This would cut off all of the local aquifers, which might then provide 4000 m^3 per day, and, once combined and raised to a height of 60 or 70 m, through recourse to a steam engine (30 hp), they would then be able to distribute water to the highest areas of the city (Pezerat, *in* Câmara … 1853).[6]

[5]Born in France, Pezerat studied civil engineering and architecture in Paris (1821). After spending some years working in Brazil and Algeria, he came to Portugal, in the late 1840s, where he initiated a collaboration with the Municipality of Lisbon. In 1852, the Municipality hired him as an engineer, entrusting him with the water supply works for the city. His activity quickly extended to urban planning and municipal works. For about 20 years, he proficiently ensured the leadership of the Technical Department of the Municipality, where he was responsible for numerous studies, projects and opinions (Paixão 2007).

[6]For reasons of coal economy, Pezerat recommended the acquisition of an engine from Alexander Hermanos from Barcelona, instead of a Cornish type (Pezerat 1855: 18).

Since this project was based on the existence of an artesian water table supplied by infiltrations in the terrigenous and carbonated beds of the local Cenozoic units, the City Council requested a judgment from experts at the Polytechnic School of Lisbon, namely, the Professor of Mineralogy, Francisco Pereira da Costa (1809–1889), and the chemist Júlio Simões Pimentel (1809–1884), who came out in favour of the utilisation of those waters (Câmara … 1853).

However, Pezerat's most important proposal was to dam the rainwaters and springs in Quintã, Carenque Valley, and to close the site where the Roman dam had once existed, allowing for the creation of a large "*conserva*." This shallow reservoir would provide water of better quality to Lisbon, through the Águas Livres Aqueduct, with a volume six times greater than that then available.

> (…) the waters from surface springs, like those that cater to the aqueducts of Lisbon, are charged with vegetable principles (*sic.*) in dissolution, together with organic elements, salts and sediments in which they saturate themselves. They cannot be free of these unless they are filtered in sandy substrates below the surface. On the contrary, the flowing waters gathered in vast and deep deposits in which they begin to accumulate their sediments, and to evaporate the lethal gases that they may have absorbed, purifying themselves, are naturally and generally more appropriate to everyday life uses (Pezerat *apud* Andrade 1851: 352).

Aware that underground waters were naturally filtered when flowing over great distances, Pezerat also considered the possibility of drawing on the spring water available in downtown Lisbon. As a whole, the works proposed were to provide approximately 16,400 m^3 of water per day to the city (Ribeiro 1867), which reflected a considerable quantitative leap in the city's supply.

The dam, which was never built, was contested by the Public Works engineer Augusto de Carvalho (1838–?), who believed that it could become a site for the disposing of filth, a place for washerwomen or even an animal cemetery. As an alternative, he defended the development of the Francesas aqueduct, a subsidiary element of the main structure, whose waters sprang from basaltic rocks, and were therefore "lighter, clearer, pleasant to the taste and less saturated with strange matter" than those from the main aqueduct, which he classified as "heavy, thick, unpalatable and saturated with salts and calcareous substances" (Carvalho 1853: 41).

The Municipality then asked Carlos Ribeiro to provide his opinion on this project. The goals involved evaluating the local conditions of soil permeability for water retention and verifying whether the extent of the hydrographic basin was sufficient to provide the amount of water promised for summertime without the risk of the reservoir becoming a source of infection due to its scarce water column.

According to the observations made in the field work carried out in 1853, the Carenque stream flowed in a thick succession of limestone beds dipping to the south, cut by the diaclases normal to such stratification planes. These levels overlaid a calcareous conglomerate and, below, there was a large set of mainly coarse sandstones outcropping northwards, which reached far beyond the boundaries of the drainage basin studied. Ribeiro had no doubts about attributing the Lower Cretaceous age to this fossil-rich sedimentary succession. He also concluded that the coarser beds were being soaked in water until they were saturated and that the water moving through the sediments was being retained by clayish beds, which behaved as impermeable layers, able to store the waters due to be dammed.

Ribeiro also focused on the local and regional tectonics, as he believed that their remote activity might have been decisive in the structural setting of the Cretaceous units. He was mostly concerned with the detached fault planes and diaclases, as they constituted zones of weakness within the rocky massif, enabling the infiltration and circulation of water.

> (…) these kinds of displacements are true crevices that cross the layers of the soil to indefinite depths, almost always filled by surface detritus and, in many cases, acting as water sinks (Ribeiro 1854: 5).

Reassuring the Municipality about the location where the dam was to be built, Ribeiro reported that loose and thin elements formed a natural cement with the clays and filled the fractures, preventing the escape of dammed water. A layer of alluvial sediments had also been deposited above these materials. From his observations, he also found that the rocks outcropping at the bottom of the future dam area were saturated fine clay-rich sandstones, thus the water would be retained, even in the summer, thereby concluding: "(…) I have no doubts about the impermeability of the bottom of the river (…) the reason the site indicated by Pezerat is adequate" (Ribeiro 1854: 6).

Also concerned with the water quality, he drew attention to the needs of hygiene and health; however, he did not believe that the purification of water by resting could solve all of the problems, as this only enabled the settling of the heftier bodies in suspension and failed to take away the bad taste caused by the decomposition of organic matter. In this sense, he recommended the use of gravel, sand, or charcoal filtration, as had been successfully deployed in other European cities, or the construction of filtering galleries,[7] as Pezerat had also suggested.

The report, delivered on April 9, was commended by the City Council, which underlined its development "concerning the nature, extent and form of the soil," and awarded him the sum of £ 20, not as payment, but as recognition of merit (Monteiro 1854).

4 The Times of the "*First* (Water) *Company*"

Even though the reinforcement of the water supply to Lisbon had been politically defined in 1852 (Schmidt et al. 2005), its practical effects only materialized later, due to the *cholera morbus* epidemics of 1853–1856, impacting dramatically on Portugal, as well as throughout Europe.

[7]This procedure was developed at the beginning of the nineteenth century by the Scottish engineer Robert Thom (1774–1847) and was used in river waters for human consumption in the city of Paisley, before becoming generalized soon afterwards.

By 1855, some Portuguese capitalists, who founded the "Waters of Lisbon Company" (known as the "first Company"), presented a proposal to the Municipality that aimed to provide a daily volume of water of 11,300 m^3 and that featured the construction of a network of tanks and conduits for distribution within the city. Water for irrigation, public baths and the fire service would be provided to the Municipality free of charge (Pinto 1989).

5 A French Expert: Louis-Charles Mary

Aware of its responsibilities, the Company was fast to engage a renowned technician to prepare the preliminary studies and project for the necessary works. On the suggestion of the engineer Vitorino Damásio (1807–1875), a professor at the Polytechnic Academy of Oporto who was visiting Paris, they contacted Louis-Charles Mary (1791–1870), an inspector of *Ponts et Chaussées* of Seine, who agreed to travel to Lisbon to analyze Pezerat's proposals and visit the prospective collection areas. Nevertheless, he warned that he was not fully informed about the specific circumstances of Lisbon and, as such, he could only recommend the application of solutions already used in his country (Pinto 1989).

The overall contours of Charles Mary's project were only adequately disclosed recently (Ramos 2011), in keeping with the failure of its primary goal: the effective reinforcement of the water flow to the city. This is ironic, as he was a critic of the Águas Livres Aqueduct, believing that it had been a huge and expensive construction that was concluded without any careful measurement of the volume of the springs collected in the Carenque valley. Serafim (2007: 75) then contradicted his opinion, stating that "countless surveys were made to ensure that the water was strictly measured" to justify such a costly work. He furthermore added (*apud* Ramos 2011) that, despite its "colossal dimensions," the gallery only allowed for the drainage of small volumes of water and wasted the surplus in times of heavier flows (Fig. 3).

As detailed by Costa and Vital (2005), Mary outlined an extensive plan for the city's supply, aiming both to pipe water into households and increase the production capacity of the Águas Livres Aqueduct. Contrary to the trend in other European capitals, he did not propose any recourse to steam engines, but rather the construction of cast iron siphons and the usage of the principle of communicating vessels to supply some reservoirs and fountains.

The project that the French engineer presented to the Company aimed at collection of the water that issued abundantly in the Vale da Mata (northwest of Lisbon) and its adduction through an 8600 m long aqueduct connected to the main Águas Livres facility. When the water arrived at the city, it was then distributed to the galleries and the Amoreiras reservoir, feeding large deposits, each with its own distribution network, and serving different altimetric zones (Mary, *apud* Ramos 2011), a pattern that was fully adopted by the Company and which is still in effect nowadays, alongside the necessary adjustments. Despite its optimistic solution, the

Fig. 3 Main aqueduct gallery depicting the water circulation gutters on each side of the central walkway. *Photo* courtesy of Pedro Inácio, 2010

project for the new subsidiary Mata aqueduct was received with apprehension by the municipal technicians, who stressed that it was only enough for the immediate satisfaction of the Company's needs, without offering any guarantees that it could actually fulfil the contract.[8] This concern soon became a reality when the summer water flow failed to exceed 500 m^3/day, producing an amount far less than what was expected, in a failure that led the government to rescind the contract and ascribe control of the urban water supply to the Municipality (Companhia 1900).

6 A "*Book of Science and Consciousness*"

Meanwhile, the Company's board of directors called Ribeiro into clarify several doubts that had been raised by Mary's project, requesting an opinion on the hydrogeological potential of Lisbon's surrounding area. He answered with a detailed geological field reconnaissance in which he described and mapped the main stratigraphic units over a topographic background drawn from the orographic map.[9]

[8]Opinion report of the Municipality, cit. in Ramos (2011: 71).
[9]Carte chorographique des environs de Lisbonne dressé sous la direction de Charles Picquet à Paris, 1821 (Ribeiro 1857).

While the chief purpose involved identifying the geological formations with higher aquifer potential, considering their distance to Lisbon and altitude so as to minimize the adduction costs and avoid the costs of steam power for raising water, his report reached far beyond everything that had been previously produced, specifically by Daniel Sharpe (1806–1856).[10] This document was published by the Royal Academy of Sciences of Lisbon in 1857, of which Ribeiro had been a full member since 1854.[11]

The quality of the observations and the results verged on those of the finest publications made at the time, especially by French and British authors. These were not limited to the regional morphology and stratigraphic description, but also focused on the lithologies and the structure of the rocky massifs that essentially controlled the water circulation within aquifers. This important document reflects not only the reputation of its author, who was scientifically up-to-date, but also the confidence of the Authorities and the Company in national scientists, in addition to the author's determination to provide a geological survey prior to establishing any efficient water supply plan.[12]

> …[without] this geological reconnaissance (…) it is not possible to understand the principles on which the exploration and acquisition of potable water should be based, in order to determine the locality or localities that can provide more quantity of them (Ribeiro 1857: 34).

The results of these fieldworks were summarized in the chapters Geology and Hydrology, in which Ribeiro proposed a stratigraphic and structural model of the regional units ranging from the Cretaceous to the cover deposits, including the volcanic layers, to which he added the main details of the orography that were fundamental to understanding the hydrographic network patterns.

In his opinion, the geological structure of the area was quite complex when compared to other "basin types" of the same age, in particular, that of Paris, where a remarkable regularity of forms and the definition of the "geognostic" horizons facilitated their study. Conversely, "the inner forces of the globe" had exerted their actions around Lisbon, disturbing the composition of the rocks and "disrupting" the continuity and uniformity of the beds, producing the consequent rugged orography (Ribeiro 1857: 25).

The main local Cretaceous units recognized by Ribeiro, reformulated in 1867 and 1881, represented an important foundation for several subsequent works and were widely used for new stratigraphic precisions. They consisted of six "andares," with marine carbonate formations interbedded with two alluvial units of coarse sandstones showing good aquifer properties (Fig. 3). Among these, the "Primeiro

[10]This British citizen was a pioneer of Portuguese geology and the president of the *Geological Society of London*. He met Ribeiro during fieldworks conducted in the Carboniferous units of Buçaco for the company Farrobo & Damásio. His publications about the region of Lisbon included a coloured geological map and a stratigraphic setting with several Jurassic and Cretaceous series.

[11]Lisbon Academy of Sciences, individual process.

[12]The accuracy of Ribeiro's geological observations was largely proven more than two decades later, when the first monograph by Choffat (1885) on the Cretaceous stratigraphy of Portugal was published, mostly with data yielded from the region of Lisbon.

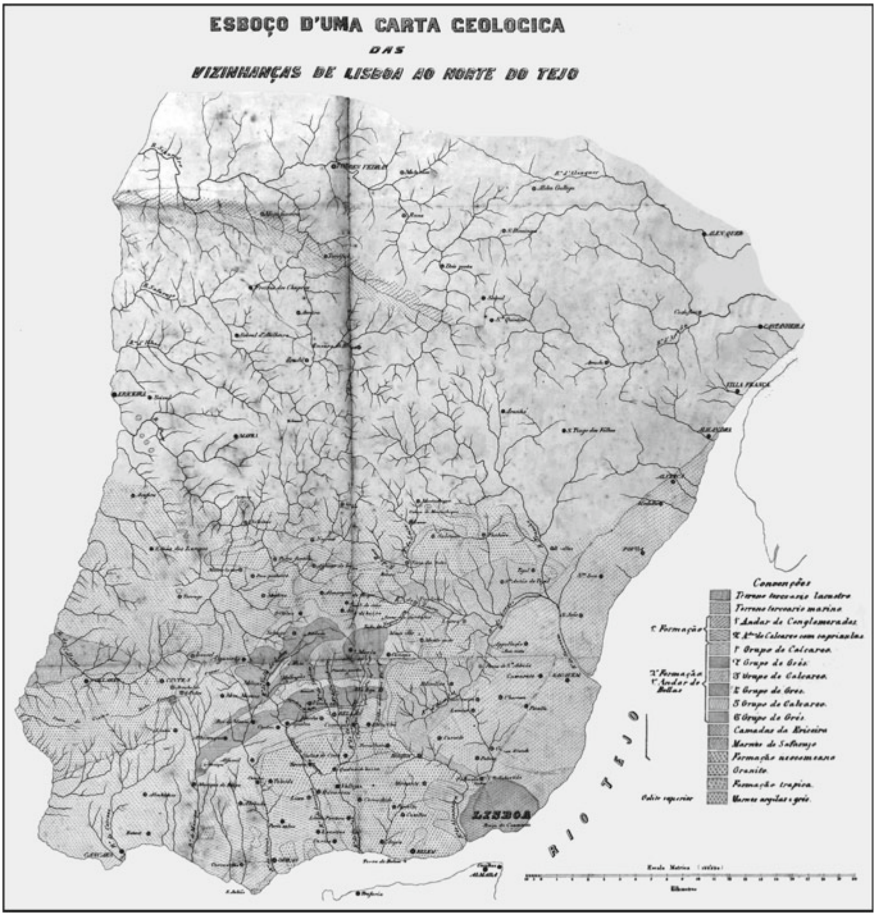


Fig. 4 Extract of the geological map of the peninsula of Lisbon by Carlos Ribeiro, published in 1857 by the Royal Academy of Sciences, Lisbon, and a detail of the main aqueducts, after Ferreira (1981)

Andar de Grés" (Ribeiro 1857) stood out, a sandstone formation later redefined by Paul Choffat (1885) as the "Almargem Beds" (Fig. 4).[13]

> Les grés d'Almargem ont une grande importance comme niveau aquifère; c'est d'eux qui provient une grand partie de l'eau qui alimente Lisbonne, c'est aussi de ces grés qui proviennent la majeure partie des sources minérales des environs de Bellas, Caneças et Cascaes (Choffat 1885: 5).

[13]Its type of locality was in a tributary valley of the Carenque stream, crossed by drainage galleries later excavated under the direction of Ribeiro, where he also collected fossil plants that were studied by the Swiss paleobotanist Oswald Heer (1809–1883).

He was certainly faced with a large number of tectonic structures affecting the region, many of them active during the Late Cretaceous intrusion of the ring-shaped igneous massif of Sintra, the extrusive episodes of the Lisbon Volcanic Complex or, more recently, the Miocene compressive phases of the Lower Tagus Basin (Pais et al. 2006). Perhaps the most influential tectonic structure for the hydrologic purposes of Ribeiro was the reverse NNW–WSW fault located northward from Belas and intercepted by the Carenque stream, conditioning a north-eastern block where the "Almargem Sandstone" outcropped extensively and concentrated the aquifers and springs flowing into the aqueduct.

The lithological study and analysis of the structural setting, including stratification, diaclases, faults and igneous dykes, allowed him to evaluate the relationship between precipitation and the absorption area of the basins and aquifers, positioned below the drainage level of the land, as determinant factors for the location and architecture of the future collection system.

Following this methodology, Ribeiro concluded that none of the streams from the eastern side of Lisbon, which flowed into the Tagus River, with their beds carved into "Tertiary" sedimentary formations, could retain their surface waters. The geological reason for this insufficiency stemmed from the central and eastern zones of Lisbon having grown over a thick succession of Miocene marine sediments organized in tabular strata that dipped slightly into the river, with fine permeability qualities due to the presence of unconsolidated terrigenous lithologies (the "absorbing nature of the rocks," as Ribeiro put it, 1857: 37). This geological framework was also unfavourable to substantial collection levels, due to the absence of impermeable layers or structural traps for retaining groundwater. Thus, in his opinion, it would be impossible to obtain the rainwater received by these layers at higher levels, unlike from the dug wells situated lower, close to the level of the Tagus. Furthermore, for an absorption surface of more than 200 km^2, Ribeiro estimated that it would be possible to obtain at least an approximate 11,000 m^3 per day by taking advantage, through a gallery, of the waters otherwise lost to the Tagus.

The hydrological conditions became more favourable in the western part of the city, especially from the Alcântara valley onwards, due to the prevalence of deformed and fractured Cretaceous calcareous units, sometimes interbedded with permeable sandstones, alongside other areas covered by basaltic lava flows and tufts:

> It is to this physical and geological constitution that Lisbon owes its abundant sources of the eastern quarters, as well as the dryness and sterility of its soil in the high, middle and western parts; as a result of such inequality and scarcity, the public administration was forced to make recourse, in the past century, to the sources of the suburbs of Lisbon, to avoid the horrors of the thirst that the inhabitants of the capital suffered for centuries (Ribeiro 1857: 33).

Ribeiro strongly criticized the layout of the Mata aqueduct planned by Charles Mary. He opposed the project and stressed that, although the rainwater-receiving basin connected to the aqueduct spanned an area of about 16 km^2, there were large volumes of limestone with unfavourable hydrogeological conditions. In addition to those constraints, the upstream space was cut by “folds and valleys” in which the waters converged, limiting the amount that reached the aqueduct, which only received water from those springs located above its planned altitude. There was also the fact that the water contained in the four main springs, which reached over 7300 m^3/day in June 1856, came from different layers (aquifers), functioning independently, which did not ensure stable water flows, due to their different recharging speeds.

According to the lithology and structure of the massif drained by the Mata aqueduct, Ribeiro estimated a collection capacity of about 5800 m^3/day, which, combined with the flow from the Águas Livres Aqueduct, would still not reach the volume of 11,300 m^3 per day proposed by the Company. To obtain this volume, it was necessary to reinforce the main structure with subsidiary galleries and collecting pipes, covering an estimated area of about 10 km^2, to capture other springs, as, due to the topographic level at which the work was planned, a large volume of water from the lowermost aquifers would not be used.[14]

Inspired by the examples of French authors such as J. Dumas and Polonceau, experts in the field of “*la science des fontaines*,” Ribeiro suggested some redemptive strategies for increasing the efficiency of Mary’s aqueduct, improving the absorption of rainwater and the volumes retained in the aquifer. These included the planting of woods on the ridges, hill slopes and stream banks and the opening of trenches along the contour lines in the areas where there were sandstone outcrops, in addition to applying the “natural fountains” method, in which a network of ditches with dry stone walls and impermeable bottoms were opened and filled with loose soil, mutually interlinked and draining into regulatory basins (Ribeiro 1857).

As an alternative to the Mata aqueduct, Ribeiro recommended the exploration of waters near the locality of Belas and the construction of a further collector, the Agualva aqueduct, at a level higher than Mata. This structure was planned to cross several streams where groundwater converged and, running approximately 2.5–3 km in length, would provide about 9000 m^3/day in the dry season and up to 24,000 m^3 during winter, due to its larger rainwater absorption surface, taking advantage of the better hydrogeological conditions, with a bedrock composed of limestone and marly layers interbedded with sandstones and claystones, dipping towards Lisbon.

Although solidly based on geoscientific data, Ribeiro’s suggestions were ignored, and Mary’s project, as well as its budget, was approved by the ordinance of June 30, 1857. Ribeiro nevertheless continued to believe that the aqueduct planned by Charles Mary was doomed to failure. In his opinion, if the Company did not take advantage of the waters of the Eastern Quarter (lower quality but potable),

[14]Ribeiro also mentioned the scope for taking advantage of sources from the eastern quarter of the city, sources that were inferior in quality but drinkable, as had been previously suggested by Pezerat. The surplus water from these sources flowed freely into the Tagus River until 1868, when the Praia Elevatory Station, the first steam pumping station installed in Lisbon, entered into operation. This new station was able to pump about 1800 m^3/day to the middle areas of the city (Bruno and Inácio 2014).

in the short term, it would be obliged to undertake new works or build another aqueduct as large as or even larger than Mata to collect other springs. In addition, Ribeiro pointed out that the short time that the French expert had spent in Lisbon was not enough for detailed observations; he had merely accepted the hypothesis of a certain volume of water in each of the sites visited, proposing its collection and adduction without truly guaranteeing its success (Ribeiro 1857). This position might be perceived as an act of professional loyalty, as emphasized by the columnist of the popular Lisbon weekly newspaper *Archivo Pittoresco* (1857), since Ribeiro reiterated his conviction that Mary had been faced with a very tight deadline. For this reason, the columnist called Ribeiro's report "a book of science and consciousness" (p. 110). However, Ribeiro still warned:

> The contempt for the study of the lithological composition and structure of the soils where water exploration, hydraulic or other works are going to be carried out, is often the motive of the best combined projects to fail (Ribeiro 1867: 111).

7 The Solution: Spring Waters *Plus* River Waters

In January 1863, the Company presented new water supply plans designed to meet the growing needs of Lisbon, including usage of the wells available within the city and the exploitation of sources from the eastern quarter. They also pointed out the scope for drawing water from the Tagus River, sent to the city through a buried siphon and raised to an appropriate topographic level, making its distribution possible in the higher urban areas (Pinto 1989).

Despite these (late) proposals, the government decided to cancel the concession, on the grounds that the company had failed to meet the contract and the government's lack of faith that the Tagus's ability to supply water was a proper solution (ordinance from October 7, 1863). Simultaneously, an evaluation committee was appointed, with the participation of Carlos Ribeiro as an expert in hydrology and regional geology. The objectives were for its members to determine how much water the Company could efficiently provide to the population in the dry season, to present a detailed technical opinion about the system's future, specifically, through an inventory of the availability and quality of new water resources, and to determine the most convenient and cost-effective ways of bringing them to Lisbon.

The work carried out and presented to the government in 1864 gave rise to an extensive "Memoir," published by the Geological Commission in 1867, in which Ribeiro analyzed each of the projected and delivered parts of the system, setting out his criticisms and suggestions, and explained his ideas about the use of river waters, deploying the situations reported by French and British authors as examples.

In this notable work, fully commented upon by Simões (2013), Ribeiro bore in mind all of his previous observations on the regional geology, namely, the distribution of the most permeable Cretaceous sandstone beds and limestones, faults and basaltic dykes that cut the sedimentary succession (Fig. 5). He also provided advice

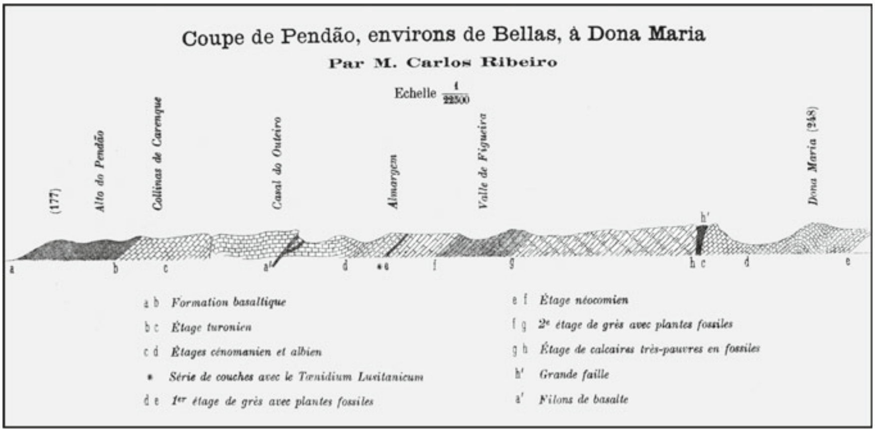


Fig. 5 Geological cross-section by Carlos Ribeiro, portraying the regional Cretaceous units, dykes and main faults. Rep. from Oswald Heer, 1881

on the conclusion of works on several Águas Livres Aqueduct subsidiary structures, as well as the extension of the Mata aqueduct, whose efficacy had previously been received with great apprehension.

Furthermore, he pointed to the substance of Pezerat's proposals in also suggesting that the capture of all of the spring waters was feasible for introduction into the aqueducts, as well as those from the eastern zone and other sources within the city. However, he was concerned, not only with the quantity of water to be supplied, but also its quality.

At the time, the idea of water as a privileged vehicle for the spread of pathogens had not yet been consolidated, even though it was known that water collecting near sewage and waste disposal sites constituted a high risk to public health. Since the Renaissance, water quality had been evaluated based on a series of empirical criteria: its smell, taste and appearance, its clearness, the absence of suspended matter, and its quality for culinary uses (Euzen and Haghe 2012; Sowina 2016).[15]

In addition to clearness, Ribeiro said that potable water should present at a nearly constant temperature, be odourless and pleasant to the taste, and be suitable for cooking vegetables and dissolving soap thoroughly. The substances in the solution should not exceed 300 mg/l, nor should organic matter be present in any appreciable quantities. Finally, the water should not register more than 24 °C in the hydrotimeter.

[15]An early example concerning the Lisbon water supply regards the Portuguese pioneer of hydraulic studies, Estevão Cabral (1734–1811), who pointed out the need to end the aqueduct at the reservoir of "Mãe de Água," because the water did not arrive "clean" due to the absence of a tank that could provide for the sedimentation of the suspended matter, by which it would be "purifying itself." He believed that the dissolved salts could also precipitate there, instead of inside of the pipes, where they caused serious damage to the runoff (Cabral 1791).

One part of these characteristics not only directly related to the crossed lithologies, but also to the time and distance that it took the water to flow into the ground. To ascertain this situation, Ribeiro sampled the main fountains of Lisbon,[16] in a way that revisited certain aspects of a study carried out in 1812 by the naturalist Alexandre Vandelli (1784–1862), who sampled the main springs, mines and dug wells that were in use by the population. He measured the temperatures of the water and the atmosphere and determined the values of density according to the content of dissolved substances, before concluding:

> On account of water that weighs less being more profitable in the *animal economy*, since the number of dissolved heterogeneous bodies is smaller, those of smaller specific gravity must be chosen for economic usage (Vandelli 1812: 81).

The samples that Ribeiro collected in January 1864 were analysed by the chemists of the Polytechnic School of Lisbon, António Augusto de Aguiar (1838–1887), also an influential politician, and Júlio de Oliveira Pimentel (1809–1884), who characterized the dissolved substances and the hydrotimetric degree, taking as his default the values for the best water quality proposed by French hygienists: a hydrotimetric degree of between 8 and 18 and with a salt content of between roughly 100 and 300 mg/l.

Their results showed significant differences between the waters sampled from different points of Lisbon, both in their salt content due to rainfall variations and lithology, according to Ribeiro's opinion, and in hydrotimetric degree, which varied between 17.5 and 35.5, with a single anomalous value of 66. As for salt content, Júlio Pimentel found values of between 562 and 749 mg/l in the main Eastern Quarter fountains, much higher than those found in the aqueduct water, 277 mg/l, a fact interpreted as a consequence of a shorter underground pathway. If these more mineralized waters from the Eastern Quarter were to travel along an underground route for as long as those collected by the aqueduct, "they would purify, reaching consumers with less dissolved salts" (Ribeiro 1867: 12).

It should be added that those waters sprang at an average temperature of over 22 °C, which, combined with their high mineralization, indicated a thermal origin. In any case, based on the examples of the foreign scientific literature and the experience of Portuguese hygienists, Ribeiro recommended their usage, given the constancy of flow and the clearness of their springs.[17]

Considering the rapid changes in the consumption habits of the population and matters of urban hygiene, as well as the amount of water available per inhabitant in many foreign cities, Ribeiro estimated that Lisbon, with nearly 200,000 inhabitants

[16]Attached to Ribeiro's (1857) report, there is an extensive inventory of the fountains, wells and other water sources of Lisbon, which support his conclusions.

[17]The physician Bernardino Gomes, a notable figure in Portuguese medicine in the nineteenth century, recommended that his patients consume water from one of these fountain systems, El-Rei, instead of the water arriving via the aqueduct (Ribeiro 1867: 16). However, after being chemically and bacteriologically analysed in 1890, the "eastern waters" were classified as being of mediocre quality, considering their high mineral content, as well as their contamination with colibacilli, possibly due to poorly constructed sewers. Its consumption had been abandoned by the 1930s (Companhia … 1900).

at the time, would require a volume of at least around 150 l/day/hab. (p. 36), an amount that would need to be increased in the future, assuming that the population of Lisbon would double or triple over the subsequent fifty years. The author's substantial knowledge on the geology of Lisbon and its neighbouring areas gave him the authority to assert that the region was far from being able to supply the capital's future needs, even considering the scope for using all of the springs identified within the city and near volcanic rocks, dikes, faults and Cretaceous sandstones.

The methodology presented in 1857 proposing the excavation of wells or galleries to capture the subsurface waters along the valleys and streams had only been deployed in isolation for the supply of a few large cities (Ribeiro 1867: 21). These more populous areas demanded the search for new perennial and abundant sources, and the eventual combination of different supply systems, depending on the geological nature of the bedrock. To solve this problem, he proposed deep collection in confined aquifers, as was practiced in Liverpool, and/or the exploitation of river waters purified by filtering galleries, as was then happening in London and Paris.[18]

To this end, he studied water samples collected in the Tagus approximately 100 km upstream from Lisbon, beyond any tidal influence, between the riverside localities of Santarém and Barquinha, subject to analysis by Augusto de Aguiar. Through his methodology, he sought to determine the relationship between the lithologies of the river banks, the amount of dissolved substances present in the water and the season of the year (Table 1), concluding that its maximum proportion occurred during the dry season, and that the concentration of dissolved salts was higher in the Tagus River sections where there were debouched tributaries with larger drainage basins rich in limestone and sandy-claystone lithologies (Ribeiro 1867).

Despite the oscillations recorded, the amount of "fixed materials" contained in the waters of the Tagus was lower than that found in some of the spring waters collected by the Águas Livres Aqueduct[19] and compatible with the limits suggested by the hygienists, thereby fully satisfying the Company's commitments (Ribeiro 1867). However, these values did not invalidate the need for natural or artificial filtration, for which Ribeiro relied on examples of successful experiences abroad, specifically, in France, the United Kingdom, Austria and Germany, including the scope for using coarse alluvial deposits from river bars as the means of ensuring natural filtration. Subsequently, he studied the Quaternary sediments of the Tagus River basin, northeast of the city, before concluding that the natural filtration of sand and gravel banks and the capture of deep circulation "artesian waters" represented a feasible option.[20]

[18]In the Portuguese cities of Coimbra and Oporto, waters from the Mondego, Douro and Sousa Rivers were already in use for public supply.

[19]In February 1864, the water from the Aqueduct was reported as 16 °C on the hydrotimeter, with 0.293 g/l of residuals (Ribeiro 1867: 43).

[20]After 1935, the Company reinforced the Lisbon supply with several underground water holes drilled into the Tagus River alluviums (naturally filtered waters) on the sites studied by Ribeiro.

Table 1 Results of the analysis of Tagus and Zêzere River waters, collected in 1863 and 1864

Sampling station	During the dry station	February, after the rains	
	Hydrotimetric degree	Hydrotimetric degree	Fixed residuals (g/l)
Tagus River waters collected in front of Barquinha	23	14	0.192
Tagus River waters collected in front of Santarém	24	16	0.238
Tagus River waters collected in front of Constância	16	19	0.268
Waters from Zêzere[a] mixed with those of the Nabão River	16		
Waters from Zêzere collected upstream the mouth of the Nabão	2.5	4	

Following Ribeiro (1867)
[a]The Zêzere is one of the main tributaries of the Tagus River. Its waters have also been collected since 1987

In sum, Ribeiro came to the view that, based on his detailed study of successful foreign cases, the overall solution for the supply of large settlements would involve the usage of Tagus waters captured upstream, far from the tidal influence or contamination by sewage and duly purified by natural or artificial filtration. However, should this recourse to river waters be rejected, the city's supply would have to be guaranteed by spring and drainage waters.

> (…) the men of sciences and the administration, when occupied with the acquisition of new spring waters for this purpose, should be obliged to leave their observations from the suburbs of Lisbon and to lengthen them many tens of kilometers to the north and northeast areas of the city (Ribeiro 1867: 64).

Ribeiro extended his studies 100 km further northward of Lisbon, to the calcareous mountain ranges of Montejunto and Aire, where perennial sources were present in the Jurassic limestones, near the localities of Rio Maior, Ota, Alenquer and Alcanena.

In spite of the distance and the higher costs of an adduction system, the vast spring of the Alviela River, known as "Olhos d'Água," undoubtedly represented an interesting possibility. This was a singular site, about 60 m above sea level, located in the intersection of two major faults, with a flow of over 200,000 m^3 of water per day, most of which proceeded freely into the Tagus River. Nevertheless, Ribeiro argued that the Alviela River was also being used by more than twenty mills along its course, which would have to stop in the dry season should the water be diverted to Lisbon, therefore advocating its usage for agriculture rather than for local consumption. Nevertheless, he suggested that nearly 30,000 m^3 per day could be sent to Lisbon without any considerable impairment on traditional uses.

However, bringing in the waters from Alviela required a greater investment than the Municipality could afford. This thus became an opportunity for the private investors who, in 1868, formed the Companhia das Águas de Lisboa (Lisbon Water Company), which still stands today, despite having undergone several transformations.[21]

8 Old Plans for New Waterworks

The year of 1874 was hard for both the Company and the population, due to a long drought that drastically diminished Lisbon's water supply. The Government commissioned Ribeiro to urgently implement a solution to reinforce the supply to the Mata and the Águas Livres aqueducts. It was requested that he source drinkable water as quickly as possible, and for the works carried out to be useful over the long term. At this time, when commenting on the situation and blaming the great water shortage in Lisbon for its effects on food and hygiene as the cause of the "plagues" that had devastated the capital, he said:

> (…) for more than twenty years Lisbon has been fed less than one-tenth of the water that is considered indispensable for its supply as the capital of a cultured nation; (…) the hygienists and the statistics have cried out that, for this reason, in Lisbon you breathe a pestilent and mortiferous air (Ribeiro 1879: 408).

With the collaboration of Nery Delgado, Ribeiro began exploring the Cretaceous layers of the Almargem sandstones, outcropping near Belas, Sabugo, Brouco and Vale de Lobos, in the intersection of three valleys located upstream from the Mata aqueduct, layers that he had first found during his fieldwork in 1857. He led expeditions into the limestone formations, as these lithologies were quite cavernous and permeable and, as such, the waters of the upper regions disappeared into them, hence the need to reach lower depths to find the confined aquifers (Ribeiro 1879). In order to extract more water, wells were excavated to depths of between 20 and 30 m, making it necessary to use a Letestu pump system driven by a locomobile to raise the water. More than 100 wells were opened, and new aqueduct branches built, allowing for the minimum collection of 400 m^3/day (Fig. 6). Although these works had to be extended in mid-1885, already under Delgado's direction, when the government decided on their temporary suspension in 1878, they could yield about 720 m^3/day (Company … 1900), a flow that mitigated the effects of the drought.

After the first works, Ribeiro sent a report to the Government reiterating that the higher relief areas in the vicinity of Lisbon contained a geological composition and structure that might contribute to increasing the city's water supply, even if,

[21]By 1868, Lisbon was served by several private wells and cisterns, 26 springs and 97 water spouts supplied by the aqueducts and scattered across various points of Lisbon, of which 48 were used by 3129 water carriers and 40 by private customers, with 9 reserved for the filling of barrels (Ferreira 1981: 130).

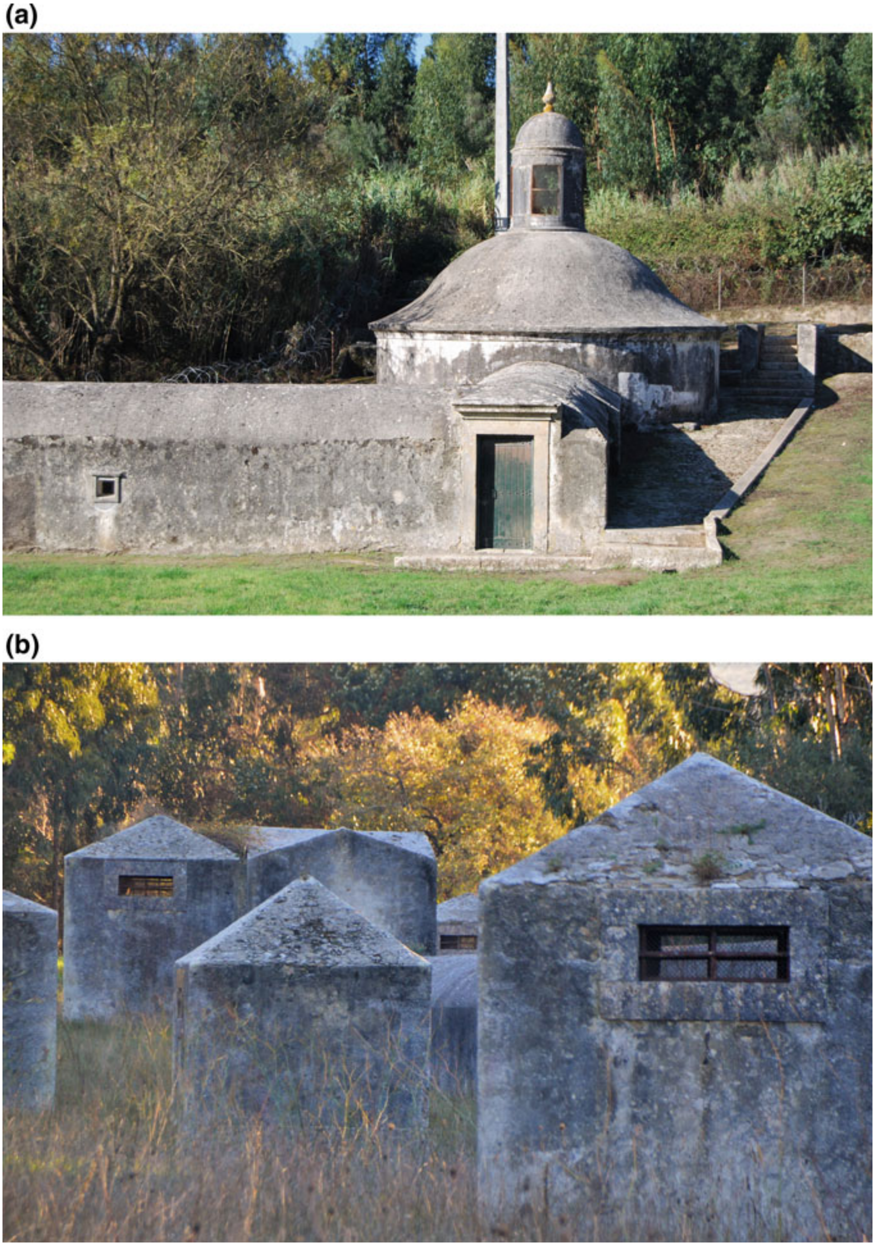


Fig. 6 **a** Detail of the system of galleries located near Belas; **b** vents from the underground captation galleries. *Photos* courtesy of Pedro Inácio, 2010

however, they was unable to provide a long-term supply on their own. Nevertheless, were his plan for the Agualva aqueduct and collection in the eastern part of the city to be executed, the Company would then have more than 14,000 m^3/day, surpassing the contracted flow:

> One of the causes that contributed most to the subterranean exploration work we indicated not being carried out (…) was the lack of faith, the lack of confidence that the exploration of drinking water by works of that nature could have inspired in so many enlightened people. Drinkable water cannot be obtained in abundance by means of underground work, even if it penetrates deep (…) in any and all geological formations; it is necessary to study and to know well the physical structure and the lithological composition of the soil of the region, and only then will it be possible to indicate the probability of finding or not finding more or less rich springs (Ribeiro 1879: 480).

While these works were ongoing, the Alviela channel was also constructed and the equipment needed for the reception and steam elevation of these waters underwent preparation.

The abduction of the Alviela waters followed a gravity flow process through underground and surface conduits, alongside two main siphons to overcome the biggest orographic accidents, installing cast iron pipes at that time manufactured by the main Portuguese foundries. This procedure was also used in Delgado's water supply project for Figueira da Foz, which was proposed to the Municipality in 1880 (Brandão and Callapez 2017). That same year, the Barbadinhos steam pumping station, built in the heart of the Eastern Quarter, was inaugurated, bringing a volume of water to Lisbon that was compatible with those of other major foreign cities (Table 2).

Table 2 Availability of water in the city of Lisbon

Year	Sources	Population	m^3/day[a]	l/inhab/day
16th century	Fountains, springs and dug wells	60,000	200 to 300	4.0
Early 18th century	Idem	80,000	540	6.0 to 7.0
1748	Idem plus water from the Águas Livres Aqueduct	90,000	780	8.4
1863	Idem plus water from the Mata and Brouco aqueducts	160,000	2360	14.7
1869	Idem plus water from the Francesas aqueduct and waters from the Lisbon Eastern Quarter	171,000	4280	25.0
1874	During the great drought		1663	
1878	After Ribeiro's works in Belas	187,000	5000	26.7
1880	Arrival of the water from the Alviela river	191,000	35,000	183.2

Following Ribeiro (1879), Montenegro (1895), Companhia … (1900)
[a]The numbers are somewhat discrepant among the authors consulted

9 Final Remarks

Even though the construction of water supply systems for human consumption has been a concern ever since Antiquity, urban networks for water and sanitation only gained momentum in the aftermath of the Industrial Revolution. Despite the importance attributed to fire safety, public health issues were decisive in the replacement of traditional water supply systems, based on dug wells and cisterns, with modern collection systems, which ensured the quality of the water delivered to households. London was a pioneer in this process, both from technological and organisational points of view (Juuti and Latko 2005; Tynan 2013; Matés-Barco 2013; Gorostiza and Cubero 2013).

Notwithstanding its character as a natural monopoly, water supply is mainly a local issue. Traditionally, this was provided for by local authorities, who managed their own systems during the nineteenth century. Many cities conceded this service to private operators, believing that they could handle the waterworks better than the municipalities and that they would bring investments and innovation. This process was soon reversed, primarily for reasons of public health or contractual inadequacies (Juuti and Latko 2005).

In Portugal, during the second half of the nineteenth century, under a new legal framework regarding property and the usage of water resources, several companies were also established, promising significant financial and technological innovations and aiming to operate the water supply systems under concession. However, the fact that water became a business did not prevent a set of positive externalities, particularly regarding public health and urban hygiene. The founding of companies that provided water exploration and distribution in Portugal resulted from this paradigmatic change. Nonetheless, it should be noted that, besides foreign technology, imported for the construction of larger waterworks, the Lisbon Water Companies also resorted to national technicians whenever it required the expertise of state geologists, particularly members of the new Geological Commission, who were informally consulted on matters related to mineral raw materials or public works and infrastructures.

In contrast to the traditional methodologies, which were mainly based on the use of surface springs and the topographic and altimetric features of water basins, the precursor works of Carlos Ribeiro in Lisbon, besides considering the hydrological cycle, involved understanding the mechanisms of groundwater circulation, their dependence on the lithology, structure and seasonal rainfall fluctuations, and the chemical and physical properties of water. These matters, which constitute the main principles of "ground-water hydrology," as James Hackett mentioned in his "summary" on the birth of this branch of geological study (1952), were also the guidelines that Nery Delgado and Paul Choffat followed. In virtue of their expertise in geology and engineering, they too were requested to issue their advice on identical situations in other Portuguese cities.

Acknowledgements The authors would like to thank the IHC (Institute for Contemporary History, NOVA University of Lisbon) and CITEUC (Centre for Research of Earth and Planetary Sciences, University of Coimbra) for their institutional support of this research. We are also grateful to Ana Duarte, Ana Simão and Bárbara Bruno for their precious suggestions, as well as to Pedro Inácio for his photographs.

References

Almeida, F. 1969. Sobre a barragem romana de « Olisipo » e seu aqueduto. *O Arqueólogo Português*, s. 3, Vol. 3: 179–189.

Andrade, J. V. [1851] 2008. *Memoria sobre chafarizes, bicas, fontes, e poços públicos de Lisboa, Belem, e muitos logares do termo… Facsimile* edition. Lisbon: EPAL-Empresa Portuguesa das Águas Livres.

Abastecimento de águas para Lisboa. *Archivo Pittoresco* I (14): 108–110, 1857.

Branco, A. S. [1957]. Notícia sobre o abastecimento de Lisboa com águas de nascentes e águas do Rio: estudos e obras dos últimos cem anos. Reprint from: *Boletim da Comissão de Fiscalização das Águas de Lisboa*, 36.

Brandão, J. M. and Callapez, P. M. 2017. *O abastecimento de água à Figueira da Foz em finais de Oitocentos*. Figueira da Foz: Câmara Municipal da Figueira da Foz.

Bruno, B. and Inácio, P. 2014. *Barbadinhos: do vapor ao museu*. Lisbon: EPAL-Empresa Portuguesa das Águas Livres.

Cabral, E. 1791. Memoria sobre o tanque e torre no sitio chamado em Lisboa Amoreiras pertencente ás Aguas Livres. In: *Memorias Economicas da Academia Real das Sciencias*, Vol. 3, pp. 291–297.

Câmara Municipal de Lisboa 1853. *Representações dirigidas a Sua Magestade a Rainha e ao corpo legislativo pela Camara Municipal de Lisboa sôbre o abastecimento d'águas na capital por meio de empreza, seguido as bases estabelecidas no decreto de 22 de Dezembro de 1852*. Lisbon: Imprensa Silviana.

Carvalho, A. 1853. *Reflexões acerca do abastecimento de agoas e sua distribuição na capital*. Lisbon: Typographia Urbanense.

Choffat, P. 1885. *Recueil de monographies stratigraphiques sur le Système Crétacique du Portugal - première étude - Contrée de Cintra, de Bellas et de Lisbonne*. Lisbon: Section des Travaux Géologiques du Portugal.

Choffat, P. 1909. Notice Nécrologique sur J. F. Nery Delgado (1835–1908). *Communicações da Commissão do Serviço Geologico de Portugal*, 7: VI–XXI.

Companhia das Águas de Lisboa 1900. *Notice sur l'alimentation de la ville de Lisbonne en eaux potables: 1900*. Lisbon: Typographie Companhia Nacional Editora.

Costa, M. R. and Vital, R. 2005. Evolução Histórica dos Sistemas de Abastecimento de Água a Lisboa. In: Bombas Grundfos Portugal *et al*. (eds.). *Manual de Engenharia; sistemas de pressurização*. Lisbon: Grundfos Portugal. pp. 7–29.

Delgado, J. F. N. 1905, *Elogio histórico do General Carlos Ribeiro*. Lisbon: Associação dos Engenheiros Civis Portugueses. Imprensa Nacional.

Euzen, A. and Haghe, J.-P. 2012. What kind of water is good enough to drink? The evolution of perception about drinking water in Paris from modern to contemporary period. *Water History*, 4: 231–244.

Ferreira, M. D. 1981. O abastecimento de água à cidade de Lisboa nos séculos XVIII e XIX. *Finisterra*, 31: 122–138.

Gomes, B. A. 1866. *Aperçu historique sur les épidémies de cholére-morbus et de fièvre jaune en Portugal, dans les années de 1833–1865*. Constantinople: Imprimerie Centrale.

Gorostiza, J. L. and Cubero, A. R. 2013. *Ideas económicas en torno al servicio de abastecimiento de agua en la Gran Bretaña del siglo XIX*. Working papers. Madrid: Universidad Complutense. http://eprints.ucm.es/20996 (access November 2017).

Hackett, J. 1952. The birth and development of ground water hydrology—A historical summary. *Transactions of the Wisconsin Academy of Sciences, Arts and Letters*, 41: 201–206.

Juuti, P. and Latko, T. (eds.) 2005. Comparative analysis and discussion. In Petri Juuti and Tapio Latko (eds.), *Water, time and European Cities. History matters for the futures*. Tampere: Tampere University Press.

Matés-Barco, J. 2013. La conquista del agua en Europa: los modelos de géstion (siglos XIX-XX). *Agua y Territorio*, 1: 21–29.

Monteiro, M. D. 1854. Ofício n.º 848 a Carlos Ribeiro acusando a receção do relatório (Lisboa, 22/04/1854) PT/LNEG/AHGM 17–4-62.

Montenegro, A. P. 1895. *Memória sobre as águas de Lisboa*. Lisbon: Imprensa Nacional.

Pais, J. et al. 2006. *Notícia Explicativa da Carta Geológica de Portugal, escala 1:50,000, folha 34-D*. Lisbon: Instituto Nacional de Engenharia, Tecnologia e Inovação.

Paixão R. A. 2007. Vida e obra do engenheiro Pedro José Pezerat e sua actividade na liderança da Repartição Técnica da Câmara Municipal de Lisboa (1852–1872). *Cadernos do Arquivo Municipal,* 9: 99–112.

Pato, J. H. (org.) 2016. *História das políticas públicas de abastecimento e saneamento de águas em Portugal: cronologia e depoimentos*. Lisbon: ERSAR.

Pezerat, P. J. 1855. *Dados e estudos para um projecto de abastecimendo de agoas e sua distribuição em Lisboa, mandados confecionar e publicar pela camara municipal da mesma cidade*. Lisbon: Typographia do Jornal do Commercio.

Pinto, L. L. 1989. *Subsídios para a história do abastecimento de água à região de Lisboa*. Lisbon: Imprensa Nacional/ EPAL-Empresa Portuguesa das Águas Livres.

Quintela, A. and Mascarenhas, J. M. 2006. Barrages romains du Portugal. Types et fonctions. In: P. Cressier et F. Wateau (coord.), *Le partage de l'eau (Espagne, Portugal, Maroc.* Vol. 36 (2). Dossier des Mélanges de la Casa de Velásquez, Madrid: Casa de Velásquez, pp. 17–38.

Ramos, P. O. 2011. *O projecto de Louis-Charles Mary para distribuição de água na cidade de Lisboa, 1856*. Lisbon: EPAL-Empresa Portuguesa das Águas Livres.

Ribeiro, C. 1854. *Considerações geraes sobre a grande conserva de aguas projectada na ribeira de Carenque mandadas publicar pela Camara Municipal de Lisboa*. Lisbon: Typographia do Jornal do Commercio.

Ribeiro, C. 1857. *Reconhecimento geológico e hidrológico dos terrenos das vizinhanças de Lisboa, com relação ao abastecimento de águas desta cidade*. Lisbon: Typografia da Academia Real das Sciencias de Lisboa.

Ribeiro, C. 1867. *Memoria sobre o abastecimento de Lisboa com aguas de nascente e aguas de rio*. Lisbon: Commissão Geologica de Portugal. Typographia da Academia Real das Siencias.

Ribeiro, C. 1879. Relatório sobre os trabalhos de exploração nas cercanias de Belas e do Sabugo. *Revista de Obras Públicas e Minas,* 10 (116–119): 408–422, 427–453.

Rocha, R.B. *et al*. (eds.) 2008. *Paul Choffat na Geologia Portuguesa*. Lisbon: Universidade Nova de Lisboa/ Instituto Nacional de Engenharia, Tecnologia e Inovação.

Saraiva, T. et al. 2014. Lisbon water regimes: politics, environment, technology and capital (1850–2010). *Flux*, 97–98: 60–79.

Schmidt, L. *et al*. 2005. In search of (hidden) Portuguese urban conflicts. The Lisbon water story (1856–2006). In B. Barraqué (ed.), *Urban Water Conflicts*. Urban Water series – UNESCO-IHP/Taylor & Francis, pp. 69–92.

Serafim, P. 2007. A dinâmica da condução e distribuição de águas à cidade de Lisboa: a vontade régia e o empenho municipal, *Cadernos do Arquivo Municipal,* 9: 65–98.

Silva, A. F. and Matos, A. C. 2004. The networked city: Managing power and water utilities in Portugal, 1850s-1920s. *Business an Economic History On-Line*, vol. 2.

Simões, M. 2013. A obra de Carlos Ribeiro na década de 1857 a 1867 e o problemático abastecimento de água potável à cidade de Lisboa. *Estudos Arqueológicos de Oeiras*, 20: 109–126.

Sowina, U. 2016. *Water, Towns and People*. Frankfurt am Main: Peter Lang.
Tynan, N. 2013. Nineteenth century London water supply: Processes of innovation and improvement. *The Review of Austrian Economics*, 26 (1): 73–91.
Vandelli, A. 1812. Memoria sobre a gravidade especifica das agoas de Lisboa e seus arredores. *Memorias Economicas da Academia Real das Sciencias*, 4: 77–81.

Shaping Landscapes

Technology of Grandeur: Early Modern Aqueducts in Portugal

Anatole Tchikine

Abstract
Aqueduct construction remains an important yet understudied chapter in the history of early modern European technology and urbanism. Combining the symbolism of form with the utility of function, aqueducts spoke the revived language of classical architecture, serving as monumental statements of princely beneficence, civic pride, and local identity. Mobilizing community resources in an act of political will, such projects marked the consolidating power of central authorities that spearheaded urban renewal through the creation and display of the improved water supply. The case of early modern Portugal is crucial for broadening the scope of this discussion, which is usually focused on sixteenth century Italy, situating it within a larger geographical and chronological context. While revealing the deep rootedness of Portuguese aqueducts in the local traditions of construction and water management, their analysis sheds new light on the central question of continuity and rupture in the transfer of hydraulic technology and knowledge from antiquity through the Middle Ages.

1 Water and Power

Among various building types that medieval and early modern Europe inherited from classical antiquity, aqueducts arguably had the most monumental impact and, at the same time, utilitarian significance. Extending for miles across the open countryside, like the Acqua Claudia outside of Rome, or bridging valleys and rivers, like the Pont du Gard near Nîmes, these imposing, arcaded structures were

A. Tchikine (✉)
Dumbarton Oaks (Trustees for Harvard University), Washington, DC, USA
e-mail: TchikineA@doaks.org

A. Duarte Rodrigues and C. Toribio Marín (eds.), *The History of Water Management in the Iberian Peninsula*, Trends in the History of Science,
https://doi.org/10.1007/978-3-030-34061-2_7

remnants of the ancient grandeur as much as they were witness to the achievements of Roman technology and engineering. Using the natural topography and the physics of gravity flow, they offered the most effective means of creating a stable water supply known to early modern authorities, enabling the provision of households and industries and the functioning of fountains. This functionality, coupled with the aesthetics of majestic yet simple forms, continued to win the admiration of both professionals and enthusiasts, from Renaissance architects and humanists to Grand Tour travelers (Evans, 2002).

Scholars of early modern technology and urbanism mainly focus on the restoration and enlargement of ancient aqueducts, beginning with the early efforts by Pope Nicholas V (r. 1447–55) soon after the return of the papacy from Avignon and culminating in the Renovatio Urbis Romae under his sixteenth century successors. They also tend to prioritize the developments in Italy, especially Rome, over those in the rest of Europe (Long, 2010; Rinne, 2010). Yet, this period marked a revival of hydraulic projects on a monumental scale, both across and beyond the territories of the former Roman Empire, to supply the growing cities with fresh running water. Old aqueducts were repaired and new ones were built based on the same hydrodynamic principles as their antique prototypes. One example was Spain, where the restoration of the spectacular Roman aqueduct of Segovia (1484–89) was followed by a series of novel initiatives, such as the Acueducto Los Arcos in Teruel (1537–58) and the Acueducto de los Pilares (1570–99) in Oviedo (Delgado, 2017, 1: 44; Llaguno y Amirola, 1829, 2: 66–67; Criado, 1987). This wide range of locations within the Iberian Peninsula—from central Castile to Aragon in the east and Asturias in the north—was echoed by an even broader geography of aqueduct construction across the Mediterranean. Such infrastructural feats included the Ottoman project (ca. 1525–30) at Kavala in northern Greece, pursued under the patronage of Grand Vizier Ibrahim Pasha (Lowry, 2008, 236–39), and the Wignacourt Aqueduct (1610–15) in Malta, built by the knights of the Order of Saint John to supply their new capital Valletta with water. Fusing with the local Aztec and Inca traditions of construction, this grand architectural idiom soon reached the Americas, as exemplified by the over 48 km long Acueducto del Padre Tembleque (1555–72) in Mexico, whose crisply delineated adobe arcades span the arid landscape of the Papalote ravine near Santiago Tepeyahualco (Olvera García and Ocaña Ponce, 2016).

While the ultimate goal of these ambitious improvement schemes was to supply urban communities with water, the combination of monumental architecture and advanced technology made aqueduct construction an effective political tool. The importance of such projects as acts of civic beneficence is illustrated by an engraving by Jacques Callot, one of a series of prints commissioned in 1614 to commemorate the notable deeds of the late Ferdinando I de' Medici (r. 1587–1609), grand duke of Tuscany (Fig. 1). This image shows the Tuscan ruler authorizing the creation of the 6 km long, mostly aboveground, aqueduct (1592–95) that brought water to Pisa from the hills near the village of Asciano to the northeast. Although largely continuing the efforts of his father, Cosimo I (r. 1537–74), who, in the

Fig. 1 Jacques Callot, Ferdinando I orders the building of the aqueduct of Pisa, engraving, ca. 1614. Washington, DC: National Gallery of Art

1550s–60s, provided the city as well as his capital, Florence, with a system of subterranean conduits,[1] Ferdinando's initiative gave a visible expression to grand ducal authority through the use of antique-style arcaded forms. A portion of another aqueduct, known as the Acquedotto Vasariano (1593–1603), which he built at Arezzo, similarly rose above the ground carried by a long series of round arches (Fig. 2). A clear recognition of this deliberate appropriation of the monumental language of antiquity was the reverse side of the medal of Cosimo I (1567) celebrating the improved water supply of Florence (Fig. 3). Along its rim ran the inscription "OPTABILIOR QVO MELIOR" ("More desirable, just as better"), referring, in the words of Giorgio Vasari (1568), to the "benefit and convenience" that the city was to gain from its new hydraulic infrastructure (Vasari, 1568, 933); while the center featured the still mostly projected Fountain of Neptune connected to the zigzag outline of an arched aqueduct, contrary to the fact that the water was to be brought by underground piping.

[1]This work—which, in the case of Pisa, involved bringing water to the Palazzo Medici, the Piazza Cairoli, and the Piazza San Nicola—was carried out by the Medici engineer David Fortini; ASF, MP, 219, fol. 136v (Cosimo I to David Fortini 23 June 1563). For Cosimo's hydraulic projects in Florence, see Tchikine (2014), Ferretti (2016).

Fig. 2 The Acquedotto Vasariano, Arezzo, 1593–1603. *Photo* Anatole Tchikine

Fig. 3 Pietro Paolo Galeotti, bronze medal celebrating the Fountain of Neptune (reverse), ca. 1566. Trustees of the British Museum

Although carried out under princely patronage—as evidenced by the decree of February 1484, with which the Catholic Monarchs, Ferdinand and Isabella, launched work on the aqueduct of Segovia—such projects were usually funded by municipal authorities with money raised by imposing special levies on vital consumer goods. The burden of this taxation was borne by the urban population, which, in this way, directly contributed to the creation and restoration of the public water supply. In August 1572, for example, the city council of Palermo sought to extend the existing tax on wine and impose an additional one on flour—a heavy toll on the poor—to subsidize the acquisition of a fountain for the future Piazza Pretoria and the related work on conducting water from the Ainisindi torrent to the center of the city.[2] Similar duties on wine and cider, sanctioned by the royal decree of September 1570, enabled the construction of the late sixteenth century aqueduct in Oviedo (Criado, 1987, 40). Less common were direct financial interventions by the ruling authorities, whose sponsorship was often linked to large garden projects, as was the case with the Acqua Felice aqueduct, initiated, according to a contemporary source, by Pope Sixtus V (r. 1585–90) to "quench the thirst of his *vigna*" (the Villa Montalto, formerly in the area of the Termini Station in Rome).[3] A later example of this characteristic symbiosis of princely agendas and public gains was the Aqueduc Médicis (Aqueduc de Rungis), commissioned in 1612 by Queen-Regent Marie de' Medici (1575–1642) to bring water to the Luxembourg Gardens in Paris.[4] Partially retracing the course of an earlier Roman aqueduct, it would receive an extra story built in 1867–74 by the engineer Eugène Belgrand (1810–78) during the capital's "Hausmannian" renovation under the Second Empire, adding a new layer to the complex architectural and historical stratigraphy of this singular structure.

Visibly, although not always historically, linked to the distant Roman past, early modern aqueducts naturalized the consolidating power of the central authorities, serving as monumental symbols of their commitment to improving the conditions of the urban population. Whether subsidized by municipal or government funds, the success of these structures was crucial to the prestige of the ruling elite. A calculation error, an engineering failure, or financial mismanagement could lead to disastrous consequences, charges of incompetence or corruption and the damaging of professional reputation and political influence. While still cardinal, Ferdinando I gained this wisdom as the papal overseer of the Acqua Felice, whose initial fiasco, attributed to the incorrect leveling of the gradient (a subtle incline that needed to be maintained to enable the movement of water) as performed by the architect Matteo Bartolani da Città di Castello, nearly precipitated his downfall.[5] Gian Lorenzo Bernini (1598–1680) suffered a similar embarrassment in trying to conduct water from Lake Bracciano to Rome through the extended Acqua Paola aqueduct, when, contrary to his expectations, the flow failed to reach the required height in one of the twin fountains in the square of Saint Peter's (Fontana, 1696, 179–81). Such a

[2]See documents transcribed in Pedone (1986), documents section, unpaginated.

[3]ASF, MP, 5120, fol. 118r (Ferdinando de' Medici to Francesco I, 22 July 1586): "che potessi cavar' la sete alla sua vigna."

[4]For the history of this aqueduct, see Belgrand (1873–78, 3.1: 147–166).

[5]ASF, MP, 5120, fol. 118r (Ferdinando de' Medici to Francesco I, 22 July 1586).

poor display was not merely an aesthetic problem. The number of fountains and the abundance of their water served as the main measure of an aqueduct's success, which, in the absence of visible infrastructure, as in the case of the Fountain of Neptune in Florence, attested to the government's efforts to harness the liquid resource for public use (see Fig. 3).

2 Survival or Revival?

A fundamental question in the study of early modern aqueducts, as posed by Magnusson (2001), is the issue of "survival or revival," which concerns the degree of continuity in the transfer of hydraulic knowledge and technology from late antiquity through the Middle Ages. The collapse of imperial rule in the Western provinces of the Roman Empire did not mean a disintegration of their urban infrastructure, leading instead to the increased role of the ecclesiastical authorities, such as bishops and abbots, in the provision and distribution of water. In the papal capital, aqueducts continued to be maintained and occasionally restored, as testified to by the eighth century fountain decorated with a colossal bronze pinecone (the Pigna) in the atrium of the old Saint Peter's basilica, supplied by the late antique Acqua Damasiana (Rinne, 2010, 16, 18). New structures were also built, such as the aqueduct of Salerno (before 850), atypical due to its patronage by a secular, rather than an ecclesiastical, prince (Squatriti, 1998, 17–18). The urban renewal of the twelfth and thirteenth centuries marked another period of transition, with the communal authorities assuming primary responsibility for managing the public water supply. Arguably, the most remarkable hydraulic system of that age was the *bottini* of Siena, an underground network of relatively short aqueducts that fed a number of large, low-placed fountains. Taking advantage of the hilly topography of the city, this technology may have derived from earlier, pre-Roman times, drawing inspiration from the Etruscan waterworks, as exemplified by the mysterious "Labyrinth of Porsenna" in the nearby hill town of Chiusi.

Humanist scholarship—with its mission to revive ancient learning, corrupted by the ostensible period of ignorance and neglect, through the recovery of classical texts—distanced itself from this living tradition, opening an apparent rift between the practical and the theoretical foundations of Renaissance engineering. The rapid diffusion of antique writings, first in manuscript and later in print, produced a semblance of "rediscovery" of the lost knowledge that was ready to revolutionize the established modes of thinking and practice. The texts newly put into broad circulation included the first century BC architectural treatise by Vitruvius, which, in Book 8, offered a brief summary of the Roman hydraulic technology of the Augustan era. Indeed, the large wooden instrument handled by the three men on the right of Callot's print, with a long shallow groove for running a stream of water, was a close replica of the Vitruvian *chorobates*, a device for laying horizontal planes that was necessary in aqueduct design (see Fig. 1). These scholarly efforts were followed by a body of original work, such as notes and drawings illustrating hydraulic and pneumatic machinery and principles by Mariano Taccola, Antonio Filarete, Francesco di Giorgio Martini, and Leonardo da Vinci, consolidating the idea that fifteenth century theorists were breaking new ground through the infusion of ancient thought.

Professional knowledge, however, can be transmitted not only through travel, observation, and theoretical writings, but, perhaps most effectively, through artisanal practice. The notion that ancient hydraulic technology was gradually lost in the course of the Middle Ages only to be recuperated through Renaissance theory finds a curious confutation in an episode involving a group of technicians, who, in August 1612, entered what they assumed to be a medieval aqueduct on the outskirts of Florence. Laid underground and only 90 m long, it presented a low passageway wide enough for two men to walk along holding a burning torch, with a channel in between. The aqueduct supplied the thirteenth century roadside fountain, the Fonti di San Gaggio, on the present Via Senese, well outside of the perimeter of the original Roman settlement. For this reason, it could not be mistaken for part of the city's ancient water supply. Given this later origin, the aqueduct's most striking feature, according to the technicians, was the mastery of its design, proportions, and stonework, including the use of an overhead masonry vault that clearly paralleled antique examples.[6] In a city that was believed to lack fresh running water between the collapse of the Roman Val di Marina aqueduct and the new conduit system inaugurated by Cosimo I, the presence of this medieval structure signaled an unbroken tradition of hydraulic engineering that connected the recent and distant past.

The thesis that, in the case of aqueduct technology, architectural theory came after, rather than before, engineering practice finds an indirect confirmation in the fact that both Taccola and Francesco di Giorgio were born in Siena, a city long celebrated for its advanced water supply. Rather than marking a new point of departure, their theoretical output codified the professional knowledge accumulated by previous generations of craftsmen, whose practical experience offered a viable alternative to the interrupted written tradition. The popularity of Vitruvius, whose first printed edition by Fra Giocondo appeared in 1511, largely served the same goals. Moreover, the revival of hydraulic learning during the Renaissance followed an odd trajectory. After a period of intensive interest in the fifteenth century, it fell outside of the scope of mainstream architectural theory—as exemplified by the treatises by Sebastiano Serlio, Jacopo Barozzi da Vignola, and Andrea Palladio—only to reemerge towards the end of the 1580s as a narrow specialized discipline through the writings of Agostino Ramelli and Giovan Battista Aleotti (Tuttle, 2018). Unsurprisingly, the designers of early modern aqueducts differed in terms of background and training. Their examples ranged from the French-born Quinto Pierres Bedel (Vedel) (d. 1567)—the architect responsible for the Acueducto Los Arcos in Teruel and the ingenious stormwater management tunnel, Mina de Daroca

[6]ASF, CPG, neri, 797 (1629), supplica 292 (Ufficiali dei Fiumi to Cosimo II, 31 August 1612): "I condotti di questa fonte sono fatti con magnificenza, e senza risparmio di spesa, perché sono murati con molta maestria, e con la sua volticiuola sopra…".

(1555–60), in the nearby town of Daroca in Aragon—to Fray Francisco de Tembleque (d. 1589), a native of Castile who spent most of his career as a Franciscan missionary in the Viceroyalty of New Spain (Sebastian, 1962; Marcuello, 1987; Valdés, 1946).

3 Early Modern Aqueducts at Work

The construction and operation of early modern aqueducts received a detailed discussion in Carlo Fontana's *Utilissimo trattato dell'acque correnti…* (1696), an ambitious treatise that drew both on the legacy of antiquity—such as the first century AD text by the Roman engineer Frontinus—and contemporary hydraulic theory, especially the work of Galileo's student Benedetto Castelli (1628). Water, originating within a catchment area, where it was supposed to abound in quantity regardless of the season, was collected from multiple veins and diverted into a closed reservoir that served as a filtering chamber (Fontana, 1696, 17–18). From there, it entered the aqueduct, whose vaulting protected the flow from being adulterated by rain, while the windows let in enough air and light to keep the interior properly ventilated (Fig. 4). The ground below often had to be reinforced with buttressing, adding to the overall costs. Service passages both inside and outside of the aqueduct needed to be sufficiently wide to accommodate the action of two men who performed the maintenance operations.

After identifying and harnessing the source of water, the next task was to conduct it to the specified destination. While negotiating the uneven topography, the aqueduct's design was supposed to avoid unfolding in long straight lines and needed to maintain the correct gradient (Fig. 5). According to Fontana, the incline that enabled gravity flow should be at least ½ *oncia* (0.93 cm) for each *canna* (2.23 m) of length (Fontana, 1696, 19). Arches that carried the visible part of the aqueduct not only raised it to the required height, but also prevented it from getting flooded from underneath by seasonal torrents. The aqueduct's course was punctuated by a series of openings, which, while marking the underground route, also served as outlets for releasing the buildup of noxious fumes and provided access to maintenance workers (Fontana, 1696, 23–24).

Once the aqueduct reached the desired location, the last challenge was the distribution of water. The terminus was another reservoir called the *castellum aquae* in Latin, generally elevated to increase pressure. Its interior walls were perforated with multiple holes of different diameter depending on the amount of water allocated to each consumer, whether private or institutional, who received their share through underground piping. As a rule, such apportions were not free. The civic authorities of Palermo, for example, planned to cover the cost of their sixteenth century aqueduct through the sale of water concessions.[7] The standard diameter of measuring holes could range from ¼ *oncia* (0.46 cm) to 8 *once* (14.88 cm), with 1

[7]See documents transcribed in Pedone (1986), documents section, unpaginated.

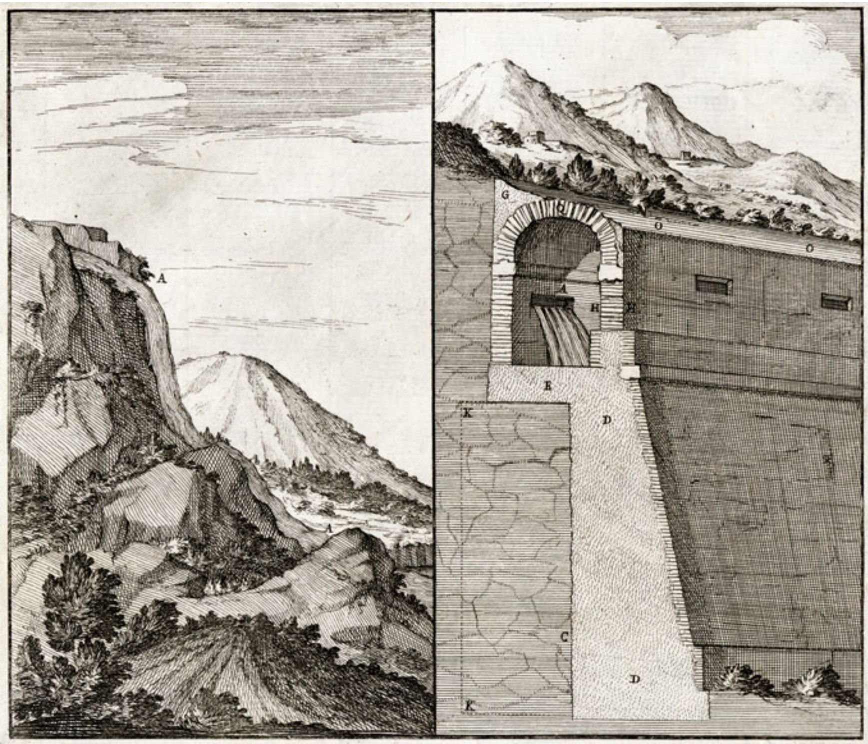


Fig. 4 Interior and exterior of an aqueduct, from C. Fontana, Utilissimo trattato dell'acque correnti… (1696). Washington, DC: Dumbarton Oaks

oncia (1.86 cm) yielding, on average, 23 l per minute. The capacity of the Acqua Vergine in Rome, for example, was around 1200 *once*, while the Acqua Felice generated 700 *once*, 30 of which (that is, about 600,000 l per day) were reserved by Sixtus V for the Villa Montalto. These measurements, however, could never be precise. In fact, in terms of the actual volume, 1 *oncia* of the Acqua Felice amounted to only half of that of the Acqua Vergine, which, therefore, through an opening of the same size, passed almost double the amount of water (Rinne, 2010, 123). The reason for this discrepancy was not only the gradient of the aqueduct, but also such factors as velocity and pressure. The incorporation of these variables—generally based on Castelli's observations—into technical calculations was Fontana's main contribution to the hydraulic theory of his day (Fontana, 1696, 28).

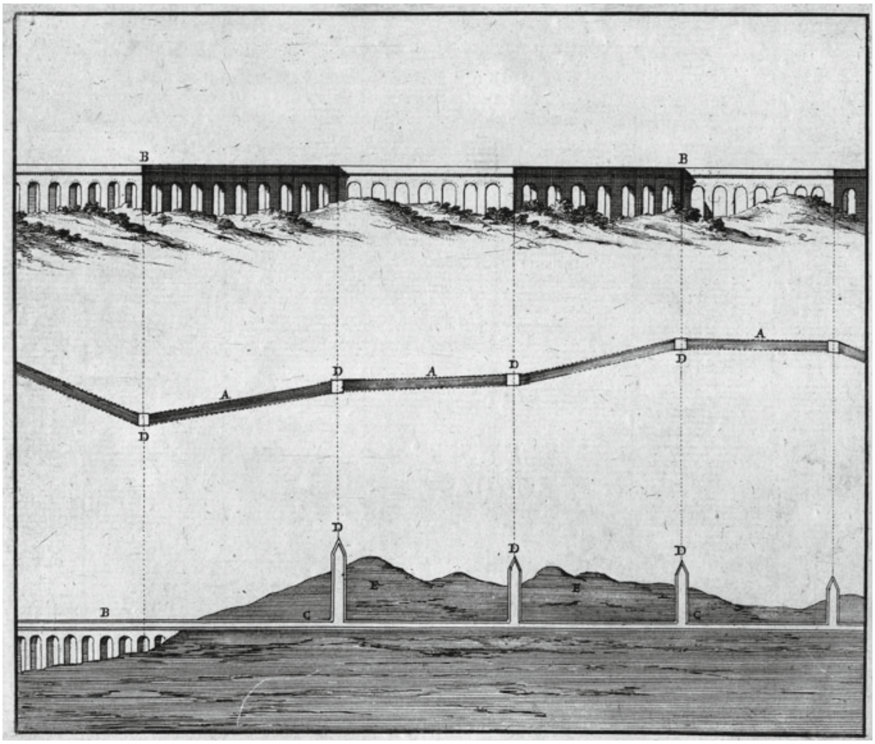


Fig. 5 Elevation, plan, and section of an aqueduct, from C. Fontana, Utilissimo trattato dell'acque correnti… (1696). Washington, DC: Dumbarton Oaks

4 The Case of Portugal

Portugal, a country with old and rich traditions of water management, presents an important case in point for broadening our perspective on both the history and the symbolic meaning of early modern aqueducts. Formerly the core of a Roman province, Lusitania, it went through a period of Muslim domination during which it adopted advanced methods of Islamic hydraulic technology, whose impact continued to resonate across the Iberian Peninsula for centuries to come. In fact, the word for fountain in Portuguese, *chafariz,* is of Arabic origin. Portugal is also home to arguably the greatest eighteenth century aqueduct, the Águas Livres (1731–48) in Lisbon, rivaled in its day only by the slightly later, but equally spectacular, Acquedotto Carolino (1754–62) in Caserta. Commissioned by King João V (r. 1706–50) and built in less than two decades, this marvel of Portuguese engineering was one of the most ambitious projects of its kind initiated in an early modern European capital and carried out on a truly majestic scale (Fig. 6).

Fig. 6 R. Black, A prospect of the new Aqueduct of Lisbon…, ca. 1750, etching with watercolor. Lisbon: Biblioteca Nacional de Portugal

In its historical trajectory, Portugal followed a pattern broadly analogous to the rest of post-Roman Europe, characterized by prolonged urban decline, with the balance of power shifting from civic to religious and feudal authorities, a process interrupted in 711 by the Muslim occupation. The ensuing period of Islamic influence not only left a lasting imprint on the practice of Portuguese agriculture, particularly strong in the southern regions of Alentejo and Algarve (see Chap. 15 in this volume), but also extended to other spheres of life, for example, the balneary culture, as evidenced by the proliferation of bathhouses (Veloso, 2012, 165–66; Trindade, 2014, 375–76). The Christian Reconquista of the twelfth and thirteenth centuries marked the consolidation of the royal authority, with new kings of Portugal, in tandem with civic councils, playing an increasingly important role in promoting the efforts of urban improvement. The presence of large medieval fountains with crenellated roofs, usually located on the outskirts of cities and displaying, often side-by-side, monarchic and municipal insignia, testifies to the collaborative nature of these attempts to supply local communities with water (Trindade, 2014, 369–73).

The best-known of these structures, the thirteenth century Chafariz de El-Rei, rebuilt by King João II (r. 1481–95) in 1487, but heavily modified since, stands at the foot of São Jorge Hill in Alfama to the east of the center of Lisbon, not far from the terminus of the ruined Roman aqueduct that used to supply the future Portuguese capital (Trindade, 2014, 379; Mascarenhas et al., 2012). Judging by its sixteenth

Fig. 7 The Chafariz de El-Rei, ca. 1570–80, Lisbon: Coleção Berardo

century depiction, this fountain, in its earlier form, presented a three-bay loggia supported by Solomonic columns and crowned with a royal coat-of-arms, with a sunken enclosed plaza at the front and featuring six sculpted animal heads that served as spouts (Fig. 7). Located in close proximity to the Tagus, one of the fountain's principal functions was to provide water to seafaring crews, as is, perhaps, suggested by the relief of a ship with billowing sails, the emblem of Lisbon, in the center. What remains unclear, however, is the exact means by which this resource was collected and directed to reach its consumers. Since the painting shows a dense crowd of people gathered next to the fountain, many of them carrying earthenware jugs, its supply must have been quite abundant. A likely analogy is the Fonti di San Gaggio in Florence, which received water from a nearby hill via a short underground aqueduct. If this parallel holds, the idea of continuity in the transfer of hydraulic technology from antiquity through the Middle Ages, as attested to by Portuguese sources (Trindade, 2014, 368), gains further ground, suggesting that, in cities with the ancient tradition of water supply, this knowledge and expertise, while no longer supported by a corpus of theoretical texts, have never fully died out.[8] Accordingly, in the case of early modern aqueducts, their impressive design mainly reflected a shift in patronage and scale, rather than marking a technological breakthrough owed to the influx of Italian Renaissance writings on architecture and engineering.

[8]Roman aqueducts existed in a number of Portuguese cities, including Lisbon, Beja, Évora, and Faro; the best preserved example is in Conimbriga (Caetano 1991, 15).

This deep-rootedness in regional traditions and historical memory—the country's unique ancient past—rather than the desire to imitate the papal ambition to restore the Eternal City to its imperial glory, remained the key principle that guided the construction of aqueducts in Portugal through the early modern period. The earliest of these efforts went back to the final decades of the fifteenth century, during the reign of João II, signaling the strengthened royal support for local attempts to spur urban renewal. This process was pioneered by the Aqueduto dos Arcos in the port city of Setúbal, south of Lisbon, begun in 1488 and financed through a combination of specially imposed taxes (known as *real de água*) and the royal subvention (Mascarenhas et al. 2013, 195).[9] Relatively short, it extended for over 3 km, bringing water from the springs of Alferrara in the hills to the northwest to the central Praça do Sapal (now Praça do Bocage). The subterranean portion of the aqueduct that was adjacent to the catchment area presented a vaulted tunnel of varying height flanked by two narrow service passages, while the aboveground part was a two-tier structure carried by a series of wide round arches (Mascarenhas et al., 2013, 197).

A similar initiative promoted by João II, parallel with the work at Setúbal, concerned the city of Évora, which, among its many antiquities, boasted the remains of an ancient aqueduct. Interrupted by the king's untimely death in 1495, this project was revived in 1533 by one of his successors, João III (r. 1521–57), at the time when the city served as a seat of the royal court. During this phase, the aqueduct's creation assumed a distinctly ideological flavor due to its championship by the country's leading humanist, André de Resende (1498–73), a native of Évora (Espanca, 1944, 10–11). Often claimed to be the founder of Portuguese archeology, he sought to enhance his antiquarian findings through the use of dubious and occasionally forged evidence, much in the tradition of a fellow Dominican, the notorious mythmaker Annius of Viterbo (1437–1502).[10] The focus of Resende's interests was the rebellious Roman general Quintus Sertorius (ca. 120–72 BC), who, from his headquarters in Évora, had made himself master of most of the Iberian Peninsula by successfully fighting, with the support of the local population, numerous armies sent against him from Italy. Developed in a polemic with another humanist scholar, Miguel da Silva (ca. 1480–1556), Bishop of Viseu, this method led to the alleged discovery of various vestiges of the antique aqueduct—especially in the area of the ruined classical temple, the so-called Templo de Diana (which, according to Resende, had served as a *castellum aquae*)—postulating the Sertorian lineage of the original watercourse, and thereby reclaiming its status as an intrinsic part of the city's historic identity (Senos, 2018).[11]

[9]Cf. the analogous situation in Elvas, where the initial work on the Aqueduto da Amoreira was also funded by a special levy on meat and fish. This tax had to be reintroduced in the early seventeenth century to continue the aqueduct's construction (Mascarenhas and Carvalho Quintela, 2008, 92, 93–94).

[10]For Resende's practice of forgery, see Spann (1981); Senos (2018).

[11]My discussion of the Água de Prata is indebted to the recent work by Francisco Bilou.

Fig. 8 The Água de Prata, Évora, 1534–56, designed by Francisco de Arruda. *Photo* Anatole Tchikine

Known as the Água de Prata by reference to the spring where its water originated, the new aqueduct, 18 km long, was supposed to overlay the ancient one, bringing it back to life both functionally and symbolically. Work was carried out under the supervision of the royal architect Francisco de Arruda (d. 1547), the creator of the Torre de Belém (1514–20), a prime example of the decorative "Manueline" style associated with the reign of King Manuel (r. 1495–1521), as echoed in the aqueduct's diminutive domed turrets that presumably marked the location of vertical shafts used as access points or air vents.[12] Such ornamental accents, however, could not compete with the monumental simplicity of tall round arcades, whose imposing forms—much more convincing than Resende's erudite arguments or forged inscriptions—served as unambiguous proof of the ancient origins of the Água de Prata (Fig. 8). This architectural strategy was particularly evident in the design of the elegant Caixa de Água (*castellum aquae*) at the aqueduct's terminus in Rua Nova (Fig. 9). Attributed to Francisco's son Miguel de Arruda (d. 1563), this building was an accomplished essay in Roman classicism, with an engaged portico that made a clear reference to the Templo de Diana as it appeared before its nineteenth century restorations, conveying a sense of unbroken continuity with the city's real or imagined antique past.

Francisco de Arruda's next related project, which he oversaw from 1537 until his death in 1547, was the Aqueduto da Amoreira in the strategically important city of Elvas on the border with Castile. Extending for only 8.5 km, and hence less than half the length of the Água de Prata, it became one of the most iconic structures associated with early modern Portugal, featuring, at its tallest part, four tiers of

[12]For Arruda, see de Sousa Viterbo (1899–1922, 1: 55–65).

Fig. 9 The Caixa de Água, Évora, ca. 1540s, attributed to Miguel de Arruda. *Photo* Wikimedia Commons

superimposed arcades. Built in a series of discrete campaigns interrupted by a chronic lack of funds and a period of political turmoil following the death of King Sebastião (r. 1557–78) during his abortive North African crusade, its design was altered several times to add extra height, necessitating the use of colossal and somewhat overbearing buttressing (Mascarenhas and Carvalho Quintela, 2008). The resulting structure was the product of successive interventions by four different architects, who, in addition to Arruda, included Afonso Álvares (d. 1580), Diogo Marques Lucas (d. 1640), and Pero Vaz Pereira (d. 1643).[13] Similarly to the Água

[13]For these architects, see, respectively, de Sousa Viterbo (1899–1922, 1: 12–15; 2: 139–141; and 2: 249).

de Prata, the Aqueduto da Amoreira was distinguished by its wildly meandering route, especially at the point where it displayed the largest number of stories. This zigzag outline was probably due less to the desire to increase the movement of water (cf. Fig. 5) than to the need to negotiate the patchwork of different properties that lay in the aqueduct's way.

Such prolonged periods of construction closely followed by repair and expansion projects meant that early modern Portuguese aqueducts were constantly works in progress.[14] Supervised by special officials with the title of *visitadores* or *provedores do cano*,[15] their operation was governed by statutes known as *regimentos* that regulated the distribution of water and imposed fines for its illegal diversion or acts of vandalism. A prerogative of the crown, such ordinances were issued or amended with notable frequency, typically by each successive ruler, and often involved the imposition of special taxes, especially on meat and fish, to support the maintenance work (Conde and Magalhães, 2008, 94).[16] They could not, however, avert damage caused by natural disasters, especially earthquakes, or the exigencies of warfare, as in the case of the Aqueduto da Amoreira, which suffered partial destruction only a few decades after its completion in 1628 due to a major fortification campaign in Elvas in the second half of the seventeenth century (Mascarenhas and Carvalho Quintela, 2008, 94–95). The principal beneficiaries of water concessions were large religious institutions, such as monasteries and hospitals, as well as members of the high nobility, who sometimes received runoff from public fountains (Espanca, 1944, 25–27).[17] The needs of the rest of the urban population were satisfied by a system of *chafarizes* and numerous water sellers, whose profession continued to thrive into the early twentieth century.[18]

Urban renewal and expansion, however, were not the only factors that brought early modern aqueducts into existence. A prominent monument of sixteenth century Portuguese engineering was the Aqueduto dos Pegões Altos of the Convento de Cristo in Tomar, the seat of the military Order of the Knights of Christ and an important monastic establishment (Antunes, 2012). Begun in 1593 by the Bolognese architect Filippo Terzi (1520–97) in the service of King Philip II of Spain (r. 1556–98)—the first monarch of the Philippine Dynasty that ruled Portugal from

[14]For example, by 1575, the Água de Prata, although still unfinished, was already in need of urgent repairs (Espanca, 1944, 24–25). The Aqueduto dos Arcos in Setúbal had to undergo similar maintenance operations in 1601–13 (Mascarenhas et al., 2013, 196).

[15]In the case of the Água de Prata, the office of *visitador do cano* was held by Francisco de Arruda, from 1542 until his death in 1547 (Sousa Viterbo, 1899–1922, 1: 64). For this position, see also Conde and Magalhães, 2008, 95.

[16]For the *regimentos* of the Água de Prata, see Espanca, 1944, 21–24, 33–37; Conde and Magalhães, 2008. For the regulations concerning the aqueduct of Setúbal, see Mascarenhas et al., 2013, 195.

[17]On August 26, 1557, for example, Dowager Queen Catarina of Austria (1507–78), acting as regent during the minority of King Sebastião, conceded runoff of the Chafariz das Portas de Moura (1556) in Évora to Teodósio (1510–63), Duke of Braganza, for the irrigation of his orchards (Espanca, 1944, 22).

[18]For water sellers in Coimbra, still active through the late nineteenth century, see Veloso, 2012, 175.

Fig. 10 The Aqueduto dos Pegões Altos, Tomar, 1593–1619, designed by Filippo Terzi. *Photo* Wikimedia Commons

1581 until the Restoration War of 1640—this aqueduct stretched for over 6 km, featuring, in its most imposing part, a two-story arcade that carried an open channel with a service passage running along the side (Fig. 10).[19] What made this structure distinct, however, was the lower order of arches, whose pointed profile gave them an unmistakably Gothic character (Caetano, 1991, 49). Using the additional buttressing strength of medieval construction, the Aqueduto dos Pegões Altos thus sported a distinctly national style of Portuguese conventual architecture, as exemplified by the Jerónimos monastery in Belém, a jewel of the glorious Manueline era.

[19]The need for this walkway, however, is not entirely clear, since service passages in the part of an aqueduct elevated above ground were not common in Portugal. Compared to the adjacent open channel, it has a flat, rather than rounded, bottom, is positioned at a lower level, and, instead of sidewalls of equal height, is flanked by a low parapet. Adding a secondary conduit to increase the capacity of the aqueduct would have involved widening the whole structure, unless the new watercourse could be placed above the original one (as in the Aqueduto da Amoreira in Elvas). Such massive rebuilding was clearly not the case at Tomar, suggesting that the passage in question was part of the original design and that its function was different. A likely reason for its inclusion concerns the substantial financial resources commanded by the monastery, which could afford this additional expense.

While employing hydraulic technology that derived from antiquity, the aqueduct's Gothic appearance subtly related it to the monastic water management practices of the Middle Ages, tying the ancient tradition to the more recent past.

The construction of the Águas Livres in Lisbon—begun almost a century and a half later, after the end of the Spanish supremacy—bolstered these symbolic connections by bringing them together in an ambitious display that celebrated the new golden age of the Portuguese monarchy (see Fig. 6). Necessitated by rapid urban expansion to the west, beyond the dominant Convento do Carmo, work on the new aqueduct was initiated by João V in response to the 1728 plea by Cláudio Gorgel do Amaral—the civic official (*procurador*) responsible for the western half of the city (divided, between 1716 and 1740, into two municipal entities)—and was the collective work of a brilliant constellation of architects and engineers who were active in Portugal at the time (Cunha Saraiva, 1938, 6–7). Beginning at the Águas Livres spring in Belas, north of Queluz, it extended for 18 km, uniting along its way a number of different branches that comprised 58 km of under- and aboveground channels (Caetano, 1991, 66). Its terminus was the Mãe de Água in the Amoreiras district, a capacious reservoir designed by the Hungarian Carlos Mardel (1695–1763) close to the point marked by the prominent triumphal arch where the water entered the city. The aqueduct's origin, as conveyed by its name, was not accidental. The need to provide the Portuguese capital with a better system of water supply, already pressing in the early sixteenth century, was famously voiced by the artist Francisco de Hollanda (1517–85), who, in his treatise *Da fábrica que falece à cidade de Lisboa* (1571), addressed to King Sebastião, urged the monarch to restore the ancient Roman aqueduct that had been fed by the same source (Hollanda, 1929, 217–218). The accompanying drawing represented Hollanda's project for a colossal fountain in the Rossio area decorated with the crowned figure of Lisbon holding a ship, which was surrounded by four elephants spouting the Águas Livres water from their gigantic trunks.

A realization of this Renaissance dream, the Águas Livres made a particularly spectacular show as it crossed the valley of Alcântara, with its series of tall pointed arches, the largest of which, 65 m high, reached 29 m in width. Although primarily considered a functional choice (Murphy, 1795, 179–180), this use of a Gothic structure, which withstood the disastrous earthquake of 1755, left no doubt as to the aqueduct's post-classical origin. Combining ancient hydraulic technology and medieval construction technique on an unprecedented scale, the Águas Livres was a tour de force of early modern engineering whose dramatic effect and utilitarian role opened a path towards the modernization of Lisbon during the Pombaline reforms under King José I (r. 1750–77). A prodigious architectural monument, the aqueduct proudly asserted its place as a bridge linking the past and the future.

Acknowledgements I would like to thank Ana Rodrigues for inviting me to contribute a chapter to this volume and for providing me, with the help of Magdalena Merlos Romero, with source materials in the course of its preparation. My additional thanks go to John Pinto for sharing with me his knowledge of the Vitruvian *chorobates* and to Jan Ziolkowski for his help translating the Latin motto on the medal of Cosimo I.

Bibliography

Manuscript Sources

Florence, Archivio di Stato, Mediceo del Principato (ASF, MP), 219.
Florence, Archivio di Stato, Mediceo del Principato (ASF, MP), 5120.
Florence, Archivio di Stato, Capitani di Parte Guelfa, numeri neri (ASF, CPG, neri), 797.

Printed Sources

Fontana, C. 1696. *Utilissimo trattato dell'acque correnti…* Rome: Buagni.
Holanda, F. de 1929. "Da fábrica que falece à cidade de Lisboa por Francisco de Olanda (1571)." *Archivo español de arte y arquelogía,* vol. 15 (4): 209–224.
Murphy, J. 1795. *Travels in Portugal…* London: Strahan et al.
Vasari, G. 1568. *Vite de' più eccellenti pittori, scultori e architettori*. Florence: Giunta.

Secondary Literature

Antunes, T. M. 2012. "O Aqueduto do Convento de Cristo, em Tomar. Análise preliminar da estrutura hidráulica." *Revista Portuguesa de História,* vol. 43: 265–289.
Belgrand, E. 1873–87. *Les travaux souterrains de Paris,* 5 vols. Paris: Dunod.
Bilou, F. 2010. *A refundação do Aqueduto da Água da Prata, em Évora (1533–1537)*. Lisbon: Edições Colibri.
Caetano, J. O. 1991. *Aquedutos em Portugal*. Lisbon: Liber.
Conde, A. & Magalhães, O. 2008. "Abordagem educativa de um monumento: o aqueduto de Évora." In: García, A. E. M. & Núñez, E. M. (eds.), *El patrimonio cultural: tradiciones, educación y turismo*. Cáceres: Imprenta Provincial de Cáceres.
Criado, M. I. P. 1987. "El Acueducto de los Pilares de Oviedo." *Liño: Revista anual de historia del arte,* vol. 7: 39–54.
Cunha Saraiva, J. da 1938. *O Aqueduto das Águas Livres e o arquitecto Ludovice*. Lisbon: s. n.
Delgado, D. C. 2017. *Preservar los puentes. Historia de la conservación patrimonial de la ingeniería civil en España (siglo XVI–1936).* Madrid: Fundación Juanelo Turriano.
Espanca, T. 1944. *Cadernos de história e arte eborense*. *O Aqueduto da Água da Prata*. Évora: Nazareth.
Evans, H. B. 2002. *Aqueduct hunting in the seventeenth century: Raffaello Fabretti's* De aquis et aquaeductibus veteris Romae. Ann Arbor: University of Michigan Press.
Ferretti, E. 2016. *Acquedotti e fontane del Rinascimento in Toscana: acqua, architettura e città al tempo di Cosimo I dei Medici*. Florence: Olschki.
Olvera García, J. & Ocaña Ponce, J. A. (eds.) 2016. *Acueducto del Padre Tembleque: patrimonio de la humanidad*. Toluca: Universidad Autónoma del Estado de México.
Llaguno y Amirola, E. 1829. *Noticias de los arquitectos y arquitectura de España desde su restauración,* 4 vols. Madrid: Imprenta Real.
Long, P. O. 2010. "Water supply." In: A. Grafton, G. W. Most, & S. Settis (eds.), *The classical tradition*. Cambridge, MA, and London: Belknap Press, 981–982.

Lowry, H. W. 2008. *The shaping of the Ottoman Balkans, 1350–1500: the conquest, settlement & infrastructural development of northern Greece*. Istanbul: Bahçeşehir University Publications.
Magnusson, R. J. 2001. *Water technology in the Middle Ages: cities, monasteries, and waterworks after the Roman Empire*. Baltimore and London: Johns Hopkins University Press.
Marcuello, J. F. 1987. "El túnel o 'mina' de Daroca: obra hidráulica del siglo XVI." *Revista de obras públicas,* vol. 3257: 253–261.
Mascarenhas, J. M. de & Carvalho Quintela, A. de 2008. "O Aqueduto da Amoreira e o sistema de abastecimento de água a Elvas." *Monumentos,* vol. 28: 92–101.
Mascarenhas, J. M. de et al. 2012. "O aqueduto romano de *Olisipo:* viabilidade ou utopia? Ensaio de traçado apoiado em modelação geográfica." *Revista Portuguesa de História,* vol. 43: 239–264.
Mascarenhas, J. M. de et al. 2013. "The Aqueduct of Setúbal (Portugal). Characterization and development as heritage." In: Wiplinger, G. (ed.), *Historische wasserleitungen: gestern, heute, morgen*. *Internationales Symposium mit besonderer Berücksichtigung ihrer denkmalgerechten und betriebssicheren Erhaltung*. Leuven: Peeters, 195–203.
Pedone, S. 1986. *La Fontana Pretoria a Palermo*. Palermo: Giada.
Rinne, K. W. 2010. *The waters of Rome: aqueducts, fountains, and the birth of the baroque city*. New Haven and London: Yale University Press.
Sebastian, S. 1962. "El arquitecto frances Quinto Pierres Vedel." *Archivo Español de Arte*, vol. 35: 289–301.
Senos, N. 2018. "An appropriate past for Renaissance Portugal: André de Resende and the city of Évora." In: K. Enenkel & K. Ottenheym (eds.), *The quest for an appropriate past in literature, art and architecture*. Leiden and Boston: Brill, 127–150.
Sousa Viterbo, F. de 1899–1922. *Diccionario historico e documental dos architectos, engenheiros e constructores portuguezes ou a serviço de Portugal*, 3 vols. Lisbon: Imprensa Nacional.
Spann, P. O. 1981. "Lagobriga expunged: Renaissance forgeries and the Sertorian War." *Transactions of the American Philological Association*, 111 (1981), 229–235.
Squatriti, P. 1998. *Water and society in early medieval Italy, AD 400–1000*. Cambridge: Cambridge University Press.
Tchikine, A. 2014. "*L'anima del giardino*: water, gardens, and hydraulics in sixteenth-century Florence and Naples." In: M. G. Lee & K. I. Helphand (eds.), *Technology and the garden*. Washington, DC: Dumbarton Oaks, 129–153.
Trindade, L. 2014. "A água nas cidades portuguesas entre os séculos XIV e XVI: a mudança de paradigma." In: M. del Mar, L. Bartolozzi & V. Méndez Hernán (eds.), *Patrimonio cultural vinculado con el agua: paisaje, urbanismo, arte, ingenieria y turismo*. Mérida: Editora Regional de Extremadura, 367–380.
Tuttle, R. J. 2018. "Il sistema delle acque a Bologna nel Rinascimento." In: E. Ferretti and F. Ceccarelli (eds.), *Il Nettuno architetto delle acque: Bologna. L'acqua per la città tra Medioevo e Rinascimento*. Bologna: Bononia University Press, 41–50.
Valdés, O. 1946. "Fray Francisco de Tembleque." *The Americas*, vol. 3 (2): 223–233.
Veloso, M. T. N. 2012. "A água na cidade de Coimbra durante a Idade Média." *Revista Portuguesa de História*, vol. 43: 159–181.

Dams in the Renaissance Gardens of the Iberian Peninsula

Carmen Toribio Marín

Abstract

Dams constitute an important dimension of many of the hydraulic systems developed by different cultures down through history. Not only relevant for their practical benefits, the scale of the territorial intervention entails deep impacts on the surrounding landscape. Great dams store large volumes of water and create perfectly horizontal surfaces within organic perimeters, which fluctuate according to the topography and the amount of water stored at each moment. In addition, they produce radical changes in their ecosystems, with important environmental consequences. Usually linked to agricultural developments, during the reign of Philip II in Spain, these structures undertook symbolic values as key facets of the territorial reorganization undertaken in that period to affirm the king's power. Generally attributed to Flemish and Dutch constructors (called "diqueros" in Spain), they also reflect the survival of the Roman techniques that were profusely employed on the Iberian Peninsula. Although these extraordinary examples have been subject to well-grounded prior research, the importance and originality of their widespread use in garden ensembles during the reign of Philip II represents an unusual fact that deserves highlighting. The exceptional example of El Bosque de Béjar, where a dam features as the main element of an axial terraced garden, complements the varied royal initiatives (Aranjuez, Casa de Campo, Valsaín, El Escorial and La Fresneda; all with irrigation structures that also served playful or compositional purposes). Based on documentation and field work, this chapter focuses on the general arrangement of these structures, their relationships with garden layouts and, especially, the hydraulic system of La Fresneda, one of the least known and best preserved.

C. Toribio Marín (✉)
ETSAM/UPM (School of Architecture of Madrid), Madrid, Spain
e-mail: carmentm@gmail.com

A. Duarte Rodrigues and C. Toribio Marín (eds.), *The History of Water Management in the Iberian Peninsula*, Trends in the History of Science,
https://doi.org/10.1007/978-3-030-34061-2_8

1 Introduction

In 1492, Granada was annexed under the reign of the Spanish Catholic Kings, following nearly 800 years of Islamic rule. Only 35 years later, Philip II was born in Valladolid. In this brief period, in Spain, as in other European countries, the medieval mindset began to give way to modern age thought and culture. The consequences were not limited to political, social or artistic forms of expression, but also gave rise to a new way of understanding the territory, and perceptions of the landscape underwent a deep transformation. The 1561 choice of Philip II in favour of Madrid as the Court capital, after discarding Toledo and Valladolid (both locations with important water supply problems), led to the establishment of Royal Sites around the main city that became equated with the idea of royalty. Located on the central plateau, the new settings representing the king displayed a clear and evident need for water supplies that was addressed through different means. Experience and experimentation in the construction of great irrigation dams clearly show how the Renaissance extended beyond the arts; this technique was also reborn in a period when the same structures developed for agricultural fields were applied to garden ensembles. Often the result of an outstanding construction method, they not only held practical usages, but also acquired symbolic meanings. Although they have been the subject of previous studies, the importance and originality of their widespread usage in garden settings during the reign of Philip II in Spain is an unusual fact that deserves highlighting. Moreover, the ways in which the hydraulic system influenced the spatial organization of gardens has yet to be fully explored. Examples such as the dams at the Royal Sites of Valsaín, Aranjuez, Casa de Campo, El Escorial and La Fresneda (the least known and best preserved), as well as the extraordinary pool at El Bosque de Béjar, provide us with the opportunity to analyse the ways in which water management became embedded in garden architecture.

Dams on the Royal Sites resulted from technological developments that were also encouraged by the construction of large water reservoirs for agricultural lands. These were fundamental in a territory of such extraordinary diversity as the Iberian Peninsula, with its strong contrasts in climate, relief, vegetation and soil, and where, despite the existence of an important Atlantic area, most of the geography displays a Continental or Mediterranean climate, both characterized by scarce precipitations. In addition, the Spanish hydrography features rivers that, except for those of the wet North, experience severe droughts and low baseflows. Even the greater volumes of water in the major peninsular rivers have traditionally been difficult to exploit, given that they are fed by tributaries with major fluctuations in their hydrological regimes. Since remote times, therefore, the need to make recourse to natural water resources has conditioned the peninsular landscape that has thus been correspondingly shaped by two different approaches to the water demand problem. On the one hand, there has been rational usage of underground water that led to the construction of different types of subterranean galleries, while, on the other hand, other solutions were focused on making best use of surface waters. During the medieval era, Muslims incorporated techniques that had originated in the East into a territory that had already developed through recourse to irrigation at least since Roman times. The numerous weirs built to intercept river water were effectively adapted to sites with ever-changing conditions, but, except for some notable exceptions (such as the irrigation pools near Castillejo of Monteagudo in Murcia), all of these structures shared a common characteristic: they were small-sized dams. The radical innovation of the Christian era involved overcoming the dependence on rivers through the aid of large dams. Constructions of this period resulted in such brilliant examples that Norman Smith came to regard Spain as the birthplace of modern dams (Smith 1971: 32). Without forgetting the Christian and Islamic contributions, the Renaissance period entailed the recovery of the distant Roman hydraulic tradition, which had already produced such monumental works as the dams of Proserpina and Cornalvo (Mérida).

Dams are one of the most singular and complex of hydraulic works. Of all of the constructions related to water, interposing an artificial barrier on a river to retain its flow is perhaps the one that produces the greatest transformations in the landscape. According to Casado (1983: 11), this construction type may be described as violent, and hardly understandable by humans in their initial relationships with water, as there are no examples in nature. Faced with the linear flow of rivers, the dam forms an artificial lake (and, as such, incurs the risk of devastating floods should the system fail) that swamps the lowlands of valleys, but transforms arid lands downstream into areas of fertile, changing flora and fauna, as well as altering the climate and population distribution. These are construction projects on a territorial scale, with broad areas of direct influence that become very extensive in some cases. During the Renaissance in Spain, some structures that recovered the monumentality of their Roman predecessors coexisted with much simpler constructions, created by placing wooden piles directly into the ground and filling the void with breakwater. In a first epoch, the most common solutions were straight or polygonal gravity dams, in which the horizontal water pressure was offset by the vertical mass of the wall. For stability, the resulting force, slanting downstream, had to reach the lower third of the wall, which had to be very thick, decreasing in section towards the crest. The result was a characteristic trapezoid profile that was, on occasion, reinforced by attaching an earthen fill-shoulder downstream. The second third of the sixteenth century distinguishes itself for the emergence of other solutions: buttress dams, which held interesting medieval precedents, reappeared; and a greater novelty sprang up, arch dams, undoubtedly the great technological innovation of the time (López Gómez 1992: 98). Due to their respective typologies and situations, we may consider three distinct groups: the extraordinary Levantine group of dams, the Extremadura buttress dams linked to flour mills and, finally, the interesting examples of the dams built for Royal Sites. Each of these groups incorporates splendid cases of adaptation to the specific characteristics of the surrounding environments, which themselves feature all of the variations typical of the Spanish landscape.

All of these dams, irrespective of their complexity and appearance, efficiently fulfilled their mission: to store or derive water meant for water supply, irrigation or industrial uses. Actions on such a scale and complexity mainly held economic purposes. The primary aim of the great majority of Renaissance dams was to solve irrigation water supply problems, thus enabling the agricultural development of areas that had formerly suffered from water shortages, a common aspect of large areas of the Peninsula. Such is the case with the Levantine group of dams, with the master builder Joanes of Temple constructing the first, Almansa, in 1596. Today, this represents the world's oldest curved gravity dam still in operation. The next dam, Tibi, held the dam height record for three centuries, with its 42 m (Smith 1975: 25). The project scale exceeded the capacities of the local authorities, thus motivating the intervention of Philip II, who sent the engineer Juanelo Turriano to advance the project.[1] However, construction work was soon paralyzed, only restarting in 1580 under the direction of Juan Bautista Antonelli, an Italian military engineer, before completion 14 years later.[2] The last dam in this group, Elche, presents similar characteristics, but is of a lower height. Built along the complex Vinalopó riverbed, this is considered the first dome dam to be constructed anywhere in the world.[3] All three are still operational today, and form part of an area of outstanding scenic interest, constituted by the valley in which the waters are collected and led to the delivery point between spectacular ravines, the large area in which the waters are impounded before the irrigation channels distribute them across a territory deeply transformed by irrigation.

Occasionally, linked to the dam's main purpose, or sometimes independent of it, these structures also served other purposes, originated by social circumstances: during the Renaissance, there was a change in the diet of the Middle Ages, which contained an important meat component in favor of cereals, motivating a significant increase in the construction of mills. Among them, the *rodezno* mills required works of a certain complexity: the construction of a dam that accumulated and raised the waters of the stream or river and a channel running towards the

[1]Its origins interlink with the disputes triggered by the irrigation of the orchard lands of Alicante since ancient times and that ended with the initiative of two neighbours from Muchamiel to build a large water tank. Fernández Ordóñez provides details of the history of its construction and its technical characteristics (1984, 224–231). Juanelo Turriano, born in Lombardy and a watchmaker to King Charles V, was well known in Spain for the hydraulic machine that he built to raise the water from the river, located almost 100 m below, to the Alcázar of Toledo. The system ranks as one of the best hydraulic works of the European Renaissance.

[2]The activities of Antonelli in Spain at first focused on the construction of fortifications and defences on the Levantine coasts and ports of North Africa. From 1580 to 1588, the year of his death, he undertook complex hydraulic works, such as the Tibi dam, and produced navigation proposals for the rivers of Spain, characteristic of this period. Some of Antonelli's drawings are conserved, among them, a general plan of the location of the Tibi dam, closer to a pictorial representation of the territory than to any engineering description for a hydraulic project.

[3]With a height of 22 m, its thickness at the base is 12 m and only 9 m at the crest (Aguiló 2002, s/n).

mill itself.[4] In Extremadura, for the first time on the Peninsula, the *albuheras* applied a new solution. These constructions included an important innovation that consisted of building a dam with one or more mills attached to its wall, sometimes complementing the structure through the use of buttresses (García-Diego 1994: 118). Usually, these dams served the so-called *regolfo* mills, a particular type of mill in which the wheel, or group of wheels, was inside of a pressure tank (the bucket) to which the water was delivered. From Extremadura, this type of solution extended progressively across the rest of the Peninsula. Most of the examples are located between Alcántara and the southern part of Cáceres, a fact that has led to consideration that the military and religious order of the same name was, perhaps, responsible for the construction of some of these dams (García-Diego 1994: 49). A geological constraint has also been pointed out: the area coincides with the granite batholith that runs through the province of Caceres, which makes it almost impossible to excavate for wells, thus making recourse to surface water the only option for solving water demand (Plasencia 2007: 11). These Extremadura buttressed dams, or *albuheras*, deployed water, not only for irrigation, but also as a source of energy to move artefacts such as water wheels, forges and sawmills.

This type of structure was commonplace in this region during the sixteenth century. For example, one of the oldest, Castellar (about 1550) now lies under the waters of a later dam. The Albuhera of San Jorge, near Trujillo, is of special interest for its associated features: begun around 1571 (although unfinished until 1690, an inscription with Renaissance ornamentation on the door of one mill dates this structure to the reign of Philip II, specifically, to 1577), this holds particular relevance due not only to its early construction, but also to the complete hydraulic system of the three mills interlinked by over 500 m of still existing and now still preserved channels (Fernández Ordóñez 1984: 218–223). The project took place under the supervision of the master builders Sancho de Cabrera and Juan García Tripa, along with the architect Francisco Becerra, who had designed the chapel at the Monastery of Guadalupe, where he may have eventually viewed the pool formed by the dam that provides the outstanding precedent to all of these examples. Here, however, he adopted a different solution, building two walls of granite ashlar with six buttresses, also made of granite; two were located inside of the mill attached to the central dam section, with the remaining grouped in pairs on either side. The interest in this construction increases still further when verifying its possible interconnection with a potentially hypothetical garden, perhaps belonging to the Renaissance period and now vanished, except for a few archaeological indications: in an enclosure placed immediately underneath the dam, a low transversal wall of perfectly cut granite, running 33 m in length, produced a new surface of water. Its overflow, in the form of a fountain flanked by figures, poured into a smaller pool in the same area that was itself accessed by two symmetrical

[4]The hydraulic wheels of the *rodezno* mills had a vertical axis, of the so-called Scandinavian type, an evolution of the Vitruvian wheels of horizontal axis. *Aceñas* were much more rudimentary and less efficient: they were built directly over the river course, without an attached dam, relying solely on the force of the current to move vertical hydraulic wheels (Plasencia 2007: 19–22).

staircases. On the right bank, a ditch, protected behind a wall, ensured that the water passed and either filled the pond or continued along the area bordering the garden, where a table with granite benches lies in front of the now destroyed palace. This structure has been utterly neglected in recent times, despite the undoubted protection that such a singular ensemble deserves. The buttress dam construction solution was exported to America, where Francisco Becerra may have built other dams of the same type that have not yet been documented. This dam style also survived in Extremadura, where there are the notable examples of Casabaya (1693) and Feria (1747), attesting to the continuity of this constructive solution. However, in singular ways, the style also appeared in some of the Royal Site-linked dams, where, as might be expected, the technological development that fostered the construction of large agricultural water reserves was implemented in parallel. Thus, water accumulation represented an objective in the early stages of work in places such as Valsaín, La Fresneda, El Escorial and Casa de Campo. Dam construction by the team made up of Juan Bautista de Toledo and Piet Janson (nicknamed "the Dutch" due to his origins), always working in conjunction with local master builders, was a constant at all Royal Sites.

Valsaín was a medieval hunting lodge that Philip II, then still a prince, had rebuilt shortly after his return from the Netherlands, clearly under the influence of his experiences there. The first works included the infrastructures necessary to ensure an appropriate water supply.[5] A channel that brought water from Peñalara ran alongside the fence, establishing the enclosure formed by the palace with the Small Forest to the north and the King's Forest to the south. Up to six dams were then constructed around the palace. Although now disappeared, except for some remains, they are referenced in a long report by Gaspar de Vega dated July 1563 that provides an account of the possible location and dimensions of the ponds proposed by Piet Janson. Of major interest is the one situated near the river, perhaps the third pond to which Gaspar de Vega refers, whose solid stone wall is still visible in Brambilla's 1821 picture (Fig. 1). Located adjacent to the King's Garden, this probably formed part of an axial terraced ensemble that likely started near the river and ended in the grotto fountain in the Queen's Garden. Thus, the spatial sequence of linked terraces unusually concluded in an enclosed courtyard garden, where there was a raised promenade installed in order to enjoy views over the gardens, the landscape and sections of the hydraulic system.

As in Valsaín, but far more clearly, a dam also constitutes part of the garden layout in El Bosque de Béjar.[6] Here, the hydraulic structure is integrated into a great axis that runs over 400 m in order to organize the terraced space of this suburban

[5]For further information about Valsaín, the Phd thesis by Pablo Gárate (2012) represents a key reference work.

[6]Built in the mid-sixteenth century for the Zuñiga family, the Dukes of Plasencia, El Bosque is a suburban Renaissance villa that today preserves a great proportion of its features. For information on this topic, see the proceedings of the different seminars that took place between 1994 and 2004 (coordinated by Urbano Domínguez Garrido and José Muñoz Domínguez). The dam is addressed in detail in Muñoz Domínguez et al. (2009). The axial organization of the ensemble and its relationship with Italian models is discussed in Muñoz Domínguez (2015).

Fig. 1 Fernando Brambilla. View of Valsaín. collection of views of the royal sites and madrid. 1821–1833 (Fernando Brambilla (pintor), Henri Pierre Léon Pharamond Blanchard (litógrafo); vista del real palacio de Balsaín tomada desde el mediodía. Photo: Patricia López Eguíluz, Museo del Romanticismo)

Renaissance villa (Fig. 2). Not only a compositional feature, the waters also provided for a fishery and, following works in 1592 to increase the size, also served to satisfy the great demand for water required by the "Tinte del Duque," a tannery installed by Francisco III of Zúñiga a short distance away from the garden (demolished in 2001).

Other dams were located outside of gardens. However, usually larger in size, they also formed important parts of architectonic ensembles. Aranjuez ranks among the most significant, a site transformed during the Renaissance into a centre of hydraulic experimentation. During Philip II's reign, the main operation laying irrigation channels from the Rivers Tagus and Jarama was complemented by the construction of an extensive water reservoir: The Mar (or Sea) of Ontígola.[7]

[7]45 km south of Madrid and the same distance from Toledo, Aranjuez has been a favoured territory ever since the distant past. During Philip II's reign, it served as the site for veritable experimental hydraulics fieldwork. A classic account on the history of the site comes from Álvarez de Quindós (1804). More recently, Merlos Romero (1998) and Sanz Hernando (2009) have made interesting contributions.

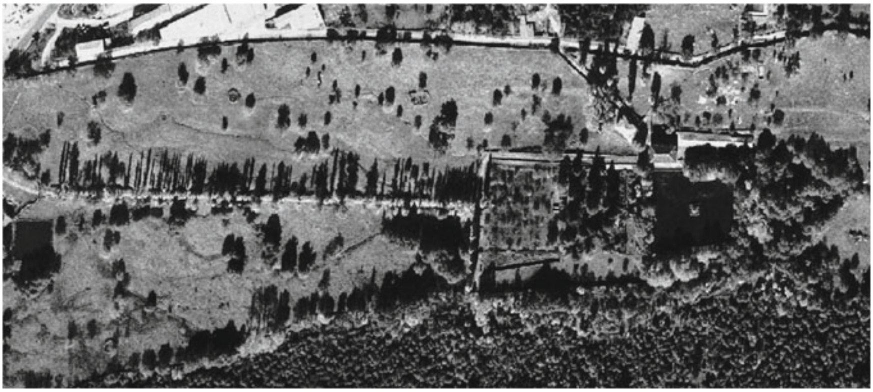


Fig. 2 Aerial view of El Bosque (Fotol, 1973–1983 CC-BY 4.0 scne.es)

According to Quindós, the work took its precedent from the *caz* ("the Cacerón") that Don Gonzalo Chacón ordered built in the meadow of Ontígola to collect the excess water from the springs and irrigate the pastures of Aranjuez (Quindós 1982 (1804): 335–340). In the time of Philip II, the need to obtain more water arose, given that the canal called the Aves lacked the capacity to irrigate the gardens and the streets, as it was located at a lower altitude and did not have enough pressure. According to the scant surviving accounts by Juan Bautista de Toledo, a dyke, initially made of earth, was built in 1561. "Sea," the name henceforth given to it, has lasted ever since, suggesting the capacity to dam a significant volume of water right from the first construction.[8] Further discoveries of new springs by *zahoríes*, who systematically worked across the Spain of that time, despite the scepticism of the technicians, led to successive changes to the first project, which was hit by repeated collapses. The successive failures led to the reinforcement of the original double ashlar masonry wall, backed up by embankment-adding buttresses. As with other major hydraulic projects, the structure was not based on any brilliant application of a new technique, but rather sprang from the practice of trial and error that adapted traditional techniques to the new requirements. The final structure, arrived at in 1572, constituted a dam of about 140 m in length and 10 m thick, running to a height of over 6 m (it must originally have reached 10 m), reinforced by five buttresses in order to hold a large volume of water: 0.4 hm^3.[9]

[8]Quindós refers to usage of the word 'sea' in the naming of this structure, a word that became very common in Spanish gardens (Quindós 1982 (1804), 336). In the same Aranjuez, the "Mar Tonta" was installed in the same period as the Huerta de los Estanques, with Father Sigüenza also comparing the largest pond of the Fresneda with a sea; the extensive reservoir at La Granja was later to receive the same name.

[9]García Tapia and Rivera Blanco (1985) provide a detailed explanation of all of the avatars of a technically complex work that, despite not being a real buttress dam (it resists by gravity), is nevertheless considered the precedent of modern structures of this type.

Dams were built on every Royal Site near Madrid. However, the most extraordinary of them all was never constructed, planned in a 1563 memorial by Janson for a forest near the Monastery of El Escorial. In keeping with its colossal dimensions (100 feet or almost 28 m high), it would have been the tallest in the world of its time, and would even have surpassed Ontígola in capacity. However, the work was halted by Philip II, because it would have flooded a large oak grove that he wished to preserve (García Tapia 1990, 386).

The Casa de Campo hydraulic works display a series of differentiating characteristics that make them worthy of a separate comment. The property, located in the valley of the River Manzanares, across the river but in front of the Madrid Alcázar, enjoyed an unbeatable location. Pertaining to the Vargas family, Philip II acquired it for the construction of a classic suburban *villa* with all of the usual components: house, formal garden, orchards, meadows and a walled forest. Taking advantage of the terrain's topography, not one, but a group of five dams was laid out along the forest's slope. Built during the intervention of Juan Bautista de Toledo, these structures endowed a unique character upon the forest.[10] Visible as scenic background in the painting of Castello (Fig. 3), and partly featured in the Texeira map, they received the names of Grande, Medio, Longuillo, La Higuera and Norte.[11] A tree-lined thoroughfare connected the formal garden ("the New Street that goes to the Pools," in Texeira's map) with the ponds, also with tree-lined perimeters (in October 1570, Gaspar de Vega oversaw the planting of between 200 and 300 black poplars brought in from Aranjuez (Navascués, Ariza, Tejero Villareal 1998: 428).

The very uncommon and technically challenging solution of constructing a series of dams that sit along a hillside was then repeated in La Fresneda.[12] With the splendid backdrop provided by the Sierra de Guadarrama towards the northwest, the property, located at the valley's toe, collects the waters arriving from the numerous subsidiary streams in the river basins traversing it: the Aulencia and the Guadarrama (AAVV 2004: 41). In a territory with drainage problems, Philip II decided to establish a rest home for the Jeronimo (Hieronymite) monks of the

[10]Before his death, Juan Bautista de Toledo gave instructions for the construction of a new pond, located above the others, which was later built under the direction of Gaspar de Vega (Rivera 1984: 249).

[11]In the eighteenth century, the names of the Grande and Norte were still in use, with the remaining names replaced by the Niño, Mujer, Puerco and Chico, respectively (Gimeno Pascual 1981. 73). An interesting representation, although from a later date, is the topographic map of the town of Madrid drafted in 1808 featuring the positions of the French forces that surrounded the city, in addition to a circular island of considerable dimensions, with its own bridge, drawn in the highest pond.

[12]The choice of the Royal Monastery of San Lorenzo site in El Escorial also determined the future of La Fresneda, which was, at first, inspected as a possible place for the main building, but was soon discarded due to the excess of waters and the difficulties of eliminating them, given the valley's location, thus contradicting Vitruvius's recommendations. On the other hand, the choice of the Jerónimos order for El Escorial was determinant: its rules obliged them to retire twice a year to rest, as San Jerónimo had done, which was called "hacer granja". Hence, the construction of La Fresneda and its later name: La Granjilla. Today, there are still significant remains of the impressive ensemble, even if it is now in private hands and in urgent need of protection. A classic research work on this subject is by Cervera Vera (1985).

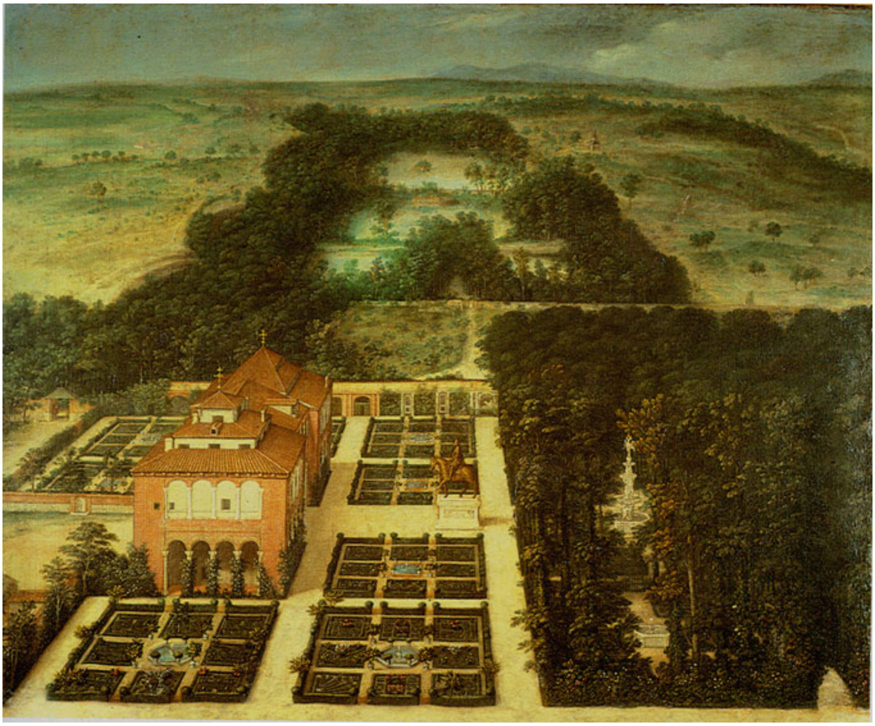


Fig. 3 Félix Castello. View of the Casa de Campo. Municipal Museum, Madrid. S. XVII (Félix Castelo—own work, CC BY-SA 3.0 https://commons.wikimedia.org/w/index.php?curid=2457943)

Monastery of San Lorenzo and, following a Spanish tradition, annexed royal rooms for the king and his court. In his constant preoccupation with storing the water necessary for maintenance before beginning any work, the site's main problem turned into a fundamental theme of its composition. As in the Casa de Campo, a group of four dams was laid out in La Fresneda. They decreased in size as they descended down the hillside and, common in Spain since at least the Islamic period, the largest water reserve was placed at the highest point, thus enabling gravity-fed irrigation systems (Fig. 4).

Although several dowsers also examined the territory, the dykes were planned by hydraulic experts: Piet Janson inspected the whole area in July 1563, looking for the most appropriate places for water reserves, which were then subsequently examined by Juan Bautista de Toledo (A.G.S, Casa y Sitios Reales, Leg. 259: fol. 391. Letter of Almaguer to Pedro del Hoyo). Another Dutch, Filippoo Spond, is named as having been involved between the years of 1588 and 1590 (López Gómez 1992: 101). Alongside the afore-mentioned, the work by local master builders such

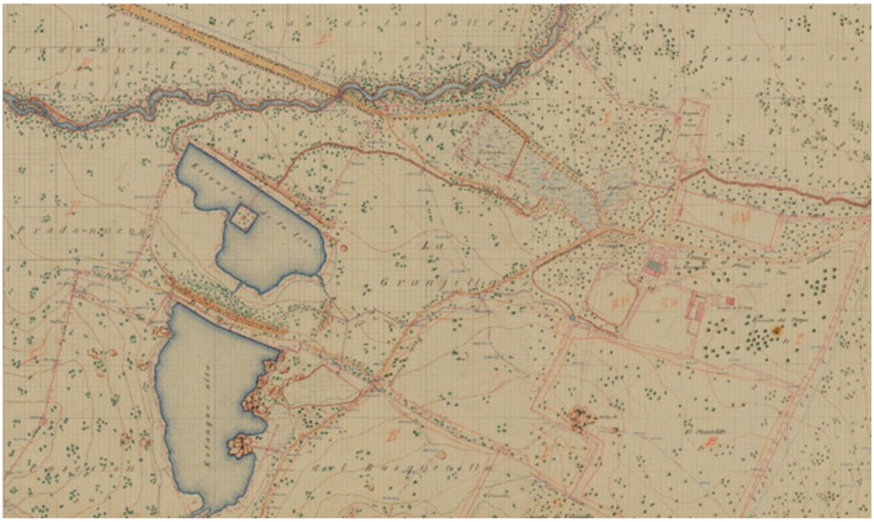


Fig. 4 Término Escorial Bajo, Hoja kilométrica 4-H. (Topografía Catastral de España, Catastro de rústica, 1860–1870. CC-BY 4.0. Instituto Geográfico Nacional)

as Pedro de Tolosa and Juan Bautista de Cabrera was also essential. It would seem that the dams were already fixed in their depth and height for the king to inspect them in April 1566; certainly, the construction of the highest and largest dam was finished by 1597 (Chías 2014).[13]

The highest reservoir, named Granjilla I, was the largest water storage facility. In 1605, Father Sigüenza described it as "a peaceful and extended lake or beach" (Sigüenza (1605) 2010, 201–202), while Father Ximénez depicts it as a "sea" and describes the barrel-vaulted stone wall that conveys the water to the next pool (Ximénez 1764, 392). Indeed, the dyke spanned an extensive linear extent along which the upstream facing masonry protruded from the crowning elevation to form a wall. Its breadth provided for the installation of a wide tree-lined walk above, both overlooking the water and intertwined with the paths of the ensemble. There are the vestiges of what might once have been a ship house, while, on the other side of the dam, there remains the structure of what was probably a mill or a water forge, built to take advantage of the sharp unevenness in the terrain (Fig. 5). In the centre of the water's surface, there survives what was perhaps originally an island for migratory birds. From this huge water reservoir, stone canals, still in usage, were laid in order to irrigate the entire property. One of them reaches the main orchard, or the Arbour Orchard. Before entering the enclosure, it divides into two channels: one of them makes a zig-zag break before entering the vegetable garden, where it forms part of

[13]The four dams are fed from the waters of the Aulencia River, by means of a diversion weir that leads the water into the higher pool. All of them are rockfill dams covered with earth, with upstream masonry walls. For its constructive details, consult Fernández Ordóñez 1984.

Fig. 5 Remains of a water mill in La Fresneda. Photo by the author

Fig. 6 Channels bringing water from the highest reservoir to the orchard near the house and other areas of the ensemble in La Fresneda. The last picture depicts the ruins of the water filter. Photos by the author

the vine arbour that extends the symmetrical axis of the buildings by over 100 m. The other channel arrives at a huge filter that cleans the water before delivering it, probably to one of the most important fountains in the ensemble: The Fountain of Neptune (Fig. 6).

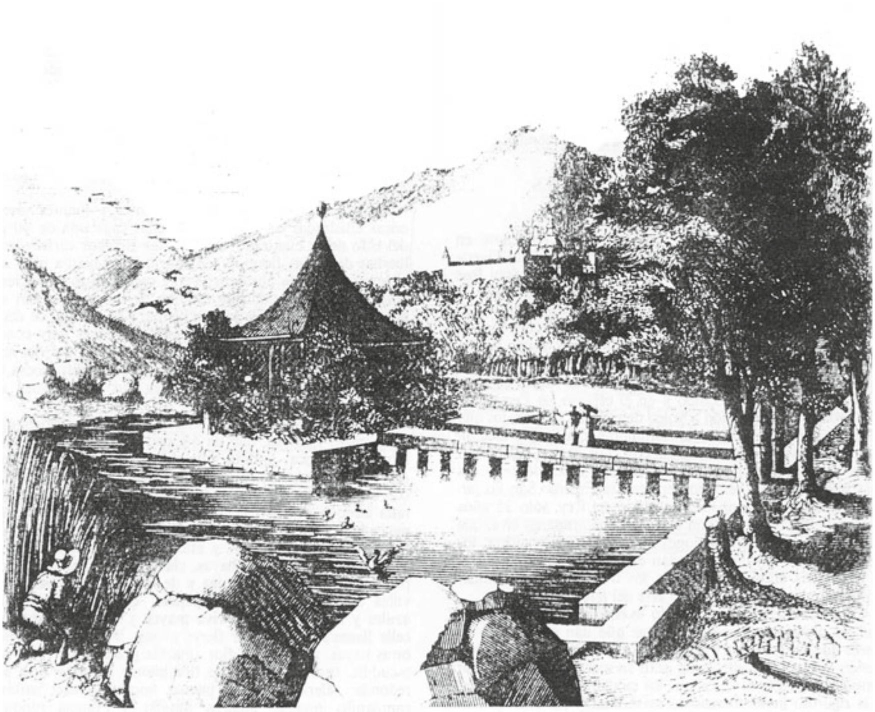


Fig. 7 The Island Pool, with the Monastery in the background. Etching by Rotondo 1863 (Public Domain)

From the higher dam, water is then conveyed into the next, Granjilla II. Its central island, reachable only by boat, must have been one of the most beautiful of this period, with a garden running around a slate roof-covered central gazebo.[14] Father Siguënza (Sigüenza (1605) 2010, 201) and Doctor Almela (Almela 1594, 230–231) described a now lost labyrinth. What is most surprising in this layout is that, even though the island enjoyed incomparable views over the mountains and the Monastery, the gazebo did not open out to its surroundings, the water and surrounding vegetation favouring the total isolation of the structure (Fig. 7). Only the incorporation of the labyrinth (Serlio's models adapt perfectly to the island's quadrangular contour) as a metaphorical form or, perhaps, a reference to the Island of Citerea might provide an explanation for such a curious composition.

[14] The bridge that nowadays leads to the island is clearly a later construction; its entrance door, although representing the same classical language as the rest of the constructions, is more monumental. Its trace is related to the gate and bridge (the so-called Puente del Rodeo) in the current access to the estate, built, like other constructions in El Escorial, in the period of Charles III. The gazebo can be seen in an etching by Rotondo (1863).

From this pool, water was again delivered to the next and, from there, onto the fourth and last, to form an outstanding hydraulic ensemble perfectly adapted to the topography and the territory that, despite having deteriorated, persists to this day. These two pools were also ornamented. The smallest and lowest in the group of four was a fishery, but, like the others, it was also used for sailing. A small gazebo, the Pescador de la Reina, was built on one of its sides: according to Father Sigüenza, this featured a slate roof and had a fountain at its centre (Sigüenza (1605) 2010: 201). Next to it, separated only by a path, was the third dam, with its small central island, probably octagonal in outline, with trees and benches around a central fountain. A key feature in the composition was visible from its centre: The Fountain of Neptune, the only mythological deity present in the La Fresneda legacy. While today completely lost, the period chroniclers describe a bronze statue of a recumbent Neptune in the centre of a small pool (Almela 1594: 230), surrounded by flower pots containing spouts that sent water shooting towards the central figure while also spraying water outwards to create the impression of artificial rainfall (Siguenza (1605) 2010: 201). Despite having disappeared, its position can be inferred by analysing the terrain and aerial photographs: it must have been in an area cleared of vegetation, approximately circular or octagonal in layout and located between the main group of buildings and the third dam. From there, it would have been possible to view not only the fountain but also the pool, its central island, the royal road on the other side and the alignments of ash trees that characterized this property.

All of these structures can be studied from different and complementary points of view. The construction technique is undoubtedly one of the most interesting dimensions, as this was the period in which a new type of buttress dam was under development on the Iberian Peninsula. This concurred with the arrival of *diqueros*, or experts in dam construction, sent from Flanders by Cardinal Granvela at the request of Philip II.[15] This probably explains the reason why this type of dam is sometimes called the "Dutch dam," even though this technique was never deployed in the Low Countries while its precedents can be traced to the Roman dams on the Iberian Peninsula. Certainly, the engagement of Dutch (for example, the aforementioned Piet Janson) and Flemish (such as Adrian van der Müller) experts attests to this, but the hydrological differences between the Peninsula and the Low Countries does raise questions about the scope of their interventions, which were, perhaps, more closely linked to controlling rivers (which, of course, included the construction of earth containment dikes) and marsh reclamation projects (stagnant water around Aranjuez, La Fresneda and Casa de Campo constituted a health

[15]Janson may feasibly have been of Dutch origin, as his nickname seems to indicate, although he arrived in Spain from Flanders, sent by Cardinal Granvela at the king's request. Together with Adrián de Bruyn, Pierre de Brun van Moerbehe and Jehan Barek, he was one of the "diqueros" named in a royal cedula of June 1561, and soon began to stand out from the rest (Barbeito and Ortega 1998: 263). These professional types were much more than simple builders; because of their training and knowledge, they were close to today's engineer profile. Their tasks also included selecting the type of fish for the ponds.

threat).[16] In fact, both Dutch and Flemish experts occasionally failed, thus prompting interventions by Spanish engineers, some trained in Italy, for example, Juan Bautista de Toledo, other Italians, such as the Calabrian Jerónimo Gili, and all of them, for instance, Gaspar de Vega and Juan de Herrera, hydraulics experts (García Tapia 1990: 376–377). However, even the work of the most renowned experts of the period was always decisively reinforced by the participation of regional and local masters, including Juan de Castro, Francisco Sánchez and Juan Bautista de Cabrera (working in La Fresneda), who were, until recently, almost entirely unknown (López Gómez 1992: 96).[17]

Although serving primarily for the irrigation of Royal Sites, all of these structures also incorporated other functions. Watermills took advantage of the motive power of the water to run their machinery and drive mechanical processes such as milling, rolling, hammering or cutting stone. Mills, as constructions, were commonly interlinked with gardens. Among other examples, a project, probably never executed, for the construction of a mill linked to the existing dams in Casa de Campo was proposed around 1575.[18] Moreover, the first known sawmill in Spain was in Aranjuez and dates from 1562, when Juan Bautista de Toledo oversaw the works (García Tapia 1990: 184). Adjacent to the largest Fresneda dam, there still remain the remnants of what might have been another water-powered sawmill, referred to by Janson in 1563, when the Dutchman inspected the site, encountering a place "under the meadows of the Canaleja in the river of the Fresneda in some rocks that are next to the water". This location was considered "appropriate to settle the dam for a pond" and proper for hosting a watermill (A.G.S, Casas y Sitios Reales, Leg. 260: fol. 475). Mills were also part of a landscape characterised by the intimately related productive and formal spaces. Pragmatic purposes were not excluded from this type of structure, even when forming part of an ensemble that was ordered in keeping with architectural criteria.

However, the extensive water surfaces created by the interposition of a dyke onto a natural watercourse also held other meanings. According to Flemish custom, they also fulfilled an environmental function (sometimes linked to bird hunting practices) as sites able to attract migratory birds. The idea came from the north of Europe, with this type of platform for birds being very common in the Netherlands, even while a distant precedent could also be traced to the artificial planted marshes propagated since classical times by the kings of Mesopotamia. Islands for birds represented one of the features that moved from the territory into the garden, with

[16]In the Netherlands, the dykes were usually earth embankments. This was also the constructive solution used by the *diqueros* in Spain, as some documents record. It would seem that Janson preferred earth dams of just two feet, as they were better for fish breeding (according to a 1565 document about a pond in the Casa de Campo, collected by Modino de Lucas 1985 vol. 1: 258–259). Merlos Romero qualifies Janson as an expert in the construction of ponds without stone, using only earthen supports (Merlos Romero 1998: 88–89).

[17]In Aranjuez, Janson was blamed for the collapse of the first dam after making a mockery of the downstream buttresses proposed by master builder Francisco Sánchez (García Tapia; Rivera Blanco 1985, 482). Adrián Van der Müller also considered Spanish dams to be too thick and tall (García Tapia 1990: 418).

[18]This was signed by Francisco Contreras, and is today conserved in the Simancas Archive (Navascués, Ariza, Tejero Villareal 1998: 429).

smaller scale pools being built such as that belonging to the imperial ambassador Hans Khevenhüller in Arganda, that of the Real de Valencia and the Palace of Infantado in Guadalajara. Dams and ponds were also places for fish breeding, an activity in which the expert Flemish and Dutch *diqueros* excelled. Janson was repeatedly commissioned to supply fish for different royal properties, some brought in from outside of Spain. In Casa de Campo, the large pools, on the one hand, supplied water to the new ensemble, solving the problem of summer droughts and guaranteeing the regular irrigation of the extensive areas of cultivation. On the other hand, they protected the territory from flash flooding caused by these streams in winter. In addition, the different pools allowed for the breeding of different fish species for fishing. This must have been a principal usage as, in examples such as Casa de Campo, the succession of ponds even enabled the breeding of different species in each one.[19] However, fishing not only had a playful purpose; the main objective was food, as, at that time, religious prescriptions imposed a total of up to 166 days of meat-free vigil throughout the year: the reservoirs were thus indispensable as fisheries (Plasencia 2007: 17). This was especially relevant in groups of a more markedly religious nature, such as the Escorial or the Fresneda.

The importance of such constructions, radically transforming the natural environment, and their symbolic values, especially noticeable in places with scant water supplies, was frequently highlighted by architectural ornaments or minor installations that reflected their playful functions. The large dams, especially those linked to Royal Sites, additionally served for recreational sailing, naumachias and other parties. In El Bosque, boating was a frequent practice (a small barge was always available to reach the central island), as well as the likely performance of naumachias. In Aranjuez, the careful treatment of the revoked Mar de Ontígola ashlar stones proves its representative purpose, as well as its functional role. The leisure usage of the dam had already emerged during the construction process: in 1565, Philip II ordered the building of parapets on the perimeter walls and the emptying of the reservoir so that some islands might protrude from the water. These initial islands probably interlinked with the Flemish tradition referred to above, also serving as bird refuges. The proposal was completed with the construction of a gazebo in the centre of the reservoir in 1625, during Philip IV's reign. Probably the work of Juan Gómez de Mora, this was reached by means of much-adorned sailboats, which were kept in the corresponding shipyard, located next to a bullring and a garden. Quindós describes a curious party that became popular in the seventeenth century. From the arbour, on the island, the kings would watch as bulls (sometimes camels, wild boars and other animals) were led to a ramp with a floor and walls of wooden planks that then ended in the water. From above, the animals would be dropped into the water, where sailboats would lead them to the gazebo before the king slaughtered them by shooting them with an arquebus (Quindós 1982 (1804): 387). Also, the dams of Casa de Campo were the scene for celebrations

[19]Jason provided the king with an invention so that he could choose the fish that he wanted without nets and without touching them (Navascués, Ariza, Tejero Villareal 1998, 427). Barbeito and Ortega give an account of his 1564 trip to France to buy brujetes, carp and other fish for ponds (1998: 264).

in which illuminated galleys and barges navigated their lengths (Rivera 1991: 124). Fray Jerónimo de Sepúlveda recounts how, on the two largest La Fresneda ponds, the royal family "sailed with two very beautiful galleys, very painted and gilded" (Sepúlveda 1924). Dr. Almela also issues an account of the boats and boathouses of the two highest La Fresneda ponds, where archaeological remains may still be found (Almela 1594: 230, manuscript). However, navigation on the main reservoir proved risky: while fishing from the dam, Philip II saw how the lives of several members of the royal house were greatly endangered as the vessel that they were in tipped over abruptly due to a windstorm, and so he ordered that nobody ever sail on it again (AAVV 2004: 50).

In conjunction with the construction techniques and the practical and recreational uses, one interesting theme of study is the relationship between the hydraulic structure and the layout of the Renaissance ensemble. From this point of view, we may discern two solutions: one in which the dam forms part of the formal garden and another in which the dam is located at a distance, usually in a walled forest adjoining the formal garden. Valsaín and El Bosque de Béjar exemplify the first solution, while Aranjuez, Casa de Campo and La Fresneda are representative of the second alternative.

Valsaín presumably was not merely an irrigation dam, as it also formed part of a very interesting garden layout: placed between the Palace and the river, this probably constituted part of a system of terraced gardens that ran from the higher grounds of the Queen's Garden in the courtyard to the King's Garden (outside of the preceding enclosure, but visible from it) and on down to the riverside across a gradation of garden spaces that has today disappeared. A similar, even clearer layout is found in El Bosque, where the dam is entirely and exceptionally intertwined with the Renaissance garden layout. Its size also exceeds the usual garden pools of that time, occupying almost the entire surface of the terrace and establishing the true organizing core of the whole ensemble.

Sometimes constructed at a significant distance from the main gardens, other dams were integrated in very different ways. The Sea of Ontígola was one more component of the hydraulic system that also formed part of the symbolic program. Its location, higher than the Garden on the Queen's Island, ensured that the water channelled through the garden by a straight pipe running along the main axis attained the necessary pressure to make the fountains work. Hydraulics, therefore, conditioned the garden's layout. The fountains were basically arranged on an axis, as determined by the Sea of Ontígola water supply in accordance with the project first embarked upon by Juan Bautista de Toledo and carried on after 1567 by different plumbers, before its completion by Juan de Herrera in 1577.[20] In Casa de Campo, the enormous water surfaces constituted the composite centre of the extensive hunting forest, the scenery for parties in which illuminated galleys and barges sailed, providing the area with a greater landscape interest and a background perspective for the house and formal garden. In La Fresneda, aerial views show how the water features, orchards and

[20]The current arrangement of the fountains results from the reform carried out by José de Villareal during Philip IV's reign (previously attributed to Sebastián Herrera Barnuevo) with some subsequent changes (Sanz 2009: 157).

buildings are radially organized around the site where the fountain of Neptune once stood. Neptune was the feature that bonded, unified and gave coherence to the whole composition. The God of the Waters was placed at a central point, perhaps to guarantee water purity, thus protecting the garden and its inhabitants from the pernicious stagnant waters drained by the large pools of La Fresneda. The arrangement of large-scale ponds in series requires solutions that are technically and economically complex, and is therefore correspondingly infrequent. For this reason, the enormous engineering Fresneda works become even more relevant today, because, unlike other cases (Casa de Campo or the monumental Roman dams built by Nero in his villa of Sublaquaeum, today disappeared), the extraordinary group of Fresneda dams still exist today, along with important remains of the hydraulic system, garden structures and other features that formed one of the most important Renaissance complexes from the reign of Philip II. Its restoration would undoubtedly re-establish one of the most extraordinary architectural, landscape, engineering and garden ensembles in Europe.

All of these examples demonstrate how knowledge derived from different disciplines can be integrated so as to fully understand a cultural period and its diverse architectonic manifestations. Hydraulic techniques, subject to the rigid force of gravity, are determinant, not only for territorial management, but also for garden layout. The basic territorial hydraulic structures also constitute part of the garden, according to criteria that assume utilitarian purposes without renouncing compositional or symbolical meanings. Thus, on the Iberian Peninsula, dams and pools were placed on the upper grounds as part of gravity-fed irrigation systems, with this layout becoming a typical feature of the Spanish garden, maintained and refined throughout history. The dam was one of the most logical of answers deriving from efforts to adapt to the environment that transformed the Renaissance Spanish garden through its varied examples of pools, with their rich solutions and wide-ranging compositional layouts.

Bibliography

Aguiló, Miguel. 2002. *La enjundia de las presas españolas II.* Madrid: Grupo A.C.S.

Almela, Juan Alonso de. (1594) 1.918. "Descripción de la Octava Maravilla del Mundo, por el doctor Juan Alonso de Almela", In Zarco Cuevas, Julián. *Documentos para la historia del Monasterio de San Lorenzo el Real de El Escorial*, tomb VI. Imprenta Helénica, Madrid.

Álvarez de Quindós, José Antonio. (1804). 1982. *Descripción histórica del Real Bosque y Casa de Aranjuez.* Aranjuez: Ayuntamiento de Aranjuez.

AA. VV. 2004. *Arquitectura y Desarrollo Urbano. Comunidad de Madrid. Tomo V (El Escorial, San Lorenzo de El Escorial).* Madrid: Dirección General de Arquitectura, Conserjería de Política Territorial: Colegio Oficial de Arquitectos de Madrid.

Barbeito, José Manuel y Ortega, Javier. 1998. "Los artífices de las obras reales". In Sociedad Estatal para la conmemoración de los centenarios de Felipe II y Carlos V. *Felipe II, el rey íntimo. Jardín y Naturaleza en el siglo XVI*. Madrid: Sociedad Estatal para la Conmemoración de los Centenarios de Felipe II y Carlos V: 243–275.

Cervera Vera, Luis. 1985. *El conjunto monacal y cortesano de la Fresneda en el Escorial*. Madrid: Real Academia de Bellas Artes de San Fernando.

Chías, Pilar, Abad, T. 2014. *La construcción del entorno del Monasterio de San Lorenzo de El Escorial. Agua, territorio y paisaje.* Informes de la Construcción, 66(536): e046. http://dx.doi.org/10.3989/ic.14.027.

Fernández Casado, Carlos. 1983. *Ingeniería hidráulica romana.* Turner: Madrid.

Gárate Fernández-Cossio, Pablo. 2013. *El palacio de Valsaín: Una reconstitución a través de sus vestigios*. E.T.S. Arquitectura (UPM). http://oa.upm.es/19853/.

García Tapia, Nicolás. 1990. *Ingeniería y arquitectura en el Renacimiento español*. Valladolid: Universidad de Valladolid.

García Tapia, Nicolás; Rivera Blanco, Javier. Mayo-junio 1985. "La presa de Ontígola y Felipe II". In *Revista de Obras Públicas:* pp. 477–490.

López Gómez, Antonio. 1992. "Presas y canales de riego en los siglos XVI y XVII". In Gil Olcina, Antonio, and Alfredo Morales Gil. *Hitos históricos de los regadíos españoles.* Madrid: Ministerio de Agricultura, Pesca y Alimentación, pp. 91–142.

Merlos Romero, María Magdalena. 1998. *Aranjuez y Felipe II. Idea y forma de un Real Sitio.* Madrid: Dirección General de Patrimonio Cultural de la Comunidad de Madrid y Ayuntamiento de Aranjuez.

Muñoz Domínguez, José. 2015. "Via non difficilis. Los viales de acceso en las villas renacentistas con desarrollo axial". In *Cuaderno de Notas,* no 16, pp. 108–118.

Muñoz Domínguez, José; Sánchez Sancho, Juan Félix; Sanz Belloso, José Carlos. 2009. "El estanque de la villa renacentista El Bosque de Béjar, una presa holandesa en Castilla". *Actas del Sexto Congreso Nacional de Historia de la Construcción, Valencia, 21–24 de octubre 2009.* Madrid: Instituto Juan de Herrera: pp. 955–965.

Plasencia Lozano, Pedro. 2007. "La presa renacentista del Casar de Cáceres". *Norba-Arte,* vol. XXVII: pp. 9–28.

Rotondo, Antonio. 1863. *Historia descriptiva, artística y pintoresca del Real Monasterio de S. Lorenzo comúnmente llamado del Escorial*. Madrid: Eusebio Aguado.

Sanz Hernando, Alberto. 2009. *El jardín clásico madrileño y los Reales Sitios.* Madrid: Ayuntamiento de Madrid.

Sigüenza, Fray José. 2010. *Historia de la Orden de San Jerónimo. Libro tercero y cuarto: La fundación del Monasterio de San Lorenzo el Real* (1605). Valencia: CMC Editor, 2010.

Smith, Norman Alfred Fischer. 1971. *A history of dams.* London: Peter Davies.

Ximénez, Andrés. 1764. *Descripción del Real Monasterio de San Lorenzo del Escorial.* Imprenta de Antonio Marín, 1764.

Water Communities on the Northern Slopes of the Guadarrama Mountain Range

Mar Pinillos Rodríguez and David Martín Carretero

Abstract

Guadarrama is a mountain range located in between the provinces of Madrid and Segovia. On the northern slopes, the population settled on the foothills, where, in the medieval period, they built *caceras* (ditches/canals) to draw water from the streams and irrigate the surrounding fields. This chapter spans two main issues that have yet to be studied in this area: the communal management of the water and the irrigation systems and the ecosystem services provided by the *caceras* as ecological corridors and biodiversity reserves. The *caceras* act to slow down the water speed of the streams, widening the effect of these waters and creating a microclimate. The flooding of the lands alongside the ditches not only generates meadows and pastures with ash trees, ensuring a great diversity of species (amphibians, orchids, etc.), but also forms natural water deposits and provides water in the dry season. This is supplemented by the waters that issue slowly from natural springs and feed fountains, both for the supply of the local population and for maintaining the ecosystem. This study looks at the way in which this water management system, handed down from generation to generation, constituted a master class of culture, hydrology, agronomy and the environment that has hitherto been undervalued and now verges on near extinction.

M. Pinillos Rodríguez (✉) · D. Martín Carretero
Tenada del Monte, Segovia, Spain
e-mail: info@tenadadelmonte.es

A. Duarte Rodrigues and C. Toribio Marín (eds.), *The History of Water Management in the Iberian Peninsula*, Trends in the History of Science,
https://doi.org/10.1007/978-3-030-34061-2_9

1 Introduction

The province of Segovia is located in the centre of the Iberian Peninsula, with its southern border formed by the Central System Mountain range, divided into different areas, including the Guadarrama mountain range.

The Guadarrama mountain range acts as a large water reservoir, due to its winter accumulation of snow, which is then gradually filtered through surface aquifers during the thawing period. Mountain rivulets and streams owe their continued water flows to these reservoirs during drought seasons, fed by the natural springs that appear at the surface (Mejías et al. 2015: 180–186). However, these streams run rapidly down through steep, narrow and cold valleys, while the population live on the lower, flatter and sunnier reaches of the mountain range. Therefore, recourse to gravity represented the only means of transporting the water from the source stream along irrigation channels, or *caceras* (Sintes et al. 1994: 22–3).

There are no complete studies explaining the communal usage and management of water in detail (Graña 1992: 79–84). However, these ditches, and their almost millenary remains, constitute signs of our land culture and a tradition of cooperation in favour of the common good. The survival of rural communities provides the key to the origin of these systems, even while they also hold relevance as ecological corridors that generate cultural landscapes and biodiversity (Plaza and Guzmán 2010: 258).

In this research, we have studied an area comprised of seven water systems and communities on the northern slope of the Guadarrama Mountain Range (in Segovia Province). This area is coherent from a geographical, historical and social point of view, and hence the cases are comparable. The analysis has drawn on three core sources of documentation:

- Personal, semi-structured interviews with key witnesses. In total, we interviewed fifty-two people. They were all aged between seventy-five and ninety years old and currently live in twenty-six different villages. These interviews focused on water management, governance, traditional ecological knowledge, land uses and recent changes in practices and the territory.
- A literature review, including primary sources from the historical archives of Segovia Cathedral, and the Provincial and Municipal archives of Segovia, Basardilla, Caballar, Santiuste de Pedraza, Turegano and Torre Val de San Pedro. In addition, we also reviewed the scientific literature related to the historical irrigation system from the agricultural, hydrological, ethnographic, historical and cultural perspectives.
- Finally, we carried out fieldwork to study the systems and their conservation in detail, alongside their usages by the local population and the ecosystem services thereby generated, particularly flora and fauna analysis, to this end, deploying specific biological methodologies for sampling, identifying and documenting the associated biodiversity.

2 Communal Management and the *Juntas del Agua*

One of the most interesting aspects of water management is its communal use: the systems and water are shared by different villages and regulated by the *Juntas del Agua*. These are institutions composed of representatives from the participating villages established to manage, organize and guard the waters, and make decisions about water-related topics. These are water courts similar to the famous “Aguas de Valencia” Court, now registered as a UNESCO World Heritage site (Giménez and Palerm 2007: 12–17).

In this research, we approached seven of these *Juntas del Agua*. Six manage water sourced from rivers, with the seventh overseeing a natural spring water source. Some of the old settlements taking part in each system have disappeared over the course of history. They are, however, detailed in the historical sources and the different local by-laws that regulate each *Junta del Agua*. The following list includes all of the historical villages belonging to each *Junta* and the dates of the first preserved by-laws:

- Cacera de Navalcaz (1515, with earlier versions lost), made up of the following villages: Rosales, Aldeanueva, Juarrillos and Gallococeado (Cacera de Navalcaz by-law, 1515).
- Cacera de Cambrones (1401), integrated by Palazuelos, Tabanera, Sonsoto, Trescasas, San Cristóbal, Aragoneses and Ojalvilla (Cacera de Cambrones by-law, 1401).
- Cacera de San Medel (1734, with earlier versions lost), made up of: Torrecaballeros, La Aldehuela, Cabanillas del Monte, Tizneros, Espirdo, La Higuera, Brieva, Adrada, Basardilla, Santo Domingo de Pirón, Pajares and Adradilla (Cacera de San Medel, 1734).
- Cacera de Río Viejo (1221–1510), made up of: Sotosalbos, Pelayos, La Cuesta, Berrocal, Carrascal, Aldeasaz, Las Navas, Losana, Tenzuela, Torreiglesias, Collado Hermoso, Robledillo, La Mata, Requijada and Yertega (Cacera de Río Viejo, 1510).
- Cacera de Arroyos Truchas y Pinar (1497), made up of: Torreval de San Pedro, Valle de San Pedro and Chavida (Carpeta de aguas, 1497).
- Cacera de Ceguilla (1551), made up of: Ceguilla, Las Navas and Galíndez (Cacera de Ceguilla by-law, 1551).
- Cacera de Caballar y Turégano (1588), made up of the villages of Caballar and Turégano (Acuerdos, 1588) (Fig. 1).

We agree here with M. Graña and his emphasis on the importance of water in the past historical process of settlement from the Medieval period: “Water was a decisive point in the installation of villages and, therefore, in their organization of the spaces and fields for exploitation. From a strictly physical and geographical point of view, water and its activities could be considered as a basic instrument in

Fig. 1 From left to right: Caceras of Navalcaz, Cambrones, San Medel, Río Viejo, Arroyos Truchas y Pinar, Ceguilla and Caballar and Turegano. Archive Tenada del Monte

the task of colonizing the rural environment, a task involving all the social elements" (Graña 1992: 84–5).

These ditches may possibly have dated from the eleventh century, when the lands of Segovia were repopulated by King Alfonso VI, following their conquest from the Muslims in 1076 (González Herrero 1974: 367). They might even have pre-existed that date, extending back into the Islamic period of al-Andaluz. Nevertheless, the earliest preserved written document concerning communal riverbed water resource usage dates to 1221. This document refers to an agreement between the Cistercian Santa María de la Sierra monastery, in Collado Hermoso, and several other villages over recourse to the waters of the Viejo River (Acuerdos, 1221).

As stated above, the Juntas de Aguas were organized by means of by-laws, written mainly over the course of the fifteenth and sixteenth centuries (Pinillos and Martín 2005: 27). However, these documents mostly refer to an earlier, ancient and immemorial tradition. Their members generally met at fixed places, normally on rocks or rocky hills located near the boundaries between territories (Pinillos and Martín 2015: 30). These significant meeting places also bestowed the name on the institutions as 'junta,' literally meaning 'meeting.' For instance, the Junta of Navalcaz was entitled the Junta de Peñaslenguas, that of the Cambrones River, the Noble Junta de Cabezuelas, while, for the Viejo River, there was the Junta de la Manzaneda. In turn, the Junta of San Medel met beside a hermitage dedicated to La Magdalena, in Ceguilla, on a rock named La Peñuela. Finally, the water community established between Caballar and Turégano used to meet in a place called Peña de la Cruz. However, we have no information about the site where the community of Truchas and Pinar met. Trials related to offences and failure to comply with the by-law took place in these special places, as did the swearing-in of members for the different positions in the Juntas. On one of the rocks, there was once an engraved cross over which oaths were made.

The essential figures in these water management systems are the Juez de Aguas, the Guardas de Aguas and the Voceros. The Juez de Aguas (Water Judge hereafter) constituted the highest authority in the Junta de Aguas. Depending on the respective Junta, this position received different titles. In Navalcaz and Cambrones, the highest authority was the Alcalde de Cartas, in San Medel, this person became the Alcalde de Pastores, Rio Viejo appointed the Fiel del Agua, and the Ceguilla and Arroyos Truchas y Pinar systems had an Alcalde de Aguas as their overseer, while we lack any information for the situations of Caballar and Turégano.

These positions typically rotated from village to village each year, except in the cases of Rio Viejo and the Ceguilla, where the Water Judge always came from Sotosalbos and Galindez, respectively. Each rotation also involved transferring the *Cartas* ("letters"), the documents generated by the Junta de Aguas (by-laws, minutes, lawsuits, etc.), from the outgoing figure of authority to the successor. Throughout centuries, these documents were stored inside of wooden chests or tin cases (as in Navalcaz).

Other figures essential to water management include the Guardas de Aguas (Water Guardians hereafter), called Aguaderos in Cambrones, Navalcaz and Caballar and Turégano; Pastores del Agua in Rio Viejo and San Medel and Guardas de la Cacera in the Arroyos Truchas and Pinar and Ceguilla water systems.

The Water Guardian was charged with caring for the common infrastructures and, correspondingly, not only repairing any existing flaw, but also reporting any failure to comply with the by-laws or water theft. In the Junta established between Turégano and Caballar, the Water Guardian was also in charge of regulating the water that ran back and forth between the two villages.

The Water Guardians in the San Medel system were the people from each village entitled to supervise the ditches on a communal and weekly basis, impose fines and extract water for their villages at the appropriate places and on specific dates. Regarding the Rio Viejo ditch, apart from communal weekly control, members were also placed in the council's service at any moment during a water shortage. The election of the Water Guardian in each village commonly took place through an auction held during council meetings, with their duration limited to the irrigation period, generally from April until the end of September (Libro de Vecindad de La Cuesta).

The Water Guardian profession is as ancient as the Juntas de Agua, and they correspondingly appear in all of the by-laws. Their work, quiet and complicated because of the conflicts generated by communal water usage, required a great deal of discernment, fairness and firmness.

Finally, the Vocero, present in every Junta de Aguas, held responsibility for instructing people to attend meetings or repair the *caceras* (Fig. 2).

3 Communal Maintenance

As with any other infrastructure, *caceras* need annual maintenance and cleaning, as vegetation grows and branches and leaves fall, blocking and/or closing the river channel, and thus hindering normal water flows. “That traditional management not only offers advantages to farmers but also promotes plant diversity and ecosystem services” (Sanchez et al. 2018: 396–402).

Several kinds of labour are required for maintaining the ditches. The first involves cleaning the main ditches, achieved by communal work, with people coming from every village involved in each irrigation system. The second corresponds to cleaning and maintaining the ditch branches that irrigate each village, carried out by labourers from each respective settlement. Finally, there are communal areas, such as pastures, that also need communal maintenance. Communal works are called *hacenderas* and, as a general rule, although there are some exceptions that we specify below, it was mandatory for all village residents to attend these cleaning sessions, with any absence resulting in monetary fines.[1]

We have studied two ditch systems: one that now receives communal management (Cambrones, San Medel, Truchas and Pinar and Caballar) and another that does not currently benefit from this communal maintenance (Ceguilla, Navalcaz and Rio Viejo). During this research, we participated in the Cambrones, San Medel and Truchas and Pinar cleaning days. In the Caballar, Ceguilla, Navalcaz and Rio Viejo ditches, we also carried out personal interviews with community members. Thus, this chapter constitutes a summary of all of the oral information collected and then compared with the historical by-laws.

The communal cleaning of the main ditches took place on the same dates as those established by the ancient by-laws. As detailed below, this correspondingly preserves some extremely interesting traditions. In the Cambrones ditch, the cleaning is carried out on the last Saturday in May. At dawn, as the historical tradition stipulates, the Water Judge and the rest of the Cabezuelas Junta meet in the place known as “La Madre” (The Mother) in order to close the lock-gate that diverts water from the Cambrones river into the ditch. This is the day of the Cacera Mayor (the main ditch or the ditch section common to all villages).

[1]Information collected in interviews with ditch users.

Fig. 2 Pastores del agua (Water Guardians) in Cacera de San Medel. Archive Tenada del Monte

Each village taking part in the maintenance oversees two *quintos* (sections hereafter), which are the ditch sections whose lengths have been interrelated according to the amount of water or *caces* corresponding to each village. After the water supply is shut off, the riverbeds are cleansed of sediments, leaves, branches and grass, with the Junta members working on short sections of the ditch. They then take a mid-morning break. After taking care of this "institutional section," the maintenance of each village section that forms part of the Cambrones hydraulic system begins, in the following order: Sonsoto, San Cristobal, Trescasas, Tabanera, Palazuelos and La Lastrilla.

The border between each section is marked and defined by a cross and a half moon, both dug into the ground with mattocks by the neighbours. This tradition suggests that the design and digging of these ditches might trace their origins to the first phase of the repopulation of Segovia around the eleventh century, as these signs seem to depict symbols of the coexistence and collaboration between Christian and Muslim communities.

After the cleaning phase and lunch, a prayer is said over each section. This prayer has survived down into contemporary times through oral tradition. The *peones* (labourers hereafter) kneel down and the oldest person in the group leads the prayer. Once it ends, people continue talking, drinking and playing cards until the water again flows through the ditch, following the opening of the lock gate. This signals that it is time to return home.[2]

On the following day, the Water Judge, accompanied by the rest of the Cabezuelas Junta, inspects the cleanness of each section and discusses any pending issue. The following week, they celebrate a communal meal dedicated to bonding and replacing the Water Judge (Fig. 3).

Creazon day is when the villages of Cacera de San Medel, which, as stated above, is made up of the villages of Torrecaballeros, La Aldehuela, Cabanillas del Monte, Tizneros, Espirdo, La Higuera, Brieva, Adrada, Basardilla and Santo Domingo de Pirón, join together to clean their ditch system. This takes place on the Saturday prior to Saint John's Day in June, in accordance with the 1734 by-law regulation. This by-law defines the number of labourers in each place and their respective organization (San Medel by-law, 1734).

Several days before the communal cleaning celebration, the mayor of Torrecaballeros sends a letter to every village notifying them of the day and time to meet. On that day, at 11:30am, the Water Guardian and labourers from each village meet at a place called "Cerca del Romo" or "Las Cruces de la Junta." As soon as they arrive, they carve out the name of their villages, along with a cross, with their mattocks, renewing the previous carvings dug a year earlier. Either the mayor of Torrecaballeros or the person whom he delegates shouts out each village's name. The Water Guardian of the said village replies by indicating the number of labourers that have come with him, a number that the mayor then repeats aloud. After checking the attendance from the different villages, the Lord's Prayer is said, both in memory of the ancestors who founded the *cacera* and for all of the people who have performed this task previously, as a way of starting the *creazón* or *criazón* (the ditch cleaning maintenance).

The mayor divides the labourers into two groups: one group heads upstream from the distribution point, called the *Tercio* ("one third"), with the Santo Domingo labourers, while the second group starts cleaning downstream of the dam, but along the same watercourse. Both groups meet at the Romo watermill. Labourers and Water Guardians gather together there to rest while chatting about the ditch and other everyday details.

After the mid-morning snack, both groups set off to carry out their respective tasks. A person named by the mayor organizes each group, ordering them as what they are to do and then checking on their labours. When both groups finish their tasks, at around 2:30 pm, they eat in the same place where they had their mid-morning snack before playing cards. Later, they recite the Lord's Prayer again, indicating that the moment of farewell until next year has arrived. The following day, they return to the ditch to verify whether the work has been properly done.[3]

---

[2]Collected during technical visits made on "Cacera Mayor" Day (Ditch cleaning) from 2004 to 2018.

[3]Collected during technical visits made on "Creazón" Day (Ditch cleaning) from 2004 to 2018.

Fig. 3 Communal cleaning in Cacera de Cambrones on the last Saturday in May. Archive Tenada del Monte

In Cacera de Navalcaz, the communal cleanings no longer take place. According to an agreement signed in 1867 (Bases, 1867), the Segovia council took charge of the safe-keeping, preservation and repair of the ditch system. In this agreement, the parties did not extract the summer surplus in order to allow the water to follow its course and ensure that the Clamores River never ran dry, because it was necessary for the functioning of different industries. Until then, the 1515 by-law, which was diligently followed, had dictated the ways in which each common stretch of the system should be cleaned and who should clean them. Following the agreement, the council of Segovia committed itself to appointing two Water Guardians, one who lived in the city, the other in Valsaín, with each walking along the ditch in opposite directions; one would walk from the source to Segovia and the other from Segovia to the source, each whilst checking the ditch's condition. These Water Guardians submitted reports detailing the conditions of the channel flow to the municipal architect and requested either improvements or money for repairs. The last Water Guardian retired in 2005. Nowadays, in order to carry out cleaning or any channel repairs, the respective parties have to reach an agreement with the Junta de Aguas and then send the respective documentation to the Segovia council, which undertakes the work.[4]

[4]Interview with Julian García Tejero, farmer of "quinto del Mercado" (Mercado section—Segovia) (2005).

Another ditch without any current maintenance is the Cacera del Rio Viejo. Currently, the cleaning days are only symbolic and only cover some sections belonging to a few villages. The Cacera del Rio Viejo was made up of councils from different jurisdictions: the Community of Villa and Land of Pedraza and the City and Land of Segovia. The organizational complexity constitutes one of the distinguishing features of this system, as, apart from the meetings and common cleaning sessions held by both jurisdictions, each also had their own dates for meeting and section-cleaning.

The cleaning of the ditch common to all villages took place on the fourth day of Pentecost at 11 am. Five men from each village held a board meeting by the “El Paredon” fountain in Mata del Fraile (oak tree forest) to “collect” the water and channel it into the ditch in order to first fix it and then clean it (González Herrero 1994: 75).

Concerning the riverbed that forks towards the Land of Pedraza, we know from the different trades sent out by some councils in the 20th century that they met between July and August at the place called “El Molinillo.” Each village was represented by a certain number of people (Oficios de limpieza, 1953).

Regarding the stretch of the Cacera del Rio Viejo that runs through the Land of Segovia, here, the organization proved somewhat more complicated, due to the numerous divisions existing among the different villages.

In fact, two different Juntas de Aguas existed: one for the councils of Sotosalbos and Pelayos, a jurisdiction of “the most revered masters Dean and Cabildo of the Cathedral Church of Segovia,” and another for the remaining villages, a jurisdiction of the “most noble and loyal city of Segovia,” which made up the so-called Junta de Aguas del Peral. Brought together, they became the Junta de Aguas del Roble (Gonzalez Herrero 1974: 401).

By 1508, both parties had reached an agreement to put an end to their mutual disconformities through drafting a by-law that settled the punishments, as well as the water distribution. On the first Saturday in April, a board meeting would take place in Pelayos (in the place called Los Robles) with six Water Judges, twelve Water Lawyers and six Water Guardians in order to clean the *cepos* (the site of water distribution) and *calderas* (a type of pond), as well as clean and inspect the water (Gonzalez Herrero 1974: 402) (Fig. 4).

Another ditch system that has suffered from neglect of its communal maintenance and cleaning is the Cacera del Río Ceguilla. Three *cuadrillas* (teams hereafter) once cleaned the stretch from the first division to the dam that captures the water. At first, this would take place on the Wednesday of the Holy Spirit Octaves, but, during the twentieth century, it was moved to the last Monday of April.

The Galíndez Water Judge was in charge of submitting requests to the Confederación Hidrográfica del Duero (the river basin authority) and making proclamations announcing the date and time of the ditch cleaning. The day before cleaning, the water was cut off so that, should any trout appear, they might be returned to the river.

Fig. 4 *Caldera* in the Cacera del río Viejo. Archive Tenada del Monte

Before meeting the other two teams, the Galíndez labourers first cleaned a ditch section in the area called "Calleja Ancha." After cleaning this, they would head off to meet the rest at the *dientes* (splitting point) of Carrapinar and engage in communal ditch-cleaning.

The groups cleaned by sections. The Water Lawyer, along with his group, accompanied them and provided the labourers with wine and refreshments. After cleaning, the teams joined together to eat in the evening and the Galindez Water Judge would swear an oath in "El Raso." As in most Juntas de Aguas, the effectiveness of the cleaning efforts was subsequently inspected. Hence, the following week, the Galíndez Water Judge would receive the oaths of the Water Judges from the two other teams (Ceguilla y Las Navas).[5]

Along the Cacera de Truchas y Pinar streams, the stretch that historically corresponded to the council of Santiuste de Pedraza was piped for domestic use many years ago, and thus it today runs along its riverbed only in years of heavy rain. The Arroyo Pinar ditch carried the water for irrigation and supplied the Sorreoyo fountain, which catered to residents in the village of Urbanos.

[5]Interview with Leandro Vicente Arcones (RIP), the last Water Judge of Galindez (2006).

In spring, labourers from La Mata and Chavida would clean the watercourse, meeting in the stream itself. They would then distribute themselves approximately every four steps across its whole width. At the "Fuente Blas," they stopped to eat before continuing cleaning as far as "Prado Cercón."[6]

According to the testimonies gathered, they never met their neighbours from the other council of Torre Val de San Pedro, who were the other water beneficiaries. The most historical news concerning when and how the latter cleaned the system comes from a complaint filed by this council in 1899 against a neighbour from Navafría concerning the theft of water from the ditch system (Carpeta de Aguas, 1899). Testimony accounts state that cleaning took place the day after the feast of Saint Peter in June, even though they tried to keep this to a Saturday or Sunday. On cleaning day, neighbours from El Valle and Torre Val worked on their respective ditch sections as far as the distribution point (*dientes*), and from there onwards jointly as far as the dam. Other neighbours went up to the springs to "collect" the water: the Bañaderos and Hiruela fountains on one side and the Sabuca stream on the other, in order to boost the flow of water.

The evening meal was celebrated in the "Pradera de las Vigas." There, some papers (some kind of regulation) were read out before the members of the Junta de Aguas were proclaimed for the following year.[7]

Nowadays, a council announcement convenes its residents to join the communal works. Attendance is no longer compulsory, but some neighbours normally take part, dividing the cleaning tasks among themselves. The council pays for refreshments and food in compensation for the work done, generally once they have returned to the village.[8]

The water coming from the fountains in Caballar, called Fresnera and Redonda, now serves a smaller area of irrigation. The oldest people in this settlement do not remember the existence of any Junta de Aguas with Turégano, but they do recall the conflicts with the nearby village related to water sharing.

The aforementioned agreements do not provide an exact date for undertaking the cleaning of the fountains, but they do detail the duty of the neighbours from Caballar to clean the fountains at their expense, although residents in Turégano also had to pay an amount of money before the day of San Antonio (June 13th) to defray part of those expenses (Concordias entre Caballar y Turégano).

According to elderly residents in Caballar, the fountains were cleaned on the Sunday before Santiago. The bailiff, on that Sunday morning, made an announcement at mass, at around 1 pm, when the sun was at its highest point, and the neighbours then fetched their mattocks and winnowing rakes and went to each fountain.

[6]Interview with Bonifacio Sanz González, mayor of Santiuste de Pedraza. (2004).
[7]Interview with Lucas Peñas Arahuetes, Alejo Arahuetes Sanz, Crescencio Arahuetes Hernanz and Manuel Orejana Ruiz from Valle de San Pedro (2014).
[8]Collected during the technical visit on Ditch Cleaning Day 2011.

Before arriving at the fountains, they drank wine and sang the Salve Regina. Around eight to ten people would climb into the fountain. In the channel, divided into stretches, they would clean up to the *el diente* (splitting point), where they then split up among the different branches.

On that day, the council distributed bread, cheese and wine in compensation for the work done. Currently, the cleaning is performed during the morning of any convenient day.[9]

4 The Distribution of Water and Irrigation

The partition of water among the different villages took place through *dientes* or *cepos*, situated at different points along the ditch. These *dientes* are enormous monolithic stones into which some equidistant slots are cut so that an equal amount of water can run through (Fig. 5).[10]

In the ditches studied, we encountered two different modes of water distribution. Many villages received water permanently, but, in other instances, villages could only access it during certain days as established by the prevailing by-laws.[11] In both cases, turns were established whenever irrigation was needed. The water distribution dates and periods were constituted so as to irrigate all of the lands holding such rights, both communal and private, and their crops.

The organization of irrigation in each council was adapted to the days and hours when the water was available. They had to combine the irrigation of the different communal lands, such as the pastures, with that of the private fields and, afterwards, account for the different existing crops. As a result, different dates were set to irrigate each particular case. This became easier through the establishment of two blocks of irrigation: one included the meadows and pastures, while the other dealt with the flax fields and vegetable gardens (Pinillos and Martin 2015: 86).

The first written reference to fields growing flax (*Linum ussitatissimum*) comes from 1221. Although the quality of the flax harvested in Segovia was routinely deemed the best in Spain into the eighteenth century (Larruga 1791: 53; Gómez de Somorrostro 1820: 178), this crop had disappeared from these fields by the mid-twentieth century. In most villages, it was sown, treated, spun and woven in these ditches, nurturing a culture that still remains in the memories of some inhabitants of the lands where it was formerly cultivated.[12]

[9]Interview with Marcelo Contreras (RIP) and Inés Tapias from Caballar (2015).

[10]In the Ceguilla ditch, these were originally wooden. Interview with Leandro Vicente Arcones (RIP), the last Water Judge of Galindez (2006).

[11]Agreements between the Turégano and Caballar, the San Medel ditch and the Navalcaz ditch bylaws establish the days and hours corresponding to each village.

[12]Interviews with Rufina Miguel Cantalejo (2006) and Pablo Egido Palacios (2005) (RIP) from Tenzuela, Juan Pinillos and Encarna Martín (2006), José Borreguero and Dolores García (2006) from Berrocal, Eduardo García from Pelayos (2006), and José González (2006) from Basardilla.

Fig. 5 "Dientes of Cabanillas" in Cacera de San Medel. Archive Tenada del Monte

Everything was interrelated with the amount of water attributed to each neighbour, while the irrigation places and the dates and times of cleaning and water management were all regulated by different by-laws. In some cases, these regulations have been preserved, while in other cases, tradition kept them alive until the mid-20th century, almost unchanged, despite the passage of centuries. Moreover, in some villages, such as La Cuesta, the comparison between oral testimonies and sixteenth century by-laws tells us that practically nothing changed for over four hundred years.

Another important aspect of water management that this research has revealed is the different ways of resolving the amount of water that belonged to each neighbour. We have identified two methods for calculating water rights, one used in Pelayos del Arroyo (Pelayos del Arroyo, 1688) and the other in Sotosalbos (Sotosalbos, 1634), both of which we might refer to as the fiscal method.

The *pecheros* (neighbours who paid taxes) were those who held water rights. With this method, depending on how much they contributed, they received more or less of the water available. Logically, those who paid more (the richer) then gained a larger amount of water. The fiscal measuring unit was the *centena* ("hundred"). Using the total amount that the council had to pay, they took the list of registered *pecheros* and divided them into *centenas* that each neighbour had to pay based on income and property. In other cases, as in the Ceguilla ditch system (Cacera de

Ceguilla, 1588), La Cuesta and their neighbourhoods (La Cuesta, 1628), the right to irrigate was determined by the number of flax *fanegas* (measurement of grain) sown by each neighbour. Some of the by-laws that we consulted specifically forbade outsiders (people not settled there) who had inherited property in the villages from irrigating flax, wheat or meadows.

The first places to be irrigated were the pastures and communal fields. Seasonally, access to these common pasture lands was prohibited (with entrance forbidden) so that they could rest and provide local cattle with food throughout most of the summer. Before access was prohibited, or just afterwards, those residents who took their cows to pasture would perform the communal works on the channel and *regaderas* (secondary ditches) of the pasture. The president or mayor held responsibility for convening the people for such cleaning tasks. A list was drafted with the names of those neighbours who were required to go, with anybody who was absent receiving a fine. Depending on the number of livestock that they owned, individuals had to clean longer or shorter stretches of the ditch.

Generally, the use of pastures was banned from March to May, being some of these days specifically fixed in order to use the whole amount of available water to irrigate this cherished field (La Cuesta 1628; Gómez et al. 2016: 32–47).

Frequently in combination with the irrigation of pastures, other meadows were also irrigated, as well as other fields dedicated to obtaining fodder for subsequent harvest. In such cases, the irrigation allowance was usually extended to as far as the end of June. The animals, during the break period for the pasture, took turns moving between different enclosures owned by neighbours or among communal plots. When the cows went back to the pasturelands, access to the private meadows and enclosures was prohibited, and they were irrigated in turns, depending on the areas owned.

Between the feast days of Saint John and Saint Peter (depending on the village), irrigating the meadows and enclosures was halted in favour of beginning to irrigate the flax fields and orchards with the water supplied to coincide with the commencement of the rotational turns for irrigation. This turn system responded to the need for a fair distribution of the water, so that everybody might be able to irrigate according to their own particular needs.

For better control over these irrigation turns, there was an “irrigation book” (*libro de riego*), which has since disappeared from many of these villages. We have found only two, in La Salceda and Caballar. However, from these, we did obtain information on the interesting composition of this type of document. When the irrigation season started, the neighbourhood mayor called a meeting to establish the turns. The irrigation times and the rules that were to be followed were assigned to each flax field. The book regulated the order of irrigation, the name of the estate, the owner and the time (Libro de riegos de La Salceda, 1848; Libro de riegos de Caballar) (Fig. 6).

Before irrigating, it was compulsory for flax field owners to have their stretch of ditch cleaned. Generally, they started irrigating the most distant part, doing it *a manta* (traditional flood irrigation), furrow by furrow, one at a time. Water entered

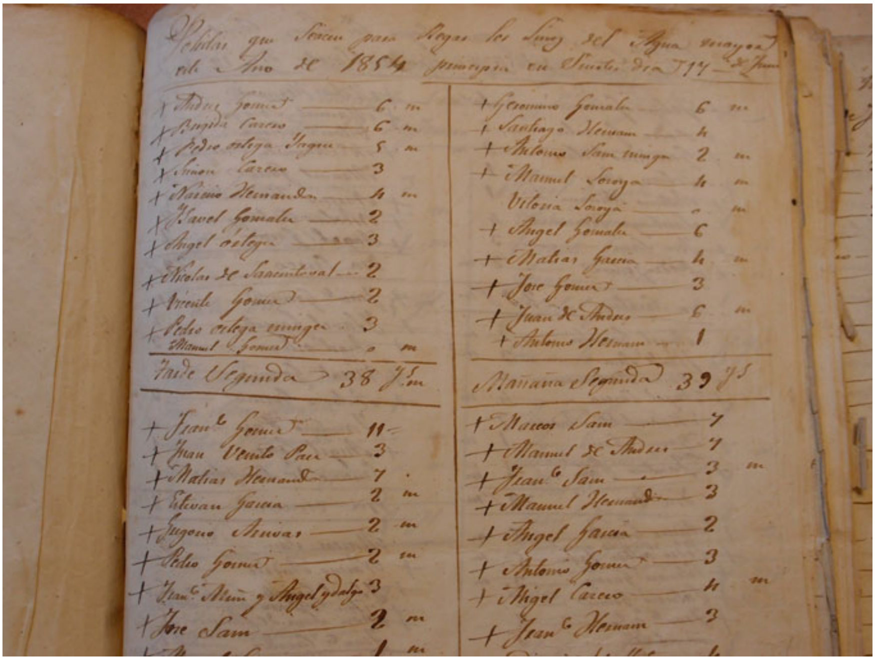


Fig. 6 Irrigation book found in La Salceda. Archive Tenada del Monte

the field through a gate opened into the ditch called a *boquerón* (literally "bib mouth"). When finishing, the *boquerón* was closed before the next one was opened, passing *la vez* ("the turn"). For everybody's sake, the guideline was that there could be no excess of water if it meant that others would lack the means for irrigation. In Caballar, they always started watering those orchards that were furthest from the fountain before moving on to irrigating the orchards and meadows.[13]

5 The Ditches: A Source of Biodiversity

The ditches represent one key part of a humanized system required for the survival of the population that benefitted from the resulting irrigation and production. They simultaneously enabled the existence of species and ecosystems in places where they would otherwise not have been able to exist. Hence, they have long since served as what contemporary environmentalists now refer to as ecological corridors (Castillo 2014: 301–320). They still retain this function, even while their neglect is causing a progressive loss in their ecological utility.

[13]Interview with Marcelo Contreras (RIP) and Inés Tapias from Caballar (2015).

The ditch system provides humidity and freshness for whichever environment it runs through. On many occasions, ditches are flanked by prickly, almost impassable bushes, where different species mingle to form a passageway through which the ditch runs. These species are usually wild roses (*Rosa sp*), blackberries (*Rubus sp*), blackthorns (*Prunus spinosa*) and hawthorns (*Crataegus monogyna*). Among them, some species of willow (*Salix sp*), privet (*Ligustrum vulgare*), elderberry (*Sambucus nigra*) and spindle tree (*Euonymus europaeus*) (Albacete et al. 2015: 396) can also be found.

In spring, all of these species blossom into life, with their flowers attracting a large number of insects, which, in turn, provide nourishment for the many birds whose nests are hidden away in the tangle of branches and thorns. By autumn, these thickets begin fruiting, constituting a food source that aids in the survival of animals that either do not migrate or that hibernate through winter. They hold an enormous protective value, as many species use them as shelters or places to sleep. They also hold great importance for the arboreal vegetation, as the thorn barrier protects the young trees from the grazing of cattle and wild herbivores and enables the growth of young trees (Pinillos and Martín 2015: 150).

Longstanding historical landscapes featuring meadows surrounded by dry stone walls and communal pastures still remain preserved in the last surviving stretches of ditches in the vicinity of some villages. In the communal pasture lands, we can find randomly scattered centenarian specimens of ashes (*Fraxinus angustifolia*) with their tops cut off (Albacete et al. 2015: 397–8). This was a traditional method of pruning to trigger the widening of the trunk and the formation of gaps that shelter a great variety of fauna, including owls (*Tyto alba*), tawny owls (*Otus scops*), little owls (*Athene noctua*), different species of bat, genets (*Genetta genetta*) and dormice (*Eliomys quercinus*), which find an almost ideal breeding environment there. The ashes contribute to the subsoil's water retention capacity while refreshing the ground with their shade. Hence, they make a major contribution towards these excellent quality pasture lands of such great economic value (Fig. 7).

The oldest ashes also sustain nests for storks (*Ciconia ciconia*), a species that finds plentiful food sources in these pasture lands. Storks may frequently be observed "grazing" there, looking for worms, insects, small mice and amphibians.

The enclosed fields, which are usually left fallow in the spring in order to irrigate them and subsequently harvest the grass for fodder, are not only a very important habitat, but are also part of our cultural and landscape heritage. Many of these enclosed fields are surrounded by beautiful, extremely old ashes and Pyrenean cork oaks (*Quercus pyrenaica*). They are also surrounded by prickly borders populated by the aforementioned species, with their fruits providing an abundant food source for the birds that winter in these meadows (Pinillos and Martín 2015: 158). Orchids bloom in spring in most of the ditch-irrigated meadows, with their diversity in the Guadarrama Mountain Range, with around 25 to 30 species present, being much higher than is generally perceived by the public.

The most common species in the hill meadows are several examples of the *Orchis* genus, such as *O.morio* and *O.mascula.* Another species of this genus that is easily encountered in some meadows is the *Orchis coriophora*. We might also find

Fig. 7 Centenarian specimens of ash in Carrascal de La Cuesta. Archive Tenada del Monte

a unique orchid in terms of its appearance: *Serapias lingua* (Martínez-Sagarra et al. 2013: 49–56).

These enclosures are also usually much more productive than the open fields, as the stone walls provide a barrier against cold and hot weather, therefore easing the variations in temperature (De Andrés et al. 2003: 28–34). When we add to this the irrigation and the fertilizing effect of cattle during the periods that they spend in the enclosures, we have an explanation for this high productivity. Many birds also contribute to the fertilization process, as they distribute the cow droppings while looking for insects in the excrement.

Traditional flood irrigation has been found to increase the diversity of both plants and insects (Müller 2017). These fertile features are present in the orchards of Caballar (an endangered cultural landscape), where many fruit trees line their boundaries and interior areas, such as mazzard cherry trees (*Prunus cerasus*), pear trees (*Pyrus communis*), apple trees (*Malus domestica*), plum trees (*Prunus domestica*) and amazing specimens of walnut tree (*Juglans regia*) (Blanco 1998: 91, 131, 135).

Another environmentally important ecosystem generated by human activities deriving from the ditch systems are the temporary wetlands, with the pools used to soak flax and the large puddles made while washing the wool providing the finest examples, although we might also add the fountains, natural springs and watering holes (Albacete et al. 2015: 394–5).

These temporary ecosystems are capable of hosting a greater amount of biodiversity than the permanent wetlands, as they preserve vegetal and animal communities adapted to the disappearance of water throughout several months of the year. They are simultaneously the place where most Amphibia, currently the most threatened animal group, reproduce. They also serve a purpose for other wild fauna species, both in regard to feeding and to quenching their thirst.

Restoring the ditches also means preserving and helping to recover the populations of Spanish ribbed newts (*Pleurodeles waltl*), mottled newts (*Triturus marmoratus*), tree frogs (*Hyla molleri*), spur toads (*Pelobates cultripes*), running toads (*Epidalea calamita*), common frogs (*Pelophylax perezi*), common toads (*Bufo spinosus*) and common obstetrician toads (*Alytes obstetricans*) (Martín Carretero 2010).

6 Conclusions

Quite simply, these ditch systems made life possible, as they generated a habitable area for the populations in these mountain foothills over one thousand years ago. Throughout the 1960s, these villages experienced depopulation, and these efficient and complex networks of ditches began to suffer from progressive abandonment due to a lack of generational renewal in the agricultural and livestock sectors. In spite of this, and in addition to all of the bureaucratic difficulties encountered by the Confederación Hidrográfica del Duero, some of these complex and singular governance systems formed by the Juntas de Aguas have survived down to our days (Cambrones, San Medel, Truchas and Pinar, Caballar and Navalcaz).

In terms of those that have already fallen into disrepair (Río Viejo, Ceguilla and Navalcaz), it would be neither difficult nor expensive to restore them, as they have only been abandoned for a short number of years and their ditches are still in relatively good condition.

Furthermore, there is an emerging pro-active social movement in the villages that backs the recovery of all of the ditch systems and their associated ecosystems. Additionally, the founding of the National and Natural Parks of the Guadarrama Mountain Range and the corresponding commitment to the conservation and recovery of the ditches represent grounds for optimism.

Ditches, far from wasting water, create a microclimate, delay hydrography and spread the effects of rivers, both by maintaining the same population of fauna and flora and by transforming the places through which they run into outstanding and flourishing gardens. Swamped soils generate meadows and pasture lands with ash trees and a great diversity of species. They simultaneously also form natural water deposits and guarantee that, during the dry season, the water that emerges slowly from natural springs and fountains remains sufficient both to meet needs of the local population and to maintain the surrounding ecosystem. Nowadays, our meadows, enclosures, fields of ashes and ponds suffer from the silence of the dry and forgotten ditches, and thus from the consequent loss of their biodiversity. These ditches form part of undervalued socio-ecosystems that we should learn from, not only for all of their social and cultural value, but also for the agronomic, hydrological and environmental value that they generate.

References

Albacete, L., Durán, J.J., Riquelme, P. & Sanjuanbenito, P. 2015. Usos tradicionales del agua en la Sierra de Guadarrama, In: M. Mejías, (Ed.), *El Parque Nacional de la Sierra de Guadarrama: cumbres, paisaje y gente.* IGME & Ministerio de Agricultura, Alimentación y Medio Ambiente. Madrid. pp. 396.

Archivo de la Catedral de Segovia: Ordenanzas de la Noble Junta de Cabezuelas. Legajo G 104.

Archivo de la Catedral de Segovia: Pergs 5. Carpeta 5.

Archivo Histórico Provincial de Segovia: Libros de las Respuestas Generales del Catastro de La Ensenada de los pueblos pertenecientes a las Comunidades de Aguas objeto de estudio.

Archivo Histórico Provincial de Segovia: Ordenanzas de la Cacera de Navalcaz. Protocolo J4384/1.

Archivo Histórico Provincial de Segovia: Información posesoria de la cacera del río Ceguilla.

Archivo Municipal de Basardilla: Acta de Notoriedad de la Cacera de San Medel y Ordenanzas.

Archivo Municipal de Caballar: Concordias de aguas entre las Villas de Turégano y Caballar.

Archivo Municipal de Caballar: Libro de riego de Caballar.

Archivo Municipal de Segovia: Ordenanzas de la Villa de Pelayos. 1688 (copia de 1821). SIGNATURA XXV-746-2.

Archivo Municipal de Segovia: Ordenanzas de la Villa de Sotos - albos. 1599 (copia de 1821). SIGNATURA XXV-746-3.

Archivo Municipal de Segovia: Ordenanzas de la Villa de La Cuesta y sus barrios. 1628 (copia de 1821). SIGNATURA XXV-746-4.

Archivo Municipal de Santiuste de Pedraza: Actas y ordenanzas de aguas.

Archivo Municipal de Torre Val de San Pedro: Libro de Riego de La Salceda.

Archivo Municipal de Torre Val de San Pedro: Carpeta agua.

Archivo Municipal de Turégano: Libros del Concejo de La Cuesta.

Blanco, E. 1998. Diccionario de Etnobotánica Segoviana, pervivencia del conocimiento sobre las plantas. Colección Hombre y Naturaleza. Tomo III. Ayuntamiento de Segovia, Caja Segovia, Diputación Provincial de Segovia & Junta de Castilla y León. Segovia, pp. 91, 131 & 135.

Castillo, J. 2014. Cultivando el agua. "Valoración y protección de los sistemas históricosde riego: El caso de la Vega de Granada". In: M.M. Lozano, V. Méndez (Coords. & Eds.), *Patrimonio cultural vinculado al agua. Paisaje, urbanismo, arte, ingeniería y turismo.* Mérida. Editorial Regional de Extremadura, Universidad de Extremadura, Ministerio de Economía y Competitividad, pp. 301–320.

De Andrés, C., Cosano, I. & Pereda, N. 2003. Diversificación del paisaje agrario andaluz. In J.C Costa (Coord) *Manual para la diversificación del paisaje agrario*. 2ª Ed. Consejería de Medio Ambiente de la Junta de Andalucía & Comité Andaluz de Agricultura Ecológica, pp. 28–34.

Giménez, M. & Palerm, J. 2007. "Organizaciones tradicionales de gestión del agua: importancia de su reconocimiento legal para su pervivencia. El caso de España", Región y Sociedad, Vol. XIX (38), pp. 12–17.

Gómez, G., López, N. & Allende, F. 2016. "Las fresnedas trasmochadas del piedemonte del Sistema Central en Madrid (España): cambios y usos actuales". Estudios Rurales, Vol. 6 (11): 32–47.

Gómez de Somorrostro, A. 1820. El acueducto y otras antigüedades de Segovia. Imprenta de D. Miguel Burgos. Madrid. Reedit. Obra Cultural de Caja de Ahorros y Monte de Piedad de Segovia.1987, pp. 178.

González Herrero, M. 1974. *Historia jurídica y social de Segovia*. Imp. Ceyde. Segovia.

González Herrero, M. 1994. *La sombra del enebro. Meditaciones sobre la Tierra de Pedraza*. Ed. Castellanas. Segovia.

Graña, M. 1992. El Duero. In: Asociación cultural Almudayna (Eds.), *Cuadernos de investigación medieval nº 10. Los regadíos hispanos en la Edad Media*. Almudayna. Madrid. pp. 79–84.

Larruga, E. 1791. Memorias políticas y económicas sobre los frutos, comercio, fábricas y minas de España. Imprenta Antonio Espinosa. Madrid. Tomo XI, pp. 53.

Martín Carretero, D. 2010. *Proyecto charcas: microrreservas de anfibios y su utilidad para la educación ambiental*. XXI Premio de Medio Ambiente. Caja de Ahorros y Monte de Piedad de Segovia. Obra Social y Cultural.

Martínez-Sagarra, G., Minaya, M. A., Alonso, P., Caparrós, R., Lucía, V., Orgaz, D. & Cebolla, C. 2013. Datos sobre los pastos del Valle de El Paular (Sierra de Guadarrama): Manteniendo riqueza florística y uso tradicional. In: L. Olea, M. J. Poblaciones, S. M. Rodrigo & O. Santamaría, *Los pastos: nuevos retos, nuevas oportunidades.* Badajoz. Sociedad Española para el Estudio de los Pastos (Eds.), pp. 49–56.

Mejías, M., Fernández, M., Vías, J., Castro, A. & del Pozo, J. 2015. El Agua: de las Cumbres a los Valles, In: M. Mejías, (Ed.), *El Parque Nacional de la Sierra de Guadarrama: cumbres, paisaje y gente.* IGME & Ministerio de Agricultura, Alimentación y Medio Ambiente. Madrid. pp. 180–186.

Müller, I.B. 2017. *The Influence of traditional flood irrigation on diversity, plant functional composition and plant nutrient availability in Central European Grassland*. University of Koblenz-Landau, Landau.

Pinillos, M., Martín, D., 2005. *Caceras de la provincia de Segovia. Un recorrido por la tradición*. XVI Premio de Medio Ambiente. Caja de Ahorros y Monte de Piedad de Segovia. Obra Social y Cultural.

Pinillos, M., Martín, D., 2015. *Ecos del agua en la Sierra de Guadarrama*. Ed. Tenada del Monte. Segovia.

Plaza, P. & Guzmán J.R. 2010. La vegetación y las acequias de Sierra Nevada, In: Guzmán, J.R., Navarro, R., *El agua domesticada. Los paisajes de los regadíos de montaña en Andalucía.* Consejería de Medio Ambiente de la Junta de Andalucía. Agencia andaluza del agua. Seville. pp. 258.

Sanchez, R., Jiménez, M.N. & Navarro, F.B. 2018. Effects of vegetation management on plant diversity in traditional irrigation systems, Journal of Environmental Managements, Vol. 22: 396–402.

Sintes, M., Heras, F., de Miguel, C. & Gómez-Limón, J. 1994. Caceras y Fuentes, In: M. Sintes, F. Heras, C. de Miguel & J. Gómez-Limón, (Eds.), *La Sierra Cambia.* CENEAM – ICONA. Segovia. pp. 22–23.

Landscape and Water Heritage in Mountainous Areas: From the Atlantic to the Mediterranean, from Northern Portugal to Southern Morocco

Desidério Batista and Miguel Reimão Costa

Abstract

This chapter presents a study of the culture of water and its shared management associated with the traditional irrigation and milling systems in the mountains of both the northwest of Portugal and the High Atlas in Morocco as lands of historical and continued human occupation. The study spans two essential themes that interrelate and overlap. It begins by characterising the historical process of socio-spatial formation of the aforementioned mountain regions, analysing the extremely intricate relationships between the inhabitants, water, and the production of foodstuffs within a context of natural resource scarcity, a climate featuring torrential downpours and a decidedly family and household-based economy. Then, it incorporates fieldwork, by surveying the traditional irrigation system and analysing the collective management of water within the scope of the different types of irrigation associated with the diverse agricultural crops and the seasons of the year, as well as investigating the use of rotating mills. The comparative study of these cases reveals the specific features stemming from the geographic, climatic and historical characteristics that have contextualised the collective usage and management of water in keeping with the irrigation practices and traditional milling methods in each of these mountainous regions. Furthermore, it simultaneously identifies a significant set of shared features that approximate the two models of settlement and territorial organisation on either side of the Mediterranean, alongside their respective modes of habitation and means of food production, whether for the inhabitants or their cattle, based upon the shared community usage of water resources.

D. Batista (✉) · M. R. Costa
Department of Earth, Sea and Environmental Sciences, Faculty of Sciences and Technology, University of Algarve, Faro, Portugal
e-mail: dbatista@ualg.pt

A. Duarte Rodrigues and C. Toribio Marín (eds.), *The History of Water Management in the Iberian Peninsula*, Trends in the History of Science,
https://doi.org/10.1007/978-3-030-34061-2_10

1 Introduction

This study on the culture of water and its social management interlinked with traditional irrigation systems and milling processes focuses on the mountains that define the "Atlantic-Mediterranean arc" as a territory that has been subject to continuous and historical human occupation. The ongoing research, its preliminary results presented here, spans two essential, interrelated and overlapping themes. One is the identification and characterisation of the historical process of socio-spatial formation in the aforementioned mountainous regions based upon analysis of the profoundly interwoven relationship among settlement, water and the production of foodstuffs within the context of a shortage of natural resources and a notably family-based rural market economy. The other focuses on the role and the importance of the traditional irrigation system and the shared management of water as a core factor within the framework of the historical model of occupation and organisation in the mountainous regions of the northwest Iberian Peninsula and the High Atlas in Morocco.

In the mountainous regions between the Atlantic and the Mediterranean, despite the environmental and cultural differences that mutually prevail, water has historically been perceived as a precious common good and a decisive factor for both the location of human settlements and the subsistence of farmers and cattle breeders. The investigation focuses upon the way(s) in which this resource, as scarce as it is vital, gets handled, managed and used by the rural communities of Northeast Portugal and the High Central Atlas mountain range in Morocco. We argue that, despite the climatic, sociocultural and religious differences, both the Berber and Portuguese civilisations share a common water culture. The expression of this water culture not only spans the material dimensions associated with traditional irrigation (water capture and storage structures and the means of surface water distribution) and milling systems (mills and their means of operation), but also encapsulates the cooperation and collaboration that arises from water management. This study shows that, beyond the local specificities, there is a shared hydraulic heritage that materialises in the landscape, associated with the usage of water both for food production and product transformation, highlighting the bridges that are extant between both shores of the Mediterranean.

The specific bibliographic review incorporates a set of diatopic and diachronic studies that deploy a transposition of scales to enable us to contextualise, across space and time, the exchange of influences between the two banks of the Mediterranean, as well as the similitudes as regards the role and importance of water culture and its social management in the long-term development of society, coupled with the nature that prevails in the respective mountain regions. Among those approaching this theme on a Mediterranean basin scale are Braudel (1995), Ribeiro (2011) and Matvejevic (1999), with their mutually complementary works that share an evocation of the profoundly intricate relationships between the distinctive civilisations and territories and their resources as the foundations for a model of occupation and spatial organisation that is identical in these two different mountain regions. This model, based on the traditional agro-forestry-pasture system, concerning the relationships among villages and their respective relationships with the irrigated fields conveys the presence and utilisation of water as a cultural factor that is essential to the settlements established there. In turn, the focus on the tangible and intangible dimensions of the shared hydraulic heritages on either side of the Mediterranean emerges from the studies by Brunhes (1902), which approach the geographic conditions, the ways and the organisation of irrigation on the Iberian Peninsula and in North Africa; by Bazzana and Meulemeester (2009) concerning the archaeology of irrigated areas in the Moorish medieval west (ninth century—fourteenth century); and the collection of works produced under the supervision of Cressier (2006), which applies a multidisciplinary perspective to approaching the processes of construction of the agrarian landscapes of the Peninsula following the Moorish-Arab invasion of the eighth century. The last study is especially focused on the techniques and social practices associated with the management and control of water for irrigation and milling, thus demonstrating how the heritage of this mastery of water in Christian societies subsequent to the Re-conquest has survived through to contemporary times.

On the local scale, we draw upon the case studies that focus on the mountains of the Iberian Peninsula and those of the High Atlas, as they deploy a methodology that interweaves theoretical study with applied research based on fieldwork, surveying the irrigation structures and the agricultural cultures and their respective crop rotations. Among them, the research carried out by Bertrand and Sánchez (2006) regarding the major irrigation channels of the Serra Nevada within the scope of a study on the origins and evolution of the Guadix territory stands out. The works by Peyron (1976) on the High Atlas of Midelt (in the eastern section of this mountain chain) and by El Faiz (2001) on the Aït Bouguemëz valley in the central High Atlas cover case studies on the mountain range that is home to the Berbers. The utilisation of an approximate methodology based on surveying irrigation and milling systems, thereby conveying a spatial layout of the structures built, was experimentally utilised in the case studies put forward in this chapter on Regoufe and Drave in Serra da Arada in the north of Portugal and about Magdaz in the central High Atlas in the south of Morocco. Following the fieldwork undertaken by Somet (1977, 1978) and Costa (2013), our work adds new knowledge to the history of water, as it associates the collective system of irrigation and milling with the territorial settlement and the socioeconomic framework in high mountain establishments, in a comparative study of both shores of the Mediterranean. Its main contribution stems from mapping of the traditional irrigation and milling systems and their interrelationship with the prevailing model of social organisation in the respective countries. In the case of Magdaz, based on unpublished data on the ownership of vegetable gardens and orchards, the plots are defined in accordance with their distribution among the families/lineages that make up the social structure of the village and the means by which the community manages the water that flows through both the watercourse and the irrigation channels/ditches.

In methodological terms, the research combines thematic cartographic interpretation (geology, hydrogeology, agriculture and forestry, soil usage, etc.) with bibliographic and documentary sources, before cross-referencing these with the fieldwork undertaken in 2016, through the financial support of the Portuguese Foundation for Science and Technology, under the auspices of a broader study on the "Architecture and Landscape in mountainous areas of the Western Mediterranean". This was done through deployment of a method based upon an interdisciplinary and multi-scale approach, with cross-references among documented evidence, cartographic analysis and the data generated by the fieldwork. The methodology used has the objective of establishing support bases for the (re)interpretation of the spatial organisation models of the ways of inhabiting and managing the sharing of irrigation water within the mountains of the Iberian Peninsula and Morocco.

The key objectives of the case study on the Portuguese territory involve the identification and characterisation of the hydraulic heritage and its shared usage. This includes the survey of the traditional irrigation system and analysis of the collective management of water within the scope of the different types of irrigation associated with the different agricultural crops and seasons of the year, as well as the utilisation of watermills. In the case study on the High Atlas mountain chain, we carried out the reading and interpretation of the water landscape and the community management of this resource, whether for purposes of irrigation or for traditional milling practices, within the context of aridity and the deficit in resources that characterises the Moroccan mountainous regions.

The comparative study of these cases also identified a significant range of shared features that approximate the models of occupation and territorial organisation on either side of the Mediterranean and their corresponding means of settlement and food production. In both cases, these models incorporate a traditional agro-forestry-pasture system that is strongly characterised by community life and the shared management of the scarce resources that are available, essentially, the pastureland, fertile soils and water. The presence and availability of water historically emerge in both mountainous contexts as determining causes and fundamental actors that govern and explain the location of settlements and the distribution of the irrigated fields.

2 On the Mountains and the Model of Occupation and Spatial Organisation

The mountains spatially and visually dominate the Mediterranean (Braudel 1995: 37) and once hosted the origins of the process that led to the humanisation of the territory (Telles 1975; Braudel 1995: 62). In its western stretch, from the Iberian Peninsula to the Maghreb, from the Atlantic to the Mediterranean, wherever the mountains do not dominate, they are still always within view and make an indelible mark on the economy and landscape of the countries that configure the "Atlantic gateway" to the Mediterranean region.

The traditional economy of the mountainous regions of these countries generally reflects a culture of self-sufficiency in which the communities carry the obligation to guarantee the different resources that are necessary to their survival. This condition results from certain fundamental principles for the transversal organisation of the different mountainous sub-regions in the territories on either side of the Western Mediterranean. These include life in a community that associates sedentism, transhumance and seasonal displacements predominantly based upon the collective management of ecosystems and natural resources such as pasture and the usage of water. This type of community life reflects an efficient mountain region settlement system—the establishments concentrated into villages (in valleys, on slopes and summits) that correlate in accordance with the complementarity of their activities: arable agriculture, forestry and pasture grazing—complying with a pattern that is heavily defined by the physical characteristics of the respective territories. This pattern of territorial organisation based on the traditional agro-forest-pasture system encapsulates a historical matrix of interdependence among the rural communities and the scarcity of natural resources. This is an interrelationship that, from the outset, has rested upon a strategy of subsistence, or even of survival, that is fundamentally delineated in accordance with the presence (very often scarce) of water and "fertile" soil (sometimes human-produced) in valley areas and the pasture lands in high altitude regions.

These characteristics determine the difficult environmental circumstances that require constant adaptation through sustained efforts based on overcoming these natural limitations. This embodies what Ribeiro (2011: 49), as regards the Mediterranean, referred to as the *fight against nature*, which, in these mountainous regions, takes the form of the struggle against: (i) the steep terrain through the building of terraces on the lower third of the slopes, associated with the watercourses that enable level surfaces that are appropriate to the production of foodstuffs, whether for the population or for the cattle (foraging cultures); (ii) the barrenness of the soil, which is almost always skeletal, through the production of soils via the accumulated sediments in the beds of the aforementioned watercourses and manure—anthroposoils; (iii) the climate, in terms of the struggle not only against drought, but also frosts, through irrigation in both the hot and cold seasons, a process that we shall analyse further below, as well as against the violence of seasonal floodwaters.

The cases subject to study, to the north and south of the Mediterranean, constitute examples that convey the way in which this model of settlement and system of land usage (in which the availability of water becomes essential) further reflects the socio-spatial organisation of the mountain territory across various scales, impacted by both the ecological and the cultural circumstances. This demonstrates how the mountain communities of both the Iberian Peninsula and North Africa based their survival strategy on the attention paid simultaneously to the distinctive means of pasturing (seasonal transhumance, sedentism, stabling), the distinctive types of agriculture, taking into consideration the irrigation involved in intensive horticulture (cereals, legumes and vegetables, foraging cultures, etc.), and the distinctive means of arboriculture (different species of fruit tree and the production of fruits, especially dried), all fully adjusted to the influences of the altitude, the relief and the shortages of fertile land and water for irrigation. Hence, in conjugating the sedentary and transhumant ways of life, through longstanding, sometimes ancient, knowledge and wisdom, they forged a cultural landscape based on a profound relationship between resilience and beauty.

In the characterisation of this organisation in these mountainous areas, we endow particular relevance upon surveying and mapping the diverse landscape structures, with a particular emphasis on the traditional irrigation system and the culture that collectively manages it as a long-term development strategy, both for nature and for society.

3 On the Culture of Water in the Mountainous Contexts on Both Sides of the Mediterranean

As stated above, this survival strategy undergoes definition at the community level, in accordance with the adaptation necessary thanks to the severe natural conditions and the socio-cultural changes and circumstances. Within this scope, access to water (Aronson 2008: 37) and the types of distribution, sharing and regulation of its usage (Brunhes 1902: 3) represent a core factor.

In the mountainous regions of these Atlantic and Mediterranean regions, despite the respective climatic differences, the understanding of water has historically encapsulated its status as a precious common good, whether for domestic consumption, irrigation or milling. In effect, access to this resource has almost always been a decisive factor in the settlement of human communities and the subsistence of farming and cattle breeding households. It is the distinctive ways in which this resource, as scarce as it is vital, gets managed by the rural communities in these different mountain contexts that we shall now approach.

Both on the Iberian High Plateau and in the Atlas Mountain chain, "…se rencontrent des enclaves de culture humaine liées à la presence et l'utilisation raisonnée de l'eau…" (Brunhes 1902: 11); "…sur l'un et l'autre bord de la Méditerranée l'homme rencontre (…) des mêmes procédés d'irrigation qu'il peut lutter contre l'aridité…" (Vidal-Lablache 1889: 384). In these territories characterised by the irregularity and insufficiency of their precipitation levels, for the production of their foodstuffs, humans are entirely dependent upon the utilisation of water, both subterranean and surface waters, for the irrigation of agricultural crops that would otherwise produce little or nothing (Ribeiro 1991a: 74; Bazzana and Meulemeester 2009: 24). Through means of a complex and diversified set of techniques and technologies for the capture, storage and distribution of water, the populations here simultaneously deploy water for irrigation and the milling of cereal. Both are inherently associated with a unique heritage built upon an ancestral form of collective water management (Ribeiro 1991b: 35) that binds human life to the exploration of the land and to life in a community.

4 On the Traditional Irrigation System and the Vernacular Architecture of Production

The landscapes of the Iberian and Maghreb mountain valleys unfurl in the cultural structure of the bonds and marks associated with the utilisation of hydric resources in the production and transformation of foodstuffs, predominantly cereals, the staple of local diets. The hydraulic structures associated with the traditional irrigation system and the mills and olive presses constitute the most common expressions of the techniques and technological processes of the usage of water and its social management.

In the Mediterranean Basin, both on the European and North African banks, from a very early period, irrigation systems were built up for both the capture and distribution of winter and spring rainfall for the purpose of producing cereals, olives (oil) and grapes (wine) (Abulafia 2014: 223), systems that have survived down through time. Following their study of the archaeology of the southwest Iberian Peninsula regions irrigated between the ninth and fifteenth centuries, Bazzana and Meulemeester (2009: 19) reported that the medieval agrarian hydraulic processes had left many remains on the contemporary landscapes associated with their morphology. These include the geometry of their irrigation channels (with their outlines remaining today) and the property holdings (the design and scale of the plots have seemed to retain their fundamental lines). These two aspects effectively and indelibly characterise the landscapes of orchards and vegetable gardens across the mountainous areas of the north and south Mediterranean. In these areas, the artificial paths of water (channels) interrelate with the paths of farmers and their smallholdings, both in the broad valleys and on the raised, loose stone terraces running along the enclosed valleys. They establish a reticular grid that corresponds to the formal and functional base of the water landscape that is interconnected with the production and transformation of foodstuffs (Fig. 1).

In effect, in the fields, all cultures undergo irrigation, both those destined for human consumption (leafy and root vegetables, legumes, fruits, cereals) and those for animal feed (pasture, legumes for foraging), with these crops also requiring the input of the manure that is essential to their successful cultivation (Ribeiro 2011: 78). Here, water management and the layout of the irrigation channels combine irrigating with the milling activities associated with the presence of mills (Ribeiro 2011: 78). These structures characterise an architecture of production that has common features across the mountainous areas under study, as verified by field-work. Such characteristics include horizontal water wheel mills (with shaft fixed wheels), the most common type in Portugal, corresponding, in many cases, to the only known type in the mountain regions of the north of the country (Oliveira et al. 1983: 112–120) (Fig. 2).

Both in the Arada Mountains and in the High Atlas, we identified small-scale mills driven by an irrigation channel via either a rudimentary dam or a weir that simultaneously served for the irrigation of some adjoining fields. These were only ever modest constructions, replicating the processes involved in house construction

Fig. 1 The irrigated fields in Northern Portugal (Regoufe and Drave) and High Atlas, Morocco (Magdaz and Imeguiss)

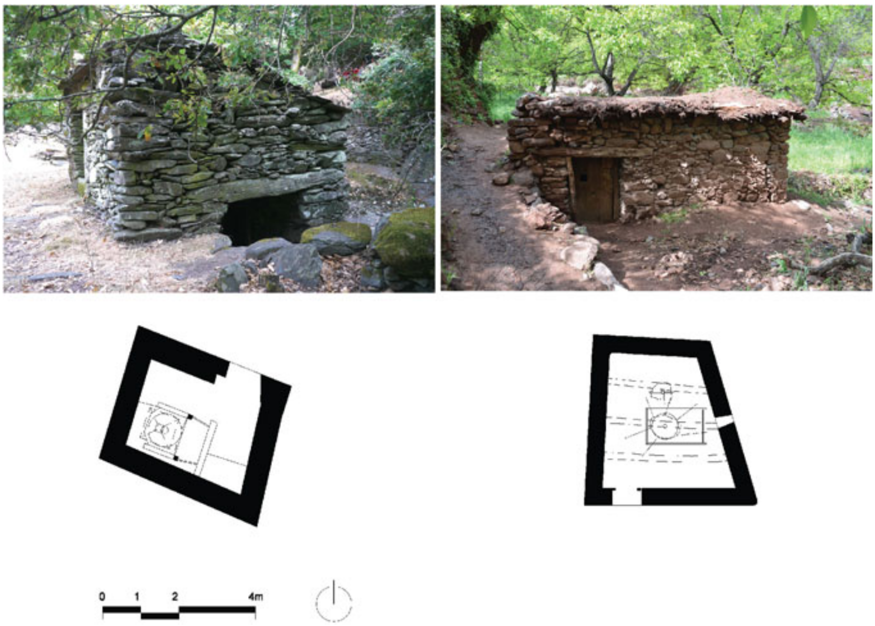


Fig. 2 A Mill in Drave (Northern Portugal) and a Mill in Magdaz (High Atlas, Morocco)

and, in both cases, combining walls of worked schist stones with a roofed covering (rammed-earth flat roofs in Magdaz and sloping slate roofs in Drave and Regoufe). In terms of their gear, the mills differed in details related to the shapes and materials of the different pieces (such as, for example, the leather hopper in the case of Magdaz, as opposed to the wooden cases in Portugal). There were also distinctive forms of positioning of pairs of mills, which, in the northerly Portuguese mountains, appear, above all, at the pavement level, contrary to what happens in the Moroccan mountains, where the upper section of the mill is located at the ground level.

Common to all of these mills is the lack of working space around the grinding stones, due to their small scale, amounting to less than three or four metres in length. This stems primarily from the fact that there is no miller in residence. Thus, in Magdaz, we encountered four mills belonging to the four main family lineages (*Ikhs*) in the village, maintained by different members of the family; in Drave, we recorded two mills run by the two largest households in the villages; and, in Regoufe, we identified four mills in the surroundings of the settlement (that only functioned in winter), together with another three mills upstream from the village on the route to Covelo de Paivô (that also operated in summer). Hence, the small mountain mills tended to multiply along the watercourses. While, in some cases, the mill might correspond to a single dam and irrigation channel, in other cases, various mills stood in succession along the course of the same channel, sharing the same dam, as is the case in Magdaz, for example, with the three mills located upstream.

The similarities among the areas subject to study also emerge out of comparisons of their irrigation systems, even though, within the broader context of these mountain regions, there remains great variety in other processes, techniques and technologies, as well as in the regime for making recourse to both surface and subterranean water sources. In any case, the old roots of irrigation spring not only from the strong Arabic influences on the peninsular territory (Bazzana and Meulemeester 2009: 48; Ribeiro 2011: 81), but also from the Iberian influence on the Maghreb region (Abulafia 2014: 489). In the former case, this emerges out of the irrigation-related vocabulary (*acéquias*, *açudes*, *minas*, *noras*), the species introduced (lettuce, carrot, aubergine) and the cultivation and irrigation practices that were improved within the scope of the traditional water culture. This is the case of the famous Valencia Water Court that, until quite recently, continued to meet every Thursday at the Cathedral entrance to distribute irrigation water among the smallholders, thereby preserving some of the principles and methods of Moorish farmers that date back to the late Middle Ages (Abulafia 2014: 422). Moreover, as regards the peninsular influence over North Africa, this spans to the introduction of specific crops such as tomatoes, potatoes, corn, oranges and the prickly pear from the seventeenth century onwards.

The multiple crops grown via irrigation, expressed in the overlapping of crops (arboreal and under coverage), require daily and intensive work to care for the soils and distribute the water that ensures such horticulture and arboriculture, closely bound to vegetable gardens, and thus represent the finely detailed art of authentic gardening (Ribeiro 2011: 78). Hence, it is natural that the French (*jardins d'irrigation*) and the

English (vegetable gardens) associate this notion of the garden with the designation of an irrigated environment that serves for the production of foodstuffs in processes that were just as delicate and vulnerable as they were essential and vital. These vegetable gardens, preferably located in the valleys or in less steeply sloping areas, as well as in a close spatial relationship with the villages, collectively established genuine clusters of greenery (*vergéis*) (Laoust 1920: 409) or mountain oases. In mountain areas, they shaped expressive socio-ecological corridors that concentrated the scant natural resources available (water, soils, flora and vegetation, avifauna) and the socioeconomic activities of self-subsistence (intensive agriculture, irrigated pasture, milling). Such resources and activities directly and deeply depended upon the presence and utilisation of water (Fig. 3).

In these mountains, men built channels whose fundamental purpose was as a means of capturing the superficial water through use of a dam or other barrier located in the bed of a watercourse, this, before water distribution took place according to a hierarchical and branching system of channels that fed both the irrigated lands and the mills by virtue of gravity. From the point of origin of its capture (whether surface or subterranean) through to the boundaries of the most distant irrigated lands, the artificial path of water was often long, but was always on the territorial scale of life in the community (Prista 1993: 117; Bazzana and Meulemeester 2009: 269). We would also stress here that the invention and dissemination of artificial irrigation techniques arose out of the initiatives of rural

Fig. 3 The vegetable gardens in the valleys of the High Atlas: the cases of the villages of Magdaz, Amezri, Imeguiis and Sidi Hamza

communities (Hassan 2011: 24) and that, in the “Age of Water-Lifting Technology (4400–2200 years ago), the mid-level technological leap also entailed a move to the use of water […] as a source of energy […]” (Hassan 2011: 32).

This interconnects with an essential facet of traditional water culture in the context of scarcity and seasonal precipitation patterns: the access to and regulation and shared usage of irrigation and milling waters. As Hassan (2011: 32) states: “Irrigation agriculture is inherently unstable because of the unpredictability of rain and frequent crop failures for other reasons. Accordingly, one of the main strategies that led to the rise of social organization was cooperation and collaboration among neighbouring farming settlements to form incipient regional water communities […]”.

In effect, both in the mountains of the Iberian Peninsula (Prista 1993; Portela 1996; Cressier 2006; Ribeiro 2011) and the Moroccan Atlas mountain range (Pascon 1977; El Faiz 2001), the social management of water forms a fundamental, intangible expression of the cultural heritage of traditional irrigation systems.

5 On the Study of the Arada Mountains Landscape Unit: Identifying and Defining the Hydraulic Heritage and Its Shared Usage

This landscape unity integrates the Freita and Arada mountain chains that largely make up a *Natura 2000* site. It is defined by their imposing reliefs (exceeding 1000 m in altitude) that alternate between granites and schists, cast into profile by a dense network of watercourses (Cancela d’Abreu et al. 2004, 37). This region forms part of a wider-reaching landscape unity that Ribeiro (1991a, 188) defined under the title of “mountains of the North of Beira and the Douro.” It is marked by the maritime influences that are integrated into the North Atlantic, even while, to a certain extent, establishing the transition to the inner region (*Trás-os-Montes*). The proximity and influence of the ocean and the availability of water, which impacts in terms of the crops grown and irrigated, especially corn, associate these mountain regions with Atlantic zones. The relevance of extensive farming, cattle breeding, habits in the community and the tendency to concentrate the settlement also ensures their resemblance to the region of *Trás-os-Montes* and the highland plateaus of inland zones. Hence, the organisation of the traditional landscapes of these mountains in the north of the *Beira Alta* region consists of the coexistence of fundamental expressions of those two worlds, further framed by the very condition of the mountainous areas that historically recall harsh and difficult environments of vast rocky and grassy areas. Furthermore, it conveys a model of human occupation based on the extremely intricate relationships among the concentrated human settlement, the availability of water and the production of foodstuffs through irrigation (both for the resident population and for their cattle).

This is the model that we encounter in the mountainous villages of the territory under study. The location of the villages of Regoufe and Drave (both at 600 m in altitude) in the landscape closely ties them to the circle of irrigated and interconnected fields and plots, in large part for pasture (in winter) and maize crops (interspersed with beans and surrounded by vines), but also for potatoes, *ferrãs* and other vegetables. While, in the valleys, which are, to a greater or lesser extent, enclosed, the irrigated *pasture-fields* (Ribeiro 1991a: 117) acquired significant importance, over on the slopes, which vary in their steepness, terraced plots account for the preponderant usage of land, alternating with grasslands and clusters of forest, traditionally oak and chestnut. The configuration of this irrigated area around the village takes place according to a traditional system of organisation that consists both of rudimentary dams (*poças*) and irrigating channels (*regos*), taking advantage of the surface capture of water from streams that characterise the diverse regions across the north, from the inland to the coastal regions.

While the summer irrigation waters interlink with the maize and vegetables mentioned above, the winter irrigation serves to water the pasture and foraging lands and to drive the mill wheels. Based upon this finding, we believe that, in the case of Regoufe, we encountered the two traditional irrigation practices identified by Ribeiro (1991a: 74): *abundance irrigation*, applied in winter to water the *pasture-fields*, and *shortage irrigation*, used in summer to irrigate the maize and vegetables that formed the local dietary staples. Furthermore, this author considers that the latter type of irrigation represents an essentially Mediterranean type (Ribeiro 1991a: 75).

In the first case, the high levels of precipitation, and the consequent abundance of water, does not place any restrictions on watering the pastures. For example, the *rega de lima* waters cover a continuous sheet across the entire terrain, with the objective of obtaining abundant grass, tender and fresh, to feed the cattle (Ribeiro 1991a: 116). The abundance irrigation of the meadows and wetlands is associated with *água de lima* or *merujar* (inundating), also applied in winter across the mountains and plateaus in Trás-os-Montes during the intense frosts as a means of protecting the pasture, defending the lands against low temperatures, warming them and, in particular, enabling the production of sources of foraging (Portela 1996: 371–383). Furthermore, during the winter season, the increase in the streamflow enables the operation of maize-grinding mills, while sowing and harvesting are activities associated with the summer season. During the hot season, when water availability is at its lowest, the maize fields are subject to scarcity irrigation. The need for community access to this resource and its seasonal scarcity force the re-organization of the frequency of irrigation (normally once per week) through the *giros de água* (turns of water). This system ensures that all of the farmers can irrigate their crops, essentially cereals, the grains of which serve as the basis for household subsistence while the rest of the plant is used for animal feed. The opportunities for irrigation, or *giros de água* as they are locally called, commonly happen twice per day, for a period of approximately three hours. The first *giro* (turn) begins before sunrise and the other is in the early afternoon.

The complexity and uniqueness of the collective irrigation system of Regoufe, expressed in the set of physical structures identified in this work, convey the functional dependence of the agricultural-pastoral communities on water: it is used for milling (in the four village mills), for irrigating the pasture lands in winter and the maize fields in summer, as drinking water for cattle and for domestic activities. While it is only under certain circumstances that the possession and utilization of water and the hydraulic structures take on a mixed character, its community use, which incorporates intensive and very intricate work for the purpose of rationally and efficiently irrigating cereal and vegetable crops, is predominant. The equitable distribution of irrigation during the dry and hot period falls within the framework of the attribution of rights of access to water that enables each village household and family unit to maintain their production of cereals, legumes, greens and vegetables to meet their needs, whether for immediate consumption or to make *broa* (maize bread) over the course of the year.

Here, the plots that are cultivated and irrigated, predominantly small in size, almost always appear flanked by hanging vines or branches that cover and provide shade for the paths and access tracks, which are sometimes connected to the actual hydraulic structures. In these cases, the channels adapt to the slope of the land, directing the water, via gravity, to the meadows and fields for irrigation. Occasionally, there is also the need to store water in tanks located on the highest terrains for later distribution, via the channels, to the seeded or cultivated plots, where hoes open up paths for the irrigation waters to follow.

An identical system in the already abandoned site of Drave, just a little over 2 km to the southeast of Regoufe, establishes a particularly interesting case study as a smaller agglomeration with a more basic system of irrigation. This settlement was historically the site for two agricultural households, a situation conveyed both by the organisation of the existing properties and by the actual surrounding landscape (Costa 2013). Located alongside a valley that is significantly more enclosed than Regoufe, the irrigated areas of Drave largely span three larger-scale plots (Fig. 4).

A first plot was the property of the Lower House (*casa de Baixo*), located to the south of the settlement and constituting one of the highest irrigated terraces in this village. They were irrigated by channel or by watering from above, and at a greater distance via the small dam (*poça*) located almost a thousand metres away. In front of these lands, on the opposite side of the watercourse, lays the most important area of irrigated land in Drave, served by two different irrigation channels. While the area irrigated by the lower channel was owned exclusively by the *Casa de Baixo*, the area irrigated by the upper channel (drawing on three different dams) was shared by both of the village households. A third plot of land, located to the southwest of the hamlet, was the exclusive property of the Higher House (*casa de Riba*) and, unlike the former cases, was not fed by the main watercourse, but rather by three small dams dug along a tributary stream.

While, in a first phase, only the water from one of the channels was shared, with the gradual fragmentation of the agricultural lands, all of the rest was converted to water sharing. Thus, before the Day of Saint John the Baptist (June 24th), the consorts and heirs would gather for conservation work on the irrigation system and

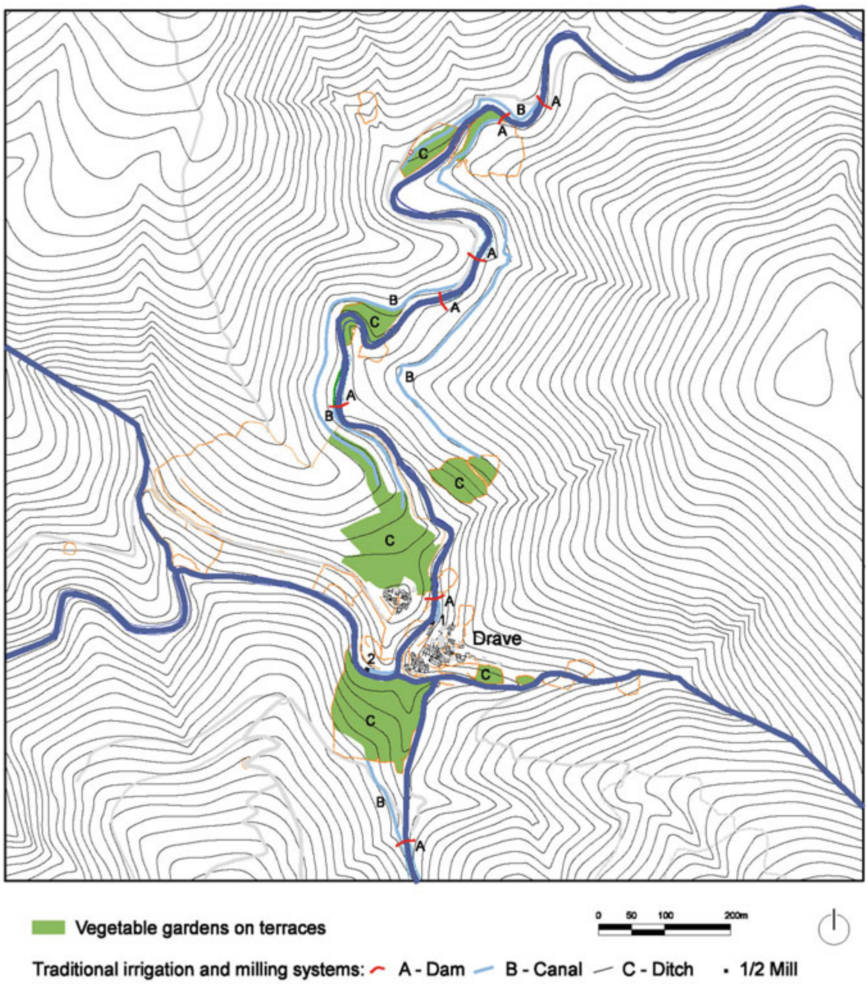


Fig. 4 Map of Drave's landscape: the irrigated terraces and traditional irrigation system

to rebuild the dams using the traditional system of stones and earthen clods. The mills that, as seen above, also confirmed the prior organisation of the village into two major households ended up gradually undergoing conversion into shared property by different heirs as well.

In addition to these watered lands, the Drave agricultural areas also included two non-irrigated fields for rye that extended out among rocky crags to the west of the village, alongside the thoroughfare leading to Regoufe. Outside of this circle of agricultural croplands, the wild areas above 500 or 600 m constituted untended grasslands, which were fundamental to the traditional economy, not only for producing charcoal, apiculture or the gathering of firewood and brush for lining the floors of the stock pens, but also, and most especially, as pastureland for cattle. Following the abandonment of the villages, part of the fields located within the irrigated perimeter underwent forestation, thus maintaining the fields and areas around as grass and pasture lands so that they could continue to serve the flocks arriving from Regoufe.

In terms of a summary, we may state that, despite the recent changes observed in the landscape of Regoufe (and in Drave, only partially due to its abandonment as a place of residence), the identity and character of the landscape remains considerably marked by the traditional culture of shared water management. The remaining irrigation and milling structures represent a set of vernacular hydraulic heritage that deserves safeguard and protection. Such measures should stem not only from the intrinsic cultural value of such heritage, taking into consideration both its tangible (the irrigation structures, techniques and technologies, their construction processes and materials) and intangible (community management of the water and hydraulic infrastructures) expressions, but also from the context of the onset of climate change, which requires using the available water as efficiently as possible, a framework in which the traditional systems, processes and methods of irrigation represent a fine example.

6 On Studying the High Atlas Case: Reading and Interpreting the Water Landscape and Its Community Management

The present case study arises from an integrated reading of the pattern of settlement and the system of land exploration in the High Tassaout. It focuses on the analysis of the interdependence between the settlements and the presence and availability of water due to the traditional irrigation system, as well as this system's deeply intricate relationship with the areas for production and the transformation of foodstuffs. The fundamental objective of this study incorporates the characterisation and graphic registration of the spatial layout of the fields, mapping the irrigation system and recording the irrigated lands in and around the village of Magdaz (Fig. 5).

The village of Magdaz is located in the High Central Atlas, at the summit of the River *Tassaout*, at 1960 m in altitude, to the north of *Jbel Tiglist* (2974 m). The boundaries of the territory that is the subject of study simultaneously incorporate criteria related to both the physical territory and its sociocultural dimensions, in a mountainous highland region characterised by the profound historical consonance of these two orders of factors. Magdaz integrates lands belonging to the *Fetouaka* tribe, to the fraction of the *Aït Mgoun* and to the sub-fraction of *Aït Attik*, with its territory spanning a total of six villages (*douar*), three of which are located along the course of the river (from downstream to upstream *Fakhour*, *Aït Ali n'Ito* and *Aït Hamza*) and the other three being next to tributaries of *Assif n'Tiftcht* (*Tiftcht*) and *Assif n'Magdaz* (*Ighi n'Imziln* to the north and *Magdaz* to the south). In addition to

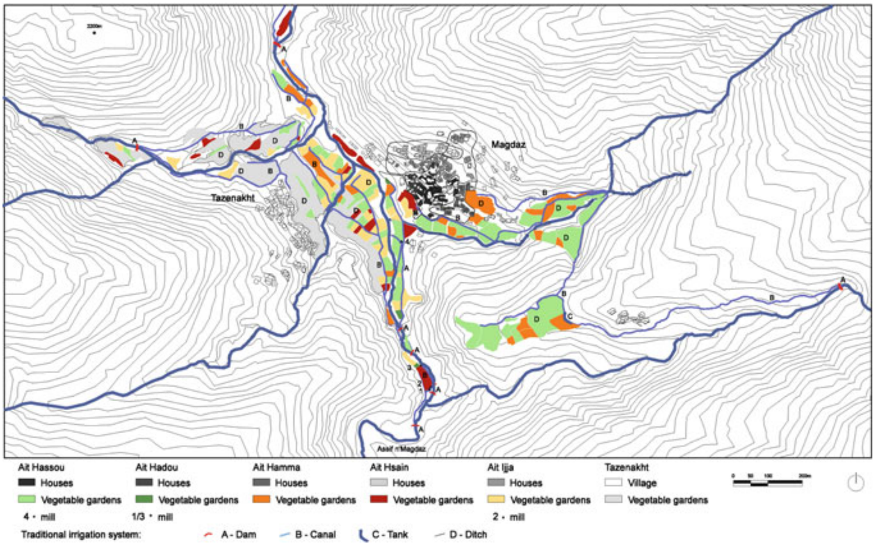


Fig. 5 Map of the cadastre and the traditional irrigation and milling systems

these villages, located in the best areas alongside watercourses, the territory of *Aït Attik* also includes a significant number of secondary settlements (*azib*), characterised by the importance of transhumant pasturing and high altitude grazing (Costa and Batista 2018).

The landscape pattern of this area on the north slope of the High Central Atlas thus determines the settlements in the form of *douars* and *azibs*, by the small scale of properties of individual ownership (*melk*), by non-irrigated lands (*bour*) and by irrigated lands (*urti*), with the average dimension of family properties (*takat*) being between 0.29 and 1.71 ha, (Somet 1977: HT1/7). In addition, the collective pasture lands and forests (*agdal*) guarantee the diverse resources that are fundamental to the traditional rural economy. In *Magdaz,* the bulk of household incomes is provided by traditional cattle breeding (bovine, ovine, caprine and equine), the growing of walnuts and, relatively recently, crops of lilies (*sossban*) for the pharmaceutical industry.

Similar to the other main tribes in the region (Aït Hamza 2012: 187–207), the Aït Attik simultaneously structure their development around different modes of cattle raising (seasonal transhumance, sedentism, stabling), agriculture, spanning both dry crops and the irrigation associated with intensive horticulture (winter and summer cereal crops, legumes and vegetables, lilies), and arboriculture (walnuts and, more recently, peach trees), perfectly tailored to the respective altitude, the geographic profile and the shortage of fertile lands and water for irrigation. These constitute the means by which the Aït Attik, balancing sedentary and transhumant ways of life, in conjunction with longstanding learning and practices, have forged a productive and beautiful landscape.

In any case, the preponderance of sociocultural structures in the organisation of the landscape clearly emerges out of the interlinking of successive scales, ranging from the broader territory of the Fetouaka tribe (which occupies the largest proportion of the Tassout Valley) down to households explored by single families. In terms of characterising the territory at the Aït Attik sub-fraction scale, in addition to the *douar* scale and the bond that this establishes with each one of its *azibs*, we necessarily have to consider the diverse lineages (*ikhs*; pl. *ikhssen*) that we encounter within the study area. As we report below, this is the scale needed, not only to interpret the social and spatial organisation of villages, as is especially clear in Magdaz, but also, and above all, to grasp the structure of its irrigated fields (El Faiz 2001: 44–46) and the distribution of mills along the streams.

The fieldwork took place in different campaigns spaced out over the different seasons of the year, thereby enabling the identification of the three main types of vegetable garden. The survey of the traditional irrigation system took into account the *paths of water* right from the catchment area in *Assif n'Magdaz* and in one of its tributaries, down to the watered plots located across different levels and associated with the distinct morphologies of the terrain: towards the summit, the lower third of the slopes and the riverbed (Costa and Batista 2018) (Figs. 6 and 7).

The system of excavated irrigation channels runs 2.5 km in length, overcoming a difference of 250 m between the highest point (which corresponds to the starting point of the hydraulic system at the dam that provides the supply, located on one of the *Assif n*'*Magdaz*'s tributaries) and the lower slopes, with plots of land irrigated on the valley bottom, downstream from the village. The labyrinthine irrigation network drives the rainwaters and meltwaters all the way to the irrigated crops in a

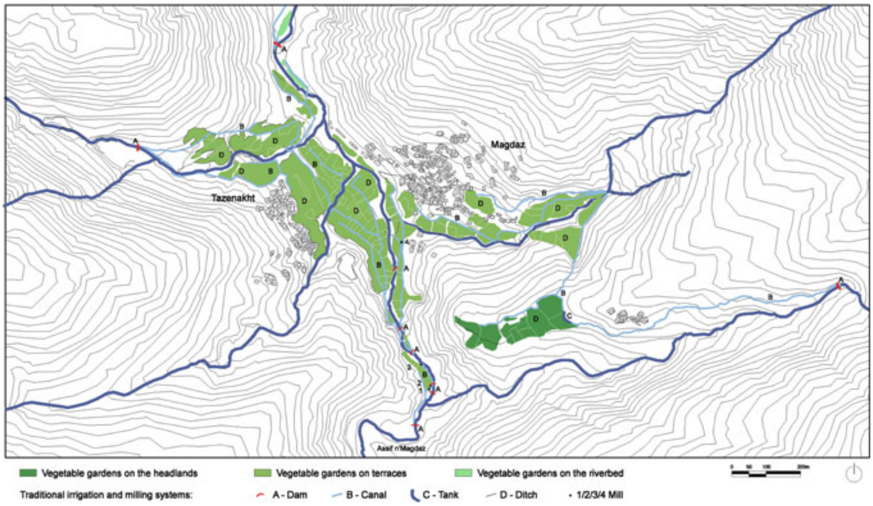


Fig. 6 Map of the typologies of vegetable garden in Magdaz and Tazenakht: in the riverbed, on terraces and in the headlands; the traditional irrigation and milling systems

Fig. 7 Images of the vegetable gardens in the riverbed/valley, on terraces and on the mountain summit

twisting and surprisingly acrobatic fashion through the hills and slopes (Somet 1978: 57). They adapt very closely to the sharp reliefs and the topographic diversity of the different and distinct morphological situations (headlands, terraces, riverbed/valley bottom). These channels are predominantly cut into earth and stone when associated with the terrace walls or when crossing the watercourse. In the latter case, they implement other traditional processes, such as hollowed poplar trunks installed to get the water from one riverbank to the other. Both the process and construction material of the irrigation channel render the Magdaz hydraulic system as a unique and exceptional case within the context of the High Atlas Mountains, where recent decades have witnessed the application of new construction materials and techniques, specifically concrete. The vernacular dimensions of the Magdaz hydraulic heritage interrelates with the ecological value of the system, built predominantly out of stone and earth, lowering the loss of water through evapotranspiration and boosting water infiltration in the soil. Altogether, this fosters the development of a permanent "pasture," with the water route transformed into a "corridor," promoting biodiversity within the dry, arid context of these mountain highlands.

In addition to being an integrative cultural and ecological structure of the landscape, the traditional irrigation system proves crucial to implementing the self-sufficiency strategy of the rural Berber communities that deploy such means for the production of foodstuffs (also for cattle) and to boost their household incomes through the selling of walnuts and lily bulbs grown in their vegetable gardens.

The terraced fields, minutely and carefully cultivated and built with dry stone walls, represent a cultural and civilizational feature of primary importance (Aït Hamza 2012: 187–207). The dimension of the walls that contain the soils and the size of the stones applied in the process of their construction appear to be out of proportion in relation to the scant surfaces of the small cultivated plots. However, the need to boost the area of crop production required their construction, in conjunction with the "manufacture" of fertile soil, based upon a mixture of sediments and organic materials, and the "design" of a system of carefully located channels that would water, by gravity and by turn, each of the plots belonging to each family household. In Magdaz, the relevance of the role played by these vegetable gardens in the evolution of this landscape of such intense and ancient human occupation can clearly be perceived and shows the result of the experiences and knowledge handed down through generations. Within this domain, and similar to other irrigated lands in the high mountains—for example, the valley of *Aït Bougmez* (El Faiz 2001: 36–48) or the lands around *Aït Iktel* (Amahan 1998: 102–111)—the water culture and its collective management, as a common good to tribally-based societies, entirely determine their artificial agricultural practices. These practices are based on a complex and hierarchical set of structures and techniques for the capture, transport, storage and distribution of water associated with the irrigation of agricultural crops that, within this context of aridity and dryness, would produce little or nothing without such irrigation (Fig. 8).

Fig. 8 The traditional irrigation system: little dams, channels, and ditches

The traditional hydraulic system of dam-channel-ditch (*uggug-targa-tiferouine* in Berber), also identified in a prior study on the Riff mountains (Batista and Matos 2014: 44–62), provides the core structure that is applied in irrigating the fields and vegetable gardens of Magdaz. In effect, what is common to the three types of vegetable garden identified above is this system of irrigation that catches surface water via the flow in the *assif n'Magdaz* and/or its tributaries through small and rudimentary dams that supply the system by means of channels (*targa*), both principal and secondary, leading to the plots where little ditches take the waters to the respective crops.

The terraced vegetable gardens located on the lower third of the slope hills, preferably between the level of the water lines and that of the village, require the construction of strong and robust dry-stone walls that reach up to 3 m in height and 0.60 m in thickness, configuring plots that are 2–5 m wide and variable in length, but always fairly short. To this end, the construction process incorporates a notable interlinkage between the *paths of water* and the *paths of man* so as to establish a horticultural mosaic that is closely bound to the smallholdings and the need of each family household to access a slice of land for the production of cereals, the core dietary staple.

In turn, the vegetable gardens located on the riverbed/valley bottom require, on account of the violence of the floodwaters, the construction of dry-stone walls that almost always prove insufficient to withstand the destruction wrought by the floods. Hence, seasonal work is frequently required to rebuild the ephemeral character of these food production spaces, as necessary as they are fragile.

Within the scope of gaining new land capable of raising levels of production, new terraces for crops, orchards and irrigated pastures (*tilliba*) have recently taken shape on the headland to the south of Magdaz. The hydraulic system associated with the irrigation (*timessuit*) of these areas incorporates an excavated channel that twists along the upper third of the aforementioned slope, fed by a dam on a small tributary of the river. The tank (*tafrawt*) supplied by the main channel, also partially excavated into the summit, stores the water that is subsequently distributed among the crops through secondary channels and small ditches. This system also feeds the majority of the areas irrigated on the lower slopes, whether they are part of the terraces or on the riverbed. While the walnuts, cereals and lilies predominantly grow on the terraces in a relationship of greater proximity and under the protection of the residence, other cereals and winter/spring leguminous crops, as well as vegetables, seasonably occupy the *assif n'Magdaz* bed. In turn, from the top of the slope, watering reaches the peach and apple trees, with cereals and lilies growing beneath, dividing this space with the lush pasture fundamental for the cows and their calves.

In any case, the hierarchical and tightly bound field plots that make up [fr.] *le carreau, la planche d'irrigation et la parcele* contain the traditional crop rotations tailored to an agricultural calendar associated both with the irregularity in the rainfall and the (ir)regularity in the growing cycle of winter cereals, which take six months, and summer cereals, which take three months, with the latter being forced into adaptation due to the shortfall in rain between May and September

(Berque 1978: 127–131). This latter aspect assumes greater importance when taking into consideration the scarcity of water during periods of drought and/or in the hot season. During this period, water mostly only comes from the melting of the snow of the mountain peaks, thus potentially causing conflicts among farmers in the villages located along watercourses regarding the community management of irrigation waters (Somet 1978: 58). The collective management of water for irrigation and milling, common to other irrigated valleys (*tamazirt*) (Amahan 1998: 93) in the High Alto Atlas, based on *droit d'eau* and *tour d'eau,* whether inside of the villages or between them (El Faiz 2001: 41–43), falls far too short during the dry season for any possible equitable distribution of this resource vital to the production of foodstuffs, both for persons and for cattle. In the vicinity of *Magdaz*, in areas both irrigated (with water constantly available) and semi-irrigated (with only intermittently available water supplies), soil usage in the cold season is relegated mainly to barley (covering around 75% of the surface area). In addition, the area occupied by barley and lilies (a biannual species that also has a significant presence) also grows durum wheat, alfalfa (foraging leguminous), broad beans (leguminous) and leafy and root vegetables.

In turn, in the hot season, the area formerly occupied by barley gets divided, with one half devoted to corn, which, given the lack of water for irrigation, is planted on the most appropriate plots, and the remaining half left fallow (*issîki*), dividing whatever portions of the first half that are not occupied by corn into equal percentages of millet, alfalfa and leafy and root vegetables. While the irrigated cultivation of cereal (barley in winter and maize in summer) plays a leading role in both the land under cultivation and the local diet, the predominance of the former necessitates the growing of lilies, followed closely by walnuts, as a fundamental supplement to household incomes, due to the sale of the bulbs after drying.

On the irrigated and semi-irrigated lands that are more distant from the village, barley is grown (as well as lilies around the borders of the plots and strips of land), and, in keeping with both the winter and the summer rotations, over a half of the surface area occupied by the barley remains fallow, with the rest of the land divided between growing maize and growing turnips. The proximity of those crops, which demand close daily tendering, to residences underlies the traditional rotations that mark the daily life of the community and configure the landscape of the fields, with the presence of old walnut trees facilitating the collection of nuts in the autumn and the dense green crowns in summer, turning the valley into a lush green garden, like a *vergel*.

Among the secondary settlements with which *Magdaz* maintains close relations, *Imeguiss*, to the south of that village, located at 2100 m in altitude on the slopes of *Jbel Tiglist* (Costa and Batista 2018), is of particular importance. This relationship particularly rests upon the fundamental components of a territory associated with a humid system and a dry system in which horticulture and livestock husbandry interrelate to reveal the construction of a place that encapsulates some of the most unique expressions of the *Aït Attik*. The fields of *Imeguiss,* running along a less enclosed valley, convey the diligence of the communities and their incessant attempts to gain new spaces for the production of foodstuffs and the generation of income. The winter and summer cereal crops, especially barley and durum wheat in the former case and maize in the latter, strengthen the dietary base, while the growing of lilies, which, due to the greater availability of water, takes on a more significant role here, contributes towards raising the level of household incomes.

The slow and continuous process of construction of the irrigated fields upwards through the valley implies, above all, replicating the traditional methods and techniques that are deployed in conjunction with other innovative means associated either with the system for capturing and supplying water for irrigation or for building up soils and "beds" for sowing. In addition to the traditional irrigation system involving the capture of surface water from the watercourse via channels and ditches, hoses have recently been introduced to get the water to the plots and fields. This introduction appeared simultaneously with another, one that is perhaps even more effective, involving the excavation of a channel that reaches the water table level or phreatic surface on the banks of the stream so as to enable the subsequent transportation of subterranean waters to a tank sited on the perimeter of the irrigated lands. In the upper section lays the main irrigation channel, which feeds a labyrinthine and hierarchical system of channels and ditches for distributing the water around the terraces, the topography (*unmila*) of which forms an amphitheatre shape (El Faiz 2001: 45; Amahan 1998: 298) that occupies the entire area between the settlement and the stream. Based upon the sediments accumulated here, which are, on occasion, subject to further grinding, in conjunction with a mixture of the manure sourced from the stock pens and stables, Berber farmers build up layers of fertile land of greater or lesser thickness for the sowing of cereals and the planting of lily bulbs.

There is only a marginal presence of some young planted walnut trees alongside the main *targa* and the stream. The current absence of these leafy trees nevertheless reveals the geometric pattern of the smallholdings, parcelled out into minute plots. These plots trace the terraces across their different layers, in an approximation of the formal language that interconnects with the architecture and the terraces of houses and shelters for animals, following a process of adaptation to the topography that indelibly stamps its mark on this landscape of water and crop fields.

7 Conclusion

Any characterisation of the mountain contexts under study to the north and south of the Mediterranean needs to emphasize the irregularity and torrential incidence of the rainfall, alongside the fragile equilibrium between abundance (in winter) and aridity (in summer). Hence, the traditional water culture and its collective management is interlinked with both the irrigation system and the process for milling cereals (the local dietary staple) and takes on major relevance both within the framework of the family-based economy and within the historical process of constructing and transforming the landscape. Underlying this scope, even in mountainous regions with clearly different biophysical conditions, is a similar model for territorial occupation and the organisation and exploration of these natural ecosystems and resources. This model of socio-spatial formation "common" to the Arada mountain in the north of Portugal and the Central High Atlas in Morocco, despite the respective specific characteristics (natural, historical and sociocultural), reveals a historical matrix of interdependence among life in community, the rural habitat of farmers-shepherds and the irrigated crops as a subsistence or even survival strategy. This emerges out of the presence and utilisation of water and fertile soil within a context of the scarcity of resources. The profoundly intricate relationships among the villages, the local natural resources (stone, soil, water, vegetation) and their exploitation in the community are most clearly expressed in the valleys. Within this scope, the collective usage of water associated with the traditional irrigating and milling processes, intertwined with the social organisation (tribal and pluri-family in Morocco, neighbourly and parentage in Portugal) and the settlement models, predominantly concentrated, constitutes a first demonstration of the means to produce and transform food. The traditional hydraulic system of dam-channel-ditch and the cereal milling process, fundamentally maize in both mountain regions, draws upon the usage of rainwaters and/or meltwaters (in summer in High Tessaout), based upon the surface capture of water and its distribution, via gravity, as far as the irrigated fields and crops. In both case studies, the community utilisation of non-divided waters for irrigation and as a source of power for milling (especially in winter) stems from the right to water, while the turns taken for irrigation are the result of a democratic code and the principle of equalitarian sharing by all family households of a resource as scarce as it is vital, occasionally reflecting the conflicts that can arise.

In this sense, the analogy of these case studies serves to highlight the existence of singularities, but also of the shared features that bring together these ways of living and means of production and transformation of foodstuffs in the Portuguese and Moroccan mountains. At their core, there is a shared cultural heritage that displays tangible (processes, techniques and technologies for irrigation and milling, as well as for cultivation) and intangible (the collective management of natural resources) expressions that, altogether, reflect the historical exchanges of influences between these two sides of the Mediterranean, characterised not by their differences, but rather by what binds them together and through which they mutually resemble each other.

Bibliography

Abulafia, D. 2014. *El Gran Mar. Una Historia Humana del Mediterráneo*. Barcelona: Crítica.

Amahan, A. 1998. *Mutations sociales dans le Haut Atlas. Les Ghoujdama*. Paris: Éditions de la Maison des Sciences de l'Homme.

Aït Hamza, M. 2012. "Les agdals du Haut Atlas central: formes d'adaptation, changements et permanences. In L. Auclair & M. Alifriqui, (coord.), *Agdal. Patrimoine socio-écologique de l'Atlas marocain*, Rabat: IRCAM/IRD, pp. 187–208.

Aronson, S. 2008. *Aridscapes. Designing in harsh and fragile lands*. Barcelona: Gustavo Gili.

Batista, D. & Matos, R. S. 2014. "The multi-functionality and resilience of the Mediterranean landscape: the traditional vegetable gardens from the Southern Portugal and Northern Morocco". In A. D. Rodrigues, (coord.), *The Garden as Lab where the Cultural and Ecological systems meet in the Mediterranean context*, Évora: CHAIA, pp. 44–62.

Bazzana, A. & Meulemeester, J. D. 2009. *La Noria, l'aubergine et le fellah. Archéologie des espaces irrigués dans l'Occident musulman médiéval (9e-15e siècles)*, Ghent University: Academia Press.

Berque, J. 1978 [1955]. *Structures Sociales du Haut-Atlas*. Paris: Presses Universitaires de France.

Bertrand, M. and Sánchez, J. 2006. L'irrigation du territoire de Guadix. Les grandes acequias. In Cressier, P. 2006. (eds.), *La maitrise de l'eau en Al-Andalus: paysages, pratiques et techniques*. Madrid: Casa de Velásquez.

Braudel, F. 1995. *O Mediterrâneo e o Mundo Mediterrânico* (1966), volume 1. Lisboa: Publicações Dom Quixote.

Brunhes, J. 1902. *L'Irrigation ses conditions géographiques, ses modes et son organisation dans la Péninsule Ibérique et dans l'Afrique du Nord*. Paris: C. Naud, Éditeur.

Cancela d'Abreu, A. *et al*., 2004. *Contributos para a Identificação e Caracterização da Paisagem em Portugal Continental*. Volume III. Lisboa: Direcção Geral do Ordenamento do Território e Desenvolvimento Urbano.

Cressier, P. (éd.). 2006. *La Maîtrise de l'eau en al-Andalus. Paysages, pratiques et techniques*. Madrid: Casa de Vélasquez.

Costa, M. R. 2013. A casa de baixo e a casa de riba na Drave: crónica de um lugar do maciço da Gralheira em Portugal. *Labor & Engenho*. Campinas: Unicamp. 7:2. pp. 45–62.

Costa, M. R. & Batista, D. 2018. Le paysage, le peuplement et l'architecture de Magdaz, dans la vallée de la Tassaout dans le contexte montagneux du Haut Atlas au Maroc. Marrakech: *Les Cahiers du Musée Berbère* IV [Fondation Jardin Majorelle, in press].

El Faiz, M. 2001. *Maroc. Cas du Haouz de Marrakech et de la vallée d'Ait Bougmez*. La Gestion de l'Irrigation en Méditerranée. Montpellier: Projet ISIIMM.

Hassan, F. 2011. *Water History for our times. IHP Essays on the Water History*, Volume 02. Paris: UNESCO Publishing.

Laoust, E., 1920. *Mots et choses berbères*. Paris: Agustin Challamel, Éditeur.

Matvejevic, P. 1999. *Mediterranean: A Cultural Landscape*. Oakland: University of California Press.

Oliveira, E. V. *et al*., 1983. *Tecnologia tradicional portuguesa – Sistemas de moagem*. Lisboa: Instituto Nacional de Investigação Científica/Centro de Estudos de Etnologia.

Pascon, P. 1977. *Le Haouz de Marrakech*. Rabat: édition du l'auteur, 2 tomos.

Peyron, M. 1976. Habitat rural et vie montagnarde dans le Haut Atlas de Midelt (Maroc). *Revue de Géographie Alpine*, 64(3):327–363.

Portela, J. 1996. "Regadios tradicionais em Trás-os-Montes". In Brito, J. P. *et al*. (coords.), *O voo do arado*. Lisboa: Museu Nacional de Etnologia, pp. 371–383.

Prista, P. 1993. *Sítios de Querença. Morfologias e Processos Sociais no Alto Barrocal Algarvio*. Dissertação de Doutoramento em Antropologia Social. Lisboa: Instituto Superior de Ciências do Trabalho e da Empresa.

Ribeiro, O. 1991a. *Portugal o Mediterrâneo e o Atlântico* (1947). Lisboa: Livraria Sá da Costa Editora (6ª edição).

Ribeiro, O. 1991b. *Opúsculos Geográficos. O Mundo Rural*, IV Volume. Lisboa: Fundação Calouste Gulbenkian.

Ribeiro, O. 2011. *Mediterrâneo. Ambiente e tradição* (1968), Lisboa: Fundação Calouste Gulbenkian (3ª edição).

Telles, G. R. 1975. "Da formação do solo à socialização da paisagem". In J. Almeida Fernandes *et al*.. *Uns comem os figos*… Lisboa: Seara Nova, pp. 55–149.

Somet, 1977. *Aménagement du Bassin Versant de la Tessaout en amont du Barrage Moulay Youssef. Monographie des Unités de Développements*. Rabat: Ministère de l'Agriculture et de la Réforme Agraire. Direction des Eaux et Forêts et de la Conservations des Sols.

Somet, 1978. *Aménagement du Bassin Versant de la Tessaout en amont du Barrage Moulay Youssef. Situation Actuelle et Potentialités. Le Secteur Agro-pastoral*. Rabat: Ministère de l'Agriculture et de la Réforme Agraire. Direction des Eaux et Forêts et de la Conservations des Sols.

Vidal-Lablache, P. 1889. *États et nations de l'Europe. Autour de la France*, Paris: Librairie Charles Delagrave.

The Technical and Social Scope of Irrigation in the Algarve

Ana Duarte Rodrigues

Abstract

Focusing on irrigation systems in the Algarve, this paper argues that both the technical and the social aspects of watering the fields in the Algarve stem from Islamic influence that has been reinvented by local culture for centuries. Moreover, its importance for the community was such that the distribution of water among the neighbors in the Barrocal, an inland area of the Algarve, fell under the umbrella of municipal powers in the second half of the nineteenth century. Likewise, pleas and conflicts arising from water flows were solved in Courts of Law. This study also tackles the importance of irrigation in Iberian theoretical production, and, while the construction of wells, noras/norias and channels for water distribution were explained in agricultural treatises written in al-Andalus, this information then disappeared from early modern Iberian agricultural treatises. Therefore, the expertise developed in the Iberian Peninsula on irrigation is essentially local and passed on orally from generation to generation.

1 Introduction

Irrigation is acknowledged as forming one of the main differences between the Iberian Peninsula and the rest of Europe as regards water systems. In Central Europe, water has seldom constituted a scarce resource, given the prevailing rainy climate. In most regions, agricultural activities simply did not require any specific techniques to provide a controlled supply of water to plants. Therefore, while, in

A. D. Rodrigues (✉)
Centro Interuniversitário de História das Ciências e Tecnologia, Faculdade de Ciências, Universidade de Lisboa, 1749-016 Lisboa, Portugal
e-mail: amnrodrigues@fc.ul.pt

A. Duarte Rodrigues and C. Toribio Marín (eds.), *The History of Water Management in the Iberian Peninsula*, Trends in the History of Science,
https://doi.org/10.1007/978-3-030-34061-2_11

most European countries, plant growth depended on being rain-fed, on the Iberian Peninsula, due to its Mediterranean climate characterized by a long dry season, the development of irrigation techniques was always crucial (Freire and Lains 2017).

It is commonly acknowledged that not only do “Iberian irrigation systems appear unparalleled in their complexity” (Squatriti 2000: xviii), they also totally different from those of the rest of Europe, due to their Islamic influence (Magnusson 2003: XI). Due to this legacy, the types of irrigation practiced on the Iberian Peninsula, ranging from a form of water abstraction and distribution in the fields to the social agreements established in the communities over distribution of the same water, were both more diversified and applied more intensively. Thus, climate, geography and history all lie behind the different water related solutions, techniques, devices and institutes. Although irrigation was practiced in some European regions,[1] the widespread use of manmade water channels was usually associated with hydro-power and not with irrigation (Rynne 2000: 3).

The first studies on irrigation systems were derived from the archeological field and consisted of tracing the route of the water from the point of abduction to the fields subject to irrigation. In medieval Iberian archaeology, Miquel Barceló dedicated his career to studying al-Andalus hydraulic systems and listed a number of principles as applying to any type of traditional hydraulics, based on his study of the hydraulic systems of al-Andalus societies (Barceló 1989). Notwithstanding his dedication to Islamic water systems, he emphasized the role of peasants in appropriating the basic principles in Andalusia, stressing how this local knowledge provided the foundations for successful Iberian agriculture (Barceló 1992; Barceló et al. 1996, just to mention the most relevant of his works proposing this argument).

Furthermore, until very recently, the history of technology did not incorporate knowledge on Iberian agriculture, to such an extent that the seminal Forbes (1966) work *Studies in Ancient Technology*, published between the 1950s and the 1960s, did not even mention Iberian Peninsula water technology. Therefore, only in recent decades have studies from the history of the field of technology tackled topics related to Iberian agriculture and water management, devoting said studies to the specific artefacts deployed to raise water from wells, known to the Romans, but which experienced more widespread utilisation in al-Andalus (Jayyusi and Marín 1994; Howden and Mather 2012). However, the greatest input came from the perspective of social history, to such an extent that water became envisioned as a *Total Social Fact* (Holt 2018). In the 1980s, Thomas Glick argued that, even if the basic technology was already known, the accumulation of knowledge gathered by peasants was vital to extracting the maximum efficiency of each hydraulic system (Glick 2005). Awareness of the basic principles of water distribution by gravity does not undermine the expertise that is still needed to build each of these systems, nor their need to be adapted to the biophysical and topographical conditions

[1]Some regions in Central and Northern Europe have practiced irrigation, such as in the Swiss Alps and Norway, following the model of German water meadows. While it is true that irrigation leads to a noteworthy agricultural surplus in arid regions, it is also true that irrigation plays a key role in mountain environments (which agronomical studies have tended to ignore). Irrigation has been practiced in the Swiss Alps for more than one thousand years.

prevailing at each respective site. Therefore, Glick also demonstrated the role that al-Andalus played in the development and diffusion of irrigation technology through evaluation of the dams, *norias* and *qanats* in the territory that now constitutes Spain.

This topic holds great potential for exploring the intersections between the history of science and technology and the history of agriculture.[2] Following the recent reframing of the history of science broadly into a history of knowledge, by tackling wider notions of water manipulation through empirical knowledge, and by including actors other than scientists, such as farmers and peasants, this topic enables the reconsideration of traditional notions of unified laws for science and technology, just as peasant knowledge of the local features of their region proved key to the success of the irrigation systems in association with the capacity of peasants to comply with the rules of water distribution established by the community. Stemming from the latest turn in the history of science towards place and practice, this study clearly demonstrates that ground-level farming practices are shaped by the environmental context of the place in which the farm is located. Place and practice rank among the most promising pathways to establishing bridges between the history of science and technology and the history of agriculture for a beneficial mutual influence. In this context, the outcomes are shaped not only by techniques and artisanal practices, but also by bodily experiences and social relationships, contributing to enlargement of the already proposed conceptual framework of the "body of the artisan" and "superior artisans" (Long 2011; Smith 2018; Valleriani 2017).

This paper tackles irrigation systems in the Algarve, not only through perspectives on their physical and technical aspects, but also through the lenses of the practitioners engaged in these activities and their associated social networks. All of these factors had to be successfully combined for a hydraulic system to operate effectively. The Algarve irrigation systems were pointed out by the German botanist Heinrich Moritz Willkomm as the reason for the transformation of inhospitable lands into a garden. In his words, "Although the whole coast of the Algarve is made up of sand, it has been transformed by the tireless application of its inhabitants, who are by no means civilized, through artificial irrigation—either through the excavation of numerous wells or through the careful use of coastal rivers—into a magnificent garden"[3] (Willkomm 1988 (1847): 187).

Furthermore, this paper argues that the Algarve, due to geographic and historical reasons, remained quite isolated from the rest of Portugal up until the beginning of the twentieth century and that the Islamic legacy was still there, in competition with

[2]"Roundtable: Agricultural History and the History of Science", in *Agricultural History*, Vol. 92, no. 4 (Fall 2018), pp. 569–604.

[3]"Apesar de todo o litoral do Algarve ser constituído apenas de areia transformou-se, porém, graças à incansável aplicação dos seus habitantes, de resto pouco civilizados, mediante a rega artificial – quer através da escavação de inúmeros poços, quer através da cuidadosa utilização dos rios costeiros – num magnífico jardim, cujo ponto mais brilhante é formado pelas imediações de Tavira," Willkomm, in *Anais do Município de Faro*, no. 18, 1988, p. 187.

modern and technological influences that were arriving from France and the United Kingdom in modern times. In fact, the Algarve was the last region in Portugal in which Moorish rule was conquered, which happened with the conquest of Silves by Christian forces in 1268. Furthermore, the Caldeirão and Monchique mountains were difficult to cross. Indeed, the easiest way to get to the Algarve was by boat. Therefore, due to their peripheral, but also specific, situation, they maintained their ancestral practices right into the early twentieth century (Guerreiro 1993; Rodrigues 2017, 2020).

In the first section of this study, I address different irrigation systems so as to demonstrate the specificity of the expertise developed on the Iberian Peninsula since al-Andalus, in conjunction with the techniques deployed in the Algarve through to the late nineteenth century. The second part tackles the social networks established by the water distribution systems in the Algarve while making comparisons with two other traditional systems of water division already studied in Portugal. On the island of Madeira, water distribution was regulated by means of written documents from its earliest history. However, in other regions, for example, in central Portugal, every plea was solved orally between neighbours. Hence, I argue here that water scarcity in Portugal pushed the intervention of the public powers, as water was already regulated in the Algarve by municipal powers in 1862, with conflicts not being solved among the community, but rather in Courts of Law. The third part addresses the social and technical scope of irrigation in the Algarve through court disputes over water struggle. Finally, this chapter details efforts to contextualise the expression of these irrigation systems in Iberian theoretical production, despite encountering no reference to this expertise in either agricultural treatises or studies on hydraulics. To illustrate this, I thus explore the treatise on agriculture that had the greatest impact on Portugal prior to the nineteenth century—Alonso de Herrera's *Book on Agriculture* (1513)—which, on other topics, reflects Iberian practices (Rodrigues 2017), but not as regards water. Ibn al-Awam's twelfth century Islamic treatise, written in Seville, gives more clues as to how the watercourse was designed than Herrera's. Moreover, the book specifically about irrigation by Francisco Vidal, published in 1778, emphasises the advancing expertise of British and Dutch hydraulic engineering while clearly underestimating Iberian water knowledge.

Due to the prevailing irrigation techniques in the Algarve—the collective distribution of water, and the form and place where conflicts were resolved—the particularity of this case study is important in illuminating the history of water. By highlighting the weight of the local versus the global, showing the dissociation between practice and theory and placing emphasis on artisanal solutions and the groups that developed them, this case also enriches the focus that the history of science and technology has lately put on artisanal practices (Valleriani 2017).

2 Irrigation Systems

Irrigation was a technique developed in ancient Persia, in the contemporary Middle East, as, for these desert people, it was only the ability to develop complex systems of water abduction, conduction and storage in reservoirs that could compensate for the hostility of their natural environment (Wilson 2008: 291). The ancient civilizations that arose around the Nile, Tigris and Euphrates Rivers took advantage of water flows, which were duly channelled to plots surrounded by dykes. This kind of basin irrigation enhanced fertilization, while the surplus water drained back into the river (Hill 2013: 18). Simultaneously, perennial irrigation was practiced in these regions whenever water from the main artery was channelled into a network of small irrigation channels forming a matrix over the field. Although the greater part of such a system operated by virtue of gravity, water-lifting devices were already being used to raise water from rivers or wells (Hill 2013: 18). In hilly geographies, terrace irrigation requires a lot of effort for the cultivation of small plots, achieved through the diversion of different sources of water to the fields by means of stored rainfall, wells and *qanats* (Hill 2013: 18). Since early times, *wadi* irrigation systems depended on sporadic rainstorms over desert-like areas. Large, high dams were built to work as water reservoirs at the tops of mountains and succeeded in transforming arid lands into productive fields (Hill 2013: 18).

Watering is usually divided into two types: irrigation of abundance and irrigation of lack. The first reinforces the action of natural agents and is used to stimulate the growth of hays, in a process also applied in Middle Europe. The second refers to watering gardens, fields and orchards during the summer and amounts to triumphing over nature. The first system was scattered across Europe as far as Iceland. Artificial irrigation was also practiced in northern Europe, for example, in the arid zone of the Gudbrand valley in Norway, where there was intense irrigation, but the diffusion areas for this second type were, par excellence, the Mediterranean basin and the Near East.

Glick established the spread of irrigation systems from the ancient Near East through the Mediterranean basin during the Roman empire, followed by further development under Muslim rule between the eighth and ninth centuries and an exponential improvement in al-Andalus, which became the new centre of knowledge diffusion (Glick 2000).

Any hydraulic system must be designed prior to its construction, as this constitutes the first principle from which everything else derives. By 'design,' Barceló and Glick mean the plan for articulating the water source, distribution channels, irrigation space, tanks, mills and any other inputs (Barceló 1989; Glick 2000). This interaction depends on water flowing by virtue of gravity, and its distribution therefore correspondingly depends on the existence of a favourable topographic layout that is susceptible to modification so as to ensure the controllable flow of water throughout the growing space. Hydraulic design cannot be improvised when planning the irrigated space. The role of gravity in the water flow entails that the design results be spaces delimited by 'stiff lines' created by establishing channels for the controlled flow of water. Therefore, any irrigated space contains an upper stiffness line, described by the main channel or channels for water distribution above which water cannot flow because the slope is unfavourable. In turn, the lowest line of stiffness is that established by the lowest slope for flowing water—a gully, a river, the lower part of a valley—or at least the lowest point at which accessible water flow serves for watering. The amount of water needed to irrigate a maximum possible area also depends on the type of crop grown and the frequency of irrigation. In this case, the lower line of stiffness may be less stable and more easily modifiable due to changes either in the irrigation procedure or in the amount of water available. The design, a concrete plan for the flow of water and for the rigidities that result from such a planning process, endows the hydraulic systems with great stability.

Glick demonstrated how the institutions that were able to guarantee the operation of a hydraulics system were also 'ultra stable' as long as they continued to demonstrate 'the ability to maintain in their essential variables within a changing natural and social environment' (Glick 2000). On the other hand, the stability of the institutions and the modes of water distribution depend, to a great extent, on the maintenance of the irrigated space under the same conditions as those found at its foundation. Any subsequent changes may easily affect the system's distribution and require renegotiation and user agreement. Similarly, any change in the design can cause the components to detach and disintegrate, forcing a new design and the establishment of a new pattern of articulation.

The traditional irrigation processes used in Portugal are many and varied. The simplest process is limited to taking advantage of natural springs, situated in places higher than the fields to be irrigated. When the water is not abundant, they build a kind of prey or puddle, where the water accumulates until it reaches a volume sufficient for irrigation. Then, the water flows through previously made *regadeiras* in order to lead it, with a minimum of loss, to the fields for application. These puddles are usually dug into the earth, fitted with a stone wall containing a hole covered by a wooden stick and rags, or simply a stone. Cemented granite tanks are also frequently used, offering the advantage of lower levels of water leakage.

Irrigation in Portugal mainly takes place via private initiatives that take advantage of small springs or wells, and sometimes rivers, to the benefit of private properties. Only in some villages where there are still remains of old community organizations can we encounter curious systems of distribution of common water, which may be affiliated with old and collective ownership irrigation customs. In such systems, rigorous and very longstanding community rules determine how to solve water issues such as water that is often lost through open cracks in the earth and because of obstructions potentially resulting from nearby plant roots or weeds, therefore making the cleaning and care of channels and waterways subject to the community (Dias and Galhano 1986: 19–23).

In the North, the so-called lime waters served to feed the natural meadows (*lameiros*) and sown fields. These waters not only irrigated, but also prevented sharp frosts from burning the grass. There is also a system of watering that does not involve opening channels, but rather letting the water spread slowly over the surfaces of flattened gardens. This is called watering *à manta* (as if using a blanket) in Bragança.

In the summer season, the most commonly used system is irrigation by foot, taking advantage of water from streams or dams directed to the fields by small gutters or channels. Within the field itself, the farmer guides the water with a hoe, opening and successively filling previously made channels so that the water reaches every plant (Dias and Galhano 1986: 20). Irrigation by foot is almost non-existent in the Barrocal region, as streams are quite rare. Those that do exist, such as the Benémola stream, were the object of rigorous management. Moreover, in the Algarve, due to its geographical conditions, only perennial irrigation was practiced. This system works entirely by gravity-flow and consists of watering crops by leading the water from a major source into supply canals and then into smaller irrigation canals inside of the vegetable gardens. In the Algarve, the sources of water were mostly wells from which water was lifted by *noras* (see Chap. 15 in this book).

3 The Collective and Individual Rights to Water

The establishment of rules of appropriation and distribution for the common usage of water, both when abundant and when lacking, were thus essential for the maintenance of traditional irrigated agriculture.

In the wake of the conquest of Spain in 711, the Arab Empire was ruled by the Umayyad dynasty from Damascus. This constitutes one factor accounting for the 'Syrianisation' of the Iberian landscape, with another deriving from the similarities in the climate and hydraulic conditions in parts of Portugal and Spain to the conditions that generated the large oasis then surrounding Damascus. Three decades ago, research reported that irrigation in the Iberian Peninsula appeared to have been divided into two models: one with characteristics from Syria, e.g., vegetable gardens with long channels diverted from rivers, and another arriving from Yemen, in the style of an oasis system in which water was distributed in units of time (Glick 1970: 214–215). This typology, however, simply represented an adaptation of a dichotomy already proposed by J. Brunhes for North Africa and Spain based on the distinction between system operating procedures in which water was relatively abundant and those in which it was scarce (water distributed over time or by units of time). Therefore, in some regions of Spain, such as the oasis-like communities of Elche, Novelda and Alicante, the water was controlled by central powers at the time (Hill 2013: 22). In other regions such as Valencia and Murcia, irrigation systems were controlled by private representatives and the water was divided into time units. From 961 through to the present day, water distribution and the maintenance of the sills and canals have been handled by farmers, and any conflicts arising in this context are ruled upon by the water tribunal of Valencia. This tribunal used to meet in the mosque and, following the Reconquest, moved their meeting place to the plaza of Valencia cathedral. Although the deliberations were strictly oral, they nevertheless held the force of law. As the Christians gradually reconquered the Iberian Peninsula, they allowed the Muslim irrigation systems to remain broadly intact. Glick consider that Christians literally rendered continuity to the Muslim practices (Glick 2000: 317).

The distribution of water by time units derives from the Islamic tradition, which Glick identified as the *Institute* in al-Andalus (Glick 2000). Irrigation institutes were agreements by which water was distributed to irrigators, deriving from the principle of proportionality. Some specific procedures, such as rules governing turns or rotations, priorities in water use, or special regimes in drought time, resulted from a complex mix of social values, climate factors and typography, in addition to the techniques for controlling water sources and metering. For example, Islamic law and Berber law always gave priority to users along the upper reaches of a river, as the water there runs very speedily and it is correspondingly difficult to harness it to water the fields (Glick 2000).

In many regions of Portugal, the distribution of water among the members of a particular community was also formerly done according to time units. The rigorous and meticulous division of the waters, with their complicated "turns," reflects the most notable aspect of the group social organization and management of collective waters. However, while this is common to all of the cases under comparison, the level of intervention of external powers in the community for the regulation of "turns" and the resolution of conflicts differs substantially.

In Várzea dos Amarelos, a small region in the center of Portugal, there are two large groups of irrigation waters: *águas que regam por seu pé* (watering by foot), hence, not requiring human, animal or motor energy, and *águas que não regam por seu pé*, waters that need elevating through recourse to one of these forces (Mano 1992: 148 and 170). There are fields that cumulatively benefit from both types of water, even while the most common situation is fields that access only one or the other of these water types (Mano 1992: 143). Watering "by your foot" was the optimal situation, and these lands are the ones that were somehow best able to resist the abandonment and decadence of the agriculture practiced in them. All the water sources are necessarily situated at a higher point in relation to the irrigating fields. Different sources of water are considered "by their feet," such as the waters of mountains, brooks, and the prey, as well as whatever emerged from springs (Mano 1992: 148). Water accumulated in mountain mines was led by a ditch to a dam or a tank from which the irrigator took it to the fields. It was from one of these reservoirs that irrigators "tempered" their waters, thus carefully regulating the flow according to the land (more or less distant, more or less inclined, more or less "muddy") and to the level of water demanded by the respective crops. Every year in April or May, according to the rainfall of the respective year, sharecroppers gathered and organized the work of cleaning the channel and repairing and cleaning the mines (Mano 1992: 149).

The aggregating and structuring force of the water system compelled the group to come together to make common decisions and define rules for water distribution, known among the community as the "Rule" (Mano 1992: 143). The Rule existed solely in an oral code that only took on meaning when contextualized and was restricted to the irrigating group. The Rule, although not written down, nevertheless held the force of law (Mano 1992: 150). This group and its water system never had any written document or other laws other than those dictated by customary law. Moreover, they never resorted to Courts of Law (Mano 1992).

The order of the *giros* (hereafter turns) changed annually, and correspondingly required organisation by the group each year. The order changed from the previous year according to the idea that "who begins watering one year, in the next becomes the last one in watering" (Mano 1992: 150). It was the job of the women who owned the turns to remember the rules, as well as the *boleto* (rotation) start day (Mano 1992). Furthermore, it was always the women who was named in the turning (Mano 1992: 152). They were the ones who knew the rules of spin and passed them down from generation to generation, in an ongoing secular tradition (Mano 1992: 165). Therefore, water management was under women's forum in Várzea dos Amarelos.

The complete turn lasted for twelve days, divided among seven neighbours. Usually, each turn would last for one day, but one could hold a six-day watering right if one had bought days of watering from other neighbours (Mano 1992: 152–154). However, this is not the only reason behind this mode of distribution, as it also takes into account the situation and morphology of the terrain. In fact, the system displays empathy for the neighbour who has fields in the middle of the hill on steep slopes, just as in Berber tradition. The crops on these lands would not withstand the time taken up by a complete turn: as a result of absorbing so little water, the plants would be dead before re-irrigation. For this reason, and in order to minimize the effects of these terrain conditions, it was contemporary practice to spread a layer of pine needles on the fields before starting irrigation. The pine needles helped conserve moisture and slowed the water, making the irrigation time longer, and thus allowing the land to be well "passed on" (Mano 1992: 156).

The costs and the work of cleaning the pipes were divided up among all participants, with each providing working time and meeting costs proportionate to their fair share of water (Mano 1992: 150).

At Várzea dos Amarelos, the distribution of water was totally community-regulated, with the rules decided and orally maintained by the women. Contrastingly, there is the case of water distribution in the Gaula region on the island of Madeira. As the practices here were not based on orality, but rather were strictly established by written rules, this case is much better documented than any other.[4]

In the fifteenth century, the first settlers discovered that, after they had opened the long channel, called Levada do Pico dos Iroses, to bring spring waters from the mountain range to their lands, the water, instead of running freely, seeped into the ground, thus resulting in the loss of a considerable proportion and giving rise to a large puddle (Freitas 2003: 11). The *levada* constituted the primary water corridor that secured the irrigation of fields, hydropower for mills and forges, and the

[4]The known written sources from this system are the register, which contains the list of all irrigators, and the "book of the levadeiro," which was distributed among the different *levadeiros*.

discharge of waterflows and grey water. Therefore, the *levada*'s flow had to be ensured, steadily and sufficiently.

Levada management was regulated by the Statutes of the Levada. Since 1461, the Statutes of the Levada had been mandatory and regulated by the Levada judges (Freitas 2003: 25). Those owning any portion of the water transported by the Levada were considered its partners (Freitas 2003: 25). The leasing, buying and selling of the Levada water did not arise out of an oral contract among community neighbours, but rather was subject to notarial action (Freitas 2003: 27). That which was divided was not really a fixed quantity of water, but instead one turn. The Levada turn consisted of the period between a watering, done at a certain hour of the day, and that which follows after a certain number of days and is carried out at the same time, considering all irrigation periods to be equal throughout the year and for all arms, or parts, into which the Levada was subdivided.

The amount of water transported by the Levada do Pico dos Eirós gradually increased over the five centuries of its existence, in keeping with the emerging needs of population growth. Both the turning and the subdivision of the Levada into arms stemmed from the increase in cultivated land and the consequent need for more water for irrigation. Thus, when there was no other flow available at the time, the immediate solution could be one of two: either another part was carved out of the Levada or the number of days in the turn was increased. However, in order to obviate the losses that previous solutions had naturally entailed, such as decreasing the flow rate and increasing the interval between irrigations, there was also a last resort that consisted of searching for further sources or improving the existing ones in order to increase the Levada flow.

The days of the turn and the areas that the Levada irrigated since its inception through to the late 1600s are not known (Freitas 2003: 33). However, we do know that, at that time, some owners possessed several hours of the whole Levada. During the eighteenth century, the turn of the Levada stood at 22 days, meaning irrigation occurred every 11 days (Freitas 2003: 33). By 1859, we know that the Levada turn stood at 24 days (Freitas 2003: 23). We do not know what the quantitative flows would have been prior to 1859, but they transformed practically the entire parish geography. In that same year of 1859, there was a flow of about *2000 penas* (equivalent to two thousand litres per minute), divided into four arms, which gave each farmer the scope to irrigate his fields with 500 litres of water per minute through the Levada (Freitas 2003: 24).

When the Levada was divided into four arms and had a turn of 24 days, it conveyed 96 h of irrigation water daily. During the 24 days, the totality of the partners of this Levada disposed of 2304 h for watering their land or for renting to others (Freitas 2003: 34).

The first Levada do Pico dos Eirós Statutes were approved at a meeting of the General Assembly of Hiréus on February 9, 1908, which took place in the churchyard. These Statutes were amended and approved on June 1, 1916, and again revised and sanctioned at an extraordinary meeting of the Hiréus General Assembly held on April 15, 1945 (Freitas 2003: 41). The General Assembly was responsible for: establishing or altering the turning of waters and changing the price of rentals;

deciding on the advisability of requiring members to contribute and setting the amount of that contribution; electing the Levada Directorate; appointing the *levadeiro* (a type of operating director); and, whenever necessary, appointing watchmen.

Although the Levada's importance derived from the irrigation of cultivated land, it also filled small wells and tanks for domestic use and ensured the operation of public lavatories. One proportion of the water from the full Levada turn, the "serving water," permanently flowed towards to the sea for usage in cooking and as drinking water (Freitas 2003: 45).

In the secondary *levada* branches and in the farm *levadas*, the *tornadoiros* (gates) were simple obstructions, or deviations to the free course of the water, usually made with stones of varying weight so as to let out as little water as possible. Over time, these *tornadoiros* of water channelled to the farms became the focus of great struggles over the possession of greater amounts of water, to such an extent that some such disagreements were discussed in the courts to the detriment of all parties (Freitas 2003: 55). One of these conflicts, known as the "Questã da Levada," which pitted the partners of the Levada do Pico dos Eiroses against those of the Levada da Roda, crawled through the courts between 1927 and 1934, before finally being taken to the Supreme Court of Law (Freitas 2003: 62–64). The Supreme Court of Law ultimately ruled against the Levada da Roda, who had been accused of deviating water.

After this problem, the turn became 32 days, with farmers thus irrigating every 16 days. Following the installation of a tank for collecting night water, the Levada began to water only during the day. Thereafter, the turning of the water changed to a new system. Due to the construction of a huge tank with sufficient capacity to collect the Levada's water for twelve hours, the Levada do Pico dos Eirós pioneered the adoption of irrigation water only during the daytime period, from seven in the morning to seven in the evening (Freitas 2003: 66–67).

The Algarve also practiced a similar system of water distribution by time units. At the beginning, as the abstractions of water were collective or shared, the regulation of access to water was translated into a set of community rules for resolving any conflicts that might occur, reinforcing the relations of autonomy and cooperation among the members of the community. However, water distribution became regulated by municipal power. The turns were then published as the Municipal Rules of the Loulé City Council in 1862.[5] Furthermore, janitors and rural guards verified whether these were applied in the parish territory.

The waters running along the Quedavae stream, on the outskirts of Loulé, have been divided as follows since ancient times: every day of the week, from sundown one day to sundown the next day, the water is taken to a certain property belonging to one or more neighbours, all duly identified in the municipal rules. In the following week, the rotation is resumed in the same order. When it became time for someone to begin their turn, one had to take possession of the water in the horses' catch by the bridge. Anyone hindering the flow of these waters, or caught using

[5] Municipal Rules of Loulé City Council, in 1862.

them at any time of the year outside of their set hours, would have to pay a fine of 6 $000 *reis* (historical Portuguese currency). Likewise, anyone who wanted to give up their hours would also have to pay an equal fine. The turn might only be given to adjacent properties so that the water never left the *levadas*, including by the weirs of the mills before the Great Mill.[6]

The minutes of the September 1, 1892 meeting of the Faro City Council also highlight the collective practices of water distribution.[7] The remains of the Public Fountain of Estói were proposed for irrigation every eight days, divided between the public and private gardens located in the area of Cercado de Marcos. Moreover, it was decided that the spouts nearest the fountain would not pour out more than 3744 l of water per hour. The two regulators established in Bicas Street were not supposed to issue more than 1690 l per hour, and turning off the first spout, which provided 514 l, provided the water to irrigate the backyards of three neighbours (José de Jesus Zeferino, Zeferino's mother and João Rosa), while shutting off the second spout was supposed to irrigate the backyards of two other neighbours (Francisco Simões Junior and Maria do Carmo Mascarenhas). These quantities were considered sufficient for watering these yards every eight days. The remainder of the second spout's waters were intended for irrigating other yards.

Having met public needs, and with the remainder distributed in the way indicated above, all of the remaining water was destined for the spouts closest to the churchyard, and its sub-sections were then deposited in the municipal tank and put on sale after safeguarding a reserve of 3 m^3 for consumption by horses.

In case of drought, the water from every spout was diminished at a fair rate—proportionally. Moreover, any waste water was sold to Francisco de Paula Mendonça, Father Francisco Ignacio dos Reis, and Joaquim Francisco de Mendonça.

Until the nineteenth century, in the Algarve, very ancient forms of water distribution were practiced, rooted in the Iberian Peninsula since al-Andalus, as similar strategies are found in both Spain and Morocco (see Chaps. 9 and 10 in this book). These resemble both the technical aspects of dividing the watercourse with stones to divert the same amount of water between neighbours and the organization established among the community to divide water by units of time. This form of collective water distribution is not unique to the Algarve, but was practiced in both mainland Portugal and on the islands. However, the degree of control over them is different. I argue that the greater the scarcity, the tighter the control has to be and the sooner one has to resort to legal institutions. Usually, the rules are passed along and enforced orally by the community of neighbours. This is certainly so in the case of Várzea dos Amarelos. By contrast, in the case of the island of Madeira, where the difficulty in conserving fresh water was greatest, writing has been used to regulate water distribution since the fifteenth century, and some conflicts were even resolved in Lisbon at the Supreme Court. The case of the Algarve lies between these two

[6]Municipal Rules of Loulé City Council, 1862.
[7]Faro's Regional Archive, Faro City Council, PT/MFAR/CMFAR/B-A/002/0001, the minutes of the September 1, 1892 meeting.

forms of control. Regulation was not determined in writing at such an early stage, but it was regulated by municipal powers in the nineteenth century. Moreover, as in Madeira, conflicts were not resolved between neighbours, but by law.

4 Conflicts Raised by the Struggle for Water

Since the conflicts generated by the collective distribution of water in the Algarve were resolved in court, these stand as fundamental sources for understanding the value of water to the community, including an individual's right to access water and their awareness of that right, as well as elucidating the actors and artisanal practices involved.

Water thus represented both an individual and a collective right. Therefore, no one was willing to abdicate it and anyone who failed to respect this did not go unforgiven by the community. The inhabitants of São Brás de Alportel's pursued a complaint against António Gago in 1849 that began as follows:

"The inhabitants of the Parish of S. Brás de Alportel, of this district, respectfully come before you to use a sacred right that guarantees them the constitution of the State—the Right of petition /C. cont. A 145-28/. Gone are the ages in which the people suffered, being currently endowed by the nature of the constituent elements of human personality, on the same scale as the Lords; closer but far off are the eras in which feudalism oppressed the servants, by a less inhuman way in the institution, but equal in the effects of slavery: far away finally go the eras in which absolutism, and despotism, twin brothers, guaranteed the whims of the powerful and valid, in spite of the weak and helpless."[8]

This claim illuminates how the nation's politics and the shift into Liberalism had an impact on the regulation and control over water distribution, clearly going beyond the scale of the neighbouring group, and thus placing the case of the Algarve on a very different level than that of the Várzea dos Amarelos. The inhabitants of São Brás de Alportel claimed, in a very Liberal narrative, even evoking the Constitution (1822), that there was a stream called *o cano* from which the community sourced all of its water for drinking, for their animals and even for washing clothes. However, a farmer, António Gago, owned a property alongside the stream, and he decided to open another fountain that not only destroyed part of the path to São Brás de Alportel, but also led to the disappearance of the water from the ancient public fountain. The inhabitants claimed that this had happened due to Gago's actions and his goal of deviating more water to irrigate his own fields.

The Court of Law's management of conflicts was frequent. In 1849, the farmer Manuel das Neves Bargues, who lived in Bordeira, a small village in St. Barbara parish, and another farmer, Antonio Luís, resident on the site of the lawn, in Estói parish, both from this municipality, sought to build a *levada* to channel water from Ribeira d'Alem, along the Vale d'Alcaide stream, for a water mill that they

[8]Faro's Regional Archive, Manuscript, 1849.

were building in the Ribeira d'Alem.[9] The *levada* would run through the village of Estói and would enter the road from this village to the one of São Brás.

They made an official promise, under penalty of law, that the flow of water would never run dry, as the water was easy to get. Additionally, they were obliged to leave the road with safe passage wherever the *levada* passed.

Water distribution was often behind the filing of civil actions, which contribute to our knowledge of the technical and social scope of irrigation in the Algarve. Between 1879 and 1881, an ordinary civil action was filed by João dos Reis and José dos Reis Peixe Rei against João Martins Baptista and his wife and Francisco António Alberto and his wife. The brothers Reis asked for the demolition of a new structure, built by the defendants, that usurped part of their land and obstructed the flow of water towards their saltwater mill in the Olhão district.[10] From analysis of this document, we know that the mill's boiler water came from several r*egueiras* (waterings) of varying width and depth that extended in several directions.[11]

In 1890, a case was submitted by António Maria Rodrigues do Passo and his wife, both residents of Fuzeta, against new work done by Manuel dos Santos Soares and his wife, because they were diverting waters from the flows that led to the salt water mill called "Rodete,"[12] thereby harming their production.

Many of the conflicts that ended up in the Court of Law not only highlighted the irrigation systems in effect, but also the practitioners who were engaged in the construction or maintenance of water devices. An ordinary civil action was filed by João Lopes Martins, who accused João António Barrot of failing to pay him 59$655 *reis* that he was due following repairs to a pump that removed water from the pit in his vegetable garden, called *Paulos*, in the vicinity of Olhão.[13] Martins claimed that, between April and May 1885, Barrot had called him to set up a *bomba* (pump) or *engenho* (mill) in his backyard on D. Luis Street in the village of Olhão. The work and material, which included iron and other components, amounted to 30$930 *reis*. Subsequently, he was contracted to repair a steam boiler that drew water in his *Paulos* garden. Due to the work of various employees engaged in this task, as well as the additional materials required, Martins charged an additional 28$725 *reis*.

In his defense, Barrot told a very different story.[14] The vegetable garden owner stated that Martins did not install a pump in his yard, but rather an *engenho*, and that he considered the bill of materials to be excessive. He reported that he actually had called Martins to repair the machine for drawing water in the *Paulos* vegetable garden, but disputed that he had dismissed the contractor from this job. On the contrary, Barrot claimed that Martins had left voluntarily as a result of Barrot having rebuked Martins' son, a small boy who was always hiding in the garden instead of applying himself to the work at hand. Thus, on May 27, Martins appeared

[9]Faro's Regional Archive, Faro City Council, PT/MFAR/CMFAR/B-A/002/0001, D4.1-E2-P4, Requirement for the Levada's construction, 1849.
[10]Faro's Regional Archive, D4.2-E5-M26-TJCOLH/2/468.
[11]Faro's Regional Archive, D4.2-E5-M26-TJCOLH/2/468, fl. 2v.
[12]Faro's Regional Archive, PT/ADFAR/JVD/TJCOLH/032/00111 or D4.2-E 38-P4.
[13]Faro's Regional Archive, D4.2-E5-M29-TJCOLH/2/720, fls. 2-2v.
[14]Faro's Regional Archive, D4.2-E5-M29-TJCOLH/2/720, fl. 14.

in the garden with a crowd of people and began insulting Barrot, telling him that, if he had dismissed his son, he would not be working for Barrot anymore either. Under these circumstances, Barrot had to call in other workmen (locksmith officers) to repair the boiler. When they arrived and saw the previous efforts by Martins, they had to start again from scratch, given the poor state of his execution. The beams placed in Barrot's backyard pump also had to be replaced with others of a greater thickness. In all, Barrot had to spend 123$000 *reis*. However, worst of all was what he lost due to the failure to irrigate his orange grove. Due to the delay in repairing the irrigation machines, his crop had eventually withered, with the damage being calculated as a loss of 200$000 *reis*. Therefore, Barrot's defense requested that Martins pay him 323$805 *reis*.

The judge ultimately sided with Barrot, not only because Martins had himself recognized the poor quality of his work in stating that "not everyone is perfect," but also because it was incontestable that Barrot had had to call in other workers to carry out the installation of both new plates in the boiler and new beams in the backyard pump.[15]

This long document is interesting both in regard to water history in general and to the history of irrigation and technology in the Algarve in particular. It reveals there was a confusion among several actors regarding the identification of the device in use, which shows that water devices' names were not stable not only in the different regions of the Iberian Peninsula, but even among different actors of the same region (see Chap. 15 in this book). Moreover, it highlights the artisans enrolled in these kind of activities, once those who repaired pumps and boilers were the locksmith officers. It also revealed the losses of fruit production due to a lack of irrigation, highlighting that agriculture, especially citrus production, cannot be pursued without artificial irrigation, but also showing that water for irrigating an orange grove would have been raised by a steam boiler, and not by a *nora*, in the Algarve late nineteenth century. And finally, this case-study showed technical problems were undermined by social issues, proving they are twin facets of the same coin.

5 Expertise on Iberian Irrigation Absent from Its Own Theoretical Production

Although the early modern period had its own specialized field of knowledge related to agriculture—oeconomy—, historians of early modern agriculture have not paid a great deal of attention to the specifically literate knowledge about farming that existed in that era. Only recent work by Jones has addressed the complex exchanges that took place between elite reformers and farmers as they sought to foster changes in agricultural practice (Jones 2016; Ambrosoli 1997). The role that books played in this context still remains to be determined. The early modern literature on husbandry, agriculture, horticulture, and oeconomy all

[15]Faro's Regional Archive, D4.2-E5-M29-TJCOLH/2/720, fl. 155.

challenged standard views about natural knowledge. Contrary to the need to transform local activities into universal knowledge (Shapin and Schaffer 1985), the writings of early modern authors on agriculture discussed their experiments in strictly local terms. Agricultural knowledge thus seems to contradict the commitment of early modern knowledge to exclusively unified natural laws (Shapin 1994; Gaukroger 2008; Dear 2009).

Although early modern Iberian books on agriculture tackle water issues, they do not go into detail about these successful irrigation systems. The Spanish gardener Alonso de Herrera wrote the book on agriculture that had the most influence, not only in Spain, but also in Portugal and the New World (Rodrigues 2016, 2017). The book was first published in 1513 and was followed by several editions in Herrera's own lifetime, with more editions and translations being released throughout the following centuries; new translations of the work were still being worked on in Portugal in the nineteenth century (Rodrigues 2016: 310–311). Nevertheless, I have argued that, while this book represents a more than adequate compendium on Iberian agronomic practices (Rodrigues 2017: 300–302), the same description cannot be extended to its treatment of water management practices, as the book includes only general statements on hydraulic systems, focusing more on the therapeutic virtues of water.

Herrera starts out by identifying the fact that, to make gardens truly fertile, having good soil is not enough, as there must also be abundant fresh and good-tasting water (Herrera, Book IV, 1818: 13). The gardener states that, wherever there are natural sources such as rivers or streams near the farm, one should build an artefact to lift the water and then, through canals, channel it to the fields for watering (Herrera, Book IV, 1818: 13). On the other hand, if there are no such natural sources, one has to dig a well (Herrera, Book IV, 1818: 13). The deeper the well, the greater the difficulty in lifting the water. Moreover, as "air and sun greatly ennoble the water," the waters from wells or those that come from the earth are not as healthy as those from fountains, which catch the air and sun (Herrera, Book IV, 1818: 13). Even worse are the waters that come from lead mines or those of other metals (Herrera, Book IV, 1818: 14). It is correspondingly clear that Herrera is not discussing water from the perspective of irrigation systems, but rather from that of water quality.

Herrera's passages on water also include the common knowledge that prevailed on how to find water sources with such techniques as had already been suggested by Vitruvius. Herrera states that, in August or September, with one's beard on the ground, if one looks eastwards and sees vapour coming out of the earth, this is a sign of water (Herrera, Book IV, 1818: 16). The presence of certain plants also provides an indication of water, as they simply do not grow without a lot of it. This list includes willows, alders, grasses and reeds, which were added in the 1528 and 1546 editions (Herrera, Book IV, 1818: 16). The greener the plants, the greater the amount of existing water (Herrera, Book IV, 1818: 16). Moreover, the type of soil also suggests the abundance or lack of water. Black earth or clay means that there is no abundance of water (Herrera, Book IV, 1818: 16). Contrastingly, gravel and sand are signs of plenty of water (Herrera, Book IV, 1818: 16).

Moreover, Herrera addresses how the waters get to the field, and adds that one of the best ways is through *acequias*. However, the process of irrigation depletes the land and takes the most enriched material out of it, thereby making the use of manure necessary (Herrera, Book IV, 1818: 23). Although some of the typical structures of Iberian irrigation systems are mentioned, the author criticizes them without ever addressing the expertise behind their design. Herrera's considerations on how to find water, and how to conduct water from the well to the vegetable garden, boil down to what we have already mentioned.

I argue that Herrera's treatise is less lucid than Ibn-al-Awam's text on the same subject. This agronomist lived in the twelfth century in Seville and wrote the best book on agriculture of the Middle Ages, a book that both reported on and influenced the agronomic practices of the Iberian Peninsula far beyond its author's time (Rodrigues 2017). It includes issues such as water quality, identifying rain as the best for watering gardens, but it goes far beyond that. Ibn-al-Awam addresses the construction of wells, terrain levelling and the use of lead wire to study the water course, as well as other instruments, such as the *al-marhifal* (Ibn-al-Awam 1864–1867: 117–130). On this matter, it is quite certain that Herrera did not follow Ibn-al-Awam, but rather the fourteenth century Italian treatise written by Piero Crescenzi.

Herrera also addresses how one should irrigate vegetable gardens (Herrera, Book IV, 1818: 22–24). Nevertheless, one still does not find any discussion of Iberian irrigation systems here, but only further considerations on water quality. Herrera recalls that, "All or most of the farmers say that the water is sweet and with good flavour, and good to drink, the better it will be to irrigate the vegetable garden" (Herrera, Book IV, 1818: 22). Vegetables should also be irrigated with cold water, although not too cold, from snow or springs in the mountains (Herrera, Book IV, 1818: 23).

Following Crescenzi on the topic as to which are the best waters, Herrera argues that the best waters come from good springs in upland areas (Herrera, Book IV, 1818: 13). The bottoms of riverbeds are better when there are pebbles than when they are muddy, as water circulates better on pebbles and, furthermore, mud adds a bad taste to water. Nevertheless, the best riverbed is sand, as it filters and cleans the water (Herrera, Book IV, 1818: 14).

However, the bulk of his advice relates to human health. For example, Herrera considers that rainwaters will quickly become corrupt and cause harm to the health of anyone who drinks them, as they injure the voice (Herrera, Book IV, 1818: 14). However, when boiled, they become acceptable. The water from some lakes in winter generates phlegm due to its great coldness and, as the lakes warm up in summer, they get corrupted and cause diseases such as cholera, swellings and hydrops (Herrera, Book IV, 1818: 15). In addition, women who drink these waters do not purge well and have difficulty getting pregnant, sometimes getting swollen, but not out of pregnancy (Herrera, Book IV, 1818: 15). Moreover, Herrera also states that water melting from snow and ice is also bad and causes illness, especially nervous disorders (Herrera, Book IV, 1818: 15). Cold water thus might help in digestion and stimulation of the appetite, but, when too cold, becomes harmful to the nerves (Herrera, Book IV, 1818: 15). On the other hand, hot water is bad for the stomach, as it corrupts the food and causes vomiting (Herrera, Book IV, 1818: 15). Murky waters, in turn, cause stones in the kidneys and bladder.

Most of these associations between waters and health issues derive from Crescenzi's treatise, with Herrera then going on to explain that natural water is always good and that whatever malignance that it may contain stems from the places through which it passes. To overcome this problem, Herrera points out several ways to assess the quality of water. If you can cook vegetables, chickpeas, beans or peas in a particular pot of boiled water, then the water is of good quality, because such items never cook well in brackish water (Herrera, Book IV, 1818: 17). Moreover, Herrera recommends filtering water, because it becomes lighter and loses its viscosities. Light waters are better than heavy ones, and thus the author suggests weighing the water by soaking the same amount of the respective waters into linen cloths of the same size and seeing which one weighs the most (Herrera, Book IV, 1818: 14).

In the late eighteenth century, the first book published in Spain to specifically address irrigation was published by Francisco Vidal on how to improve agriculture through irrigation (Madrid, 1778). He presented his study in the form of dialogues that were designed to be more appealing to the public (Vidal y Cabasés 1778: 3), with the lead characters being a count and a knight (*Conde* and *Caballero*). This book is based on the practical agricultural operations witnessed by Vidal and on the theoretical works by Herrera, Gustavo Adolfo Gyllemborg,[16] Duhamel de Monceau,[17] Jethro Tull,[18] and Rozier (Vidal y Cabasés 1778: 3–4). Nevertheless, the influence of these five authors is not at all balanced, as Herrera's individual impact unquestionably outweighs that of all of the other sources put together. Herrera is quoted 232 times in this 253-page book, while Gyllemborg and Duhamel are quoted only nine times each and Rozier five times, mostly regarding the selection of vines and issues in regard to wine production (Vidal y Cabasés 1778: LV-LVI).

The book is divided into nine dialogues. The first dialogue is dedicated to the decadence of agriculture when compared with former times, particularly during the era of the Roman Empire and the Maritime Expansion, and correspondingly advocates for its recovery. Vidal recalls Herrera's report on the Viscaya and Montanas region, where they used to cultivate the fields twice a year. The period

[16]Gustavo Adolfo Gyllemborg wrote *Natural and Chemical Elements of Agriculture* in English, and it was translated into Spanish and published in 1775. There was a second edition published in 1794. Gómez Ortega, Casimiro (tr.), *Elementos Naturales y Chymicos de Agricultura del Conde Gustavo Adolfo Gyllemborg*, Madrid: Vda. Ibarra, 1794.

[17]The Frenchman Duhamel de Monceau wrote a book on forestry, which was also translated from French into Spanish by Casimiro Gómez Ortega, the translator of Gyllemborg's treatise. *Tratado del cuidado y aprovechamiento de los montes y bosques, corta, poda, beneficio y uso de sus maderas, y lenas: escrito em frances por Mr. Duhamel du Monceau; y traducido al castellano com varias notas por el Dr. D. Casimiro Gomez de Ortega*, Madrid: D. Joachin Ibarra, 1773–1774.

[18]Jethro Tull, *The new horse-houghing husbandry: or, an essay on the principles of tillage and vegetation. Wherein is shewn, a method of introducing a sort of vineyard-culture into the corn-fields, in order to increase their product, and diminish the common expense, by the use of instruments lately invented*, London: printed for the author, 1731.

that Vidal considered to be of great wealth and fertility was then perceived as one of shortage, in keeping with the position of Herrera's treatise. At that time, the reasons for writing such books included the promotion of agriculture.

The second dialogue covers methods of fertilization and plant growth; the third is on how to cultivate wheat; the fourth is dedicated to vineyards; the fifth is on methods for discovering water and constructing channels, specifically by the Swiss; the sixth covers the measurement of fields, the work done in them and the sort of expenses it incurs; the seventh is dedicated to the construction of reservoirs and the field distribution of water alongside the construction of water wheels; the eighth deals with the construction of water-lifting machines; and the ninth focuses on the construction of *noria* wells.

Both of Vidal's characters stress the difficulty of lifting water. However, the count argues that any child knows that water that comes from underground channels is projected quite high in the fountains of a garden or plaza, while the knight insists that expertise in the field of water manipulation is required (Vidal y Cabasés 1778: 85). Thus, a deposit of water in a mountain might be higher than its source, with that area containing many underground channels and tubes.

Techniques for discovering water in the eighteenth century were still based on the lessons handed down by Vitruvius, Pliny, Palladio, and Kircherio (Vidal y Cabasés 1778: 86), as well as the Priest Juan Francisco in his treatise on fountains (Vidal y Cabasés 1778: 88). Just before dawn, he writes, one should lay on the ground to check whether any vapours are being released from the soil (Vidal y Cabasés 1778: 86). He also mentions Casiodoro, who, in a letter to Theodorico, said that the best *fontaneros* believe that clouds of flies flying around a certain area might also be a sign of water (Vidal y Cabasés 1778: 87). In Portugal, the *vedor* was the artisan responsible for the location and transportation of water from one point to another. At the time, they used a kind of drill to identify the composition of a certain area of soil. In Vidal's opinion, the Marquis of Turbily was the person who best knew how to build and use such devices (Vidal y Cabasés 1778: 88). And, through this expertise, one can find abundant sources of water and dig efficacious wells that do not need to run very deep (Vidal y Cabasés 1778: 88).

Although this study only relies on these books, the contents that they include do not reflect the practice of the Iberian Peninsula regarding the capture of water and its conduction through manmade channels for the purpose of watering the fields. This expertise, resulting from a practical and empirical knowledge that lags behind the Iberian Peninsula's agricultural success for centuries, has not been transposed into the literary production, which only briefly mention digging a well and bringing water through *acéquias*. Even in regard to that with which they are most concerned —finding water—it is noted that the texts are essentially written on the basis of other authors' work and not on practical experience.

6 Final Remarks

Comparative analysis of the irrigation practiced in the Algarve in the nineteenth century has allowed us to understand the techniques used there, but also the social, legal and administrative relations that existed at the time, establishing a relationship of interdependence.

Although it is clear that there is similarity in the division of waters, not only with the Islamic tradition, but also with other cases found in both Spain and Portugal, the case of the Algarve has its own specificities. There is almost no 'watering by foot.' The effort required to irrigate the Algarve fields is great: one has to find water, open a well and raise it with a *nora* or other lifting device. Once the water is at the ground level, it is necessary to secure its distribution into the fields with the least possible loss and covering the largest possible area. The few streams were precious. The water's flow was divided into twelve arms, with each neighbor receiving an equal share of this water. Natural springs were also vital and access to them was sacred. Access was a right for each individual, but also represented a duty to neighbors not to abuse or divert water for one's own benefit. Even water that was not used for irrigation, but rather to produce energy for mills, like the salt water that powered the mills on the shore, could not be diverted in any way.

The scarcity of water not only determined the expertise required to manage it, but also conditioned social relations among those who shared the same source. And, since the good was as scarce as it was precious, the rules that would have been established orally at the time have since been written down. Disagreements that would have been resolved between neighbours and within communities were resolved by the court in the nineteenth century. Therefore, municipal positions began to determine the time within which each neighbour, properly identified in a public document, had the right to water his fields. Any default would thus be liable to civil action in a Court of Law.

Multiple documents on legal proceedings brought about as a result of water diversion, constructions that ended up harming the passage of water and arrangements of water-lifting devices whose failure ended up deterring production show that water distribution was already envisioned as a citizen right, rather than being a right acquired through tradition.

Finally, this chapter compared the Iberian irrigation systems with the main theoretical output that may have elaborated upon them: a Spanish treatise on agriculture published in 1513, but still partially translated into Portuguese in the nineteenth century, and a treatise on irrigation, published in Madrid in the late eighteenth century. Moreover, the quality of water and related health issues occupy most of Herrera's book, while Vidal's book serves as better evidence of the impact that the development of hydraulics had on Holland and England than of the expertise developed in the Iberian Peninsula since al-Andalus. However, the cases of canals and irrigation systems were not included, certainly because of the fact that what determines their success is very local and unlikely to be translated into general laws.

References

Primary Sources

Manuscripts

Faro's Regional Archive

PT/MFAR/CMFAR/B-A/002/0001.
PT/MFAR/CMFAR/B-A/002/0001, D4.1-E2-P4.
D4.2-E5-M26-TJCOLH/2/468.
PT/ADFAR/JVD/TJCOLH/032/00111.
D4.2-E5-M29-TJCOLH/2/720.

Printed Sources

Municipal Rules of Loulé City Council, in 1862, in Museu da Água.
Carneiro, Luis Damasio Ferreira. 1864. *O Reino do Algarve*. Lisboa: L. D. F. Carneiro.
Herrera, Gabriel Alonso de. 1513. *Obra de Agricultura*. Alcalá de Henares: Arnoa Guillén de Brocar.
Fortes, Mário Paes da Cunha. 1913. *Um problema de Irrigação*. Lisboa: Tipografia da Cooperativa Militar.
Ibn-al-Awam. 1864–1867. *Le Livre de l'Agriculture*. Paris: A. Franck Albert l. Herold.
Lopes, João Baptista da Silva. 1841. *Corografia ou Memoria Economica, Estadistica, e Topografica do Reino do Algarve*. Lisboa: Typ. da Academia.
Willkomm, Heinrich Moritz. 1988 (1847). Zwei Jahre in Spanien und Portugal. In Eberhard Axel Wilhelm, "O Algarve há 140 anos", *Anais do Município de Faro*, vol. 18. Câmara Municipal de Faro, pp. 177–213.

Bibliography

Ambrosoli, Mauro. 1997. *The Wild and the Sown: Botany and Agriculture in Western Europe, 1350–1850*. Cambridge: Cambridge University Press.
Barceló, Miquel. 1989. "El diseno de espacios irrigados em al-Andalus: um enunciado de princípios generales," in *El agua em las zonas áridas: Arqueologia e Historia. I Coloquio de Historia y Medio Físico*, vol. I. Almería, pp. XV–XLXI.
Barceló, Miquel. 1992. "Por qué los historiadores académicos preferien hablar de islamización em vez de hablar de campesinos?," *Archeologia Medievale*, XIX, pp. 63–73.
Barceló, Miquel and Helena Kirchner and Carmen Navarro. 1996. *El agua que no duerme: Fundamentos de la arqueologia hidráulica andalusí*. Granada: Universidad de Granada.
Dear, Peter. 2009. *Revolutionizing the Sciences: European Knowledge and Its Ambitions, 1500–1700*. Princeton: Princeton University Press.

Dias, Jorge and Fernando Galhano. 1986. *Aparelhos de elevar a água de rega: contribuição para o estudo do regadio em Portugal*. Lisboa: D. Quixote.

Forbes, Robert Jacobus. 1966. *Studies in Ancient Technology*. Leiden: Brill.

Freire, Dulce and Pedro Lains. 2017. *An agrarian history of Portugal, 1000–2000: economic development on the European frontier*. Leiden/Boston: Brill.

Freitas, José Lourenço de Gouveia e. 2003. *Levadas e levadinhas de Hireus da Freguesia de Gaula*. Ilha da Madeira: Câmara Municipal.

Gaukroger, Stephen. 2008. "Knowledge, Evidence and Method". In: Donald Rutherford (ed.), *The Cambridge Companion to Early Modern Philosophy*. Cambridge: Cambridge University Press, pp. 39-66.

Glick, Thomas. 1970. *Irrigation and Society in Medieval Valencia*. Harvard University Press.

Glick, Thomas. 2000. *Hydraulic Systems and Technologies of Islamic Spain: History and Archeology*. Boston: Brill.

Glick, Thomas. 2005. *Islamic and Christian Spain in the Early Middle Ages*. Leiden, Boston: Brill.

Guerreiro, João Pinto. 1993. *Sistemas Agrários do Algarve. Da exclusividade autárquica à integração pluriactiva*. Ph.D. Dissertation. University of the Algarve.

Herrera, Gabriel Alonso de. 1818. *Agricultura General*. Madrid: Imprenta Real.

Hill, Donald. 2013. *A history of engineering in Classical and Medieval Times*. London and New York: Routledge.

Holt, Emily. 2018. *Water and Power in Past Societies*. New York: State University of New York.

Howden, Nicholas and John Mather (eds.). 2012. *History of Hydrogeology*. London, New York, Leiden: Taylor & Francis Group.

Jayyusi, Salma Khadra and Manuela Marín (eds.). 1994. *The Legacy of Muslim Spain*. Leiden, New York and Koln: Brill.

Jones, Peter M. 2016. *Agricultural Enlightenment: Knowledge, Technology, and Nature 1750–1840*. Oxford: Oxford University Press.

Long, Pamela. 2011. *Artisan/practitioners and the Rise of the New Sciences, 1400–1600*. Oregon: Oregon State University Press.

Louka, Elli. 2008. *Water Law & Policy*. Oxford University Press.

Magnusson, Roberta J. 2003. *Water Technology in the Middle Ages: Cities, Monasteries and Waterworks after the Roman Empire*. Baltimore and London: The John Hopkins University Press.

Mano, Maria Emília Marques. 1992. *Sistema agrário e reprodução social: águas colectivas no lugar de Várzea dos Amarelos*. Master Thesis. Nova University of Lisbon.

Raposo, José Rasquilho. 1989. *A rega em Portugal*. Lisbon: Secretaria de Estado da Agricultura.

Rodrigues, Ana Duarte. 2016. "Gardening knowledge through the circulation of agricultural treatises in Portugal from the sixteenth to eighteenth centuries". Hubertus Fischer, Volker R. Remmert and Joachim Wolschke-Bulmahn, *Gardens, Knowledge and the Sciences in the Early Modern period.* Cham: Springer International Publishing, pp. 305–317.

Rodrigues, Ana Duarte. 2017. "Sustainable beauty for Algarvean gardens: cross-boundaries solutions between the humanities and the sciences". *Interdisciplinary Science Reviews* 42: 3, pp. 296–308.

Rodrigues, Ana Duarte. 2020. "Working with Nature: 19th Century Vineyards in the Algarve". In: Ana Cristina Roque, Brito, C. and Veracini, C. (eds.), *Peoples, Nature and Environments: Learning to Live Together*. Cambridge Scholars Publishing, pp. 208–219.

Rynne, C. 2000. "Water-power in medieval Ireland", in Squatriti, Paolo (ed.). *Working with Water in Medieval Europe: Technology and Resource-use*. Leiden, New York and Koln: Brill, pp. 1–50

Shapin and Schaffer. 1985. *Leviathan and the Air-pump: Hobbes, Boyle, and the Experimental Life*. Princeton: Princeton University Press.

Shapin, Steven. 1994. *A Social History of Truth: Civility and Science in Seventeenth-Century England*. Chicago: Chicago University Press.

Squatriti, Paolo (ed.). 2000. *Working with Water in Medieval Europe: Technology and Resource-use*. Leiden, New York and Koln: Brill.

Smith, Pamela. 2018. *The Body of the Artisan: Art and Experience in the Scientific Revolution*. Chicago: The University Chicago Press.

Valleriani, Matteo. 2017. *The Structures of Practical Knowledge*. Springer.

Vidal y Cabasés, Francisco. 1778. *Conversaciones instructivas em que se trata de fomentar la agricultura por medio del riego de las tierras*. Madrid: en la Imprenta de D. Antonio de Sancha.

Wateau, Fabienne. 2000. *Conflitos e Água de Rega. Ensaio sobre a Organização Social no Vale de Melgaço*. Lisboa: Publicações Dom Quixote.

Wilson, Andrew. 2008. "Hydraulic Engineering and Water Supply", *Handbook of Engineering and Technology in the Classical World*, John Peter Oleson (ed.), New York: Oxford University Press.

Water Management, Water Devices and Theoretical Knowledge

The Aesthetical Application of Water in Iberian Gardens

Ana Duarte Rodrigues and Carmen Toribio Marín

Abstract

Focusing on the aesthetics conveyed by bodies of water in Iberian gardens, this chapter argues that, due to its Islamic and Mediterranean past, the Iberian sensitivity towards water in Renaissance and Baroque gardens differs from that prevailing elsewhere in Europe. This emerges, for example, in the role that water plays in design of villas, in the aesthetical and utilitarian usage of water mirrors, in the taste for murmuring waters and slender jets of water, in the strategies employed for conveying suggestions of water abundance and in the advantage found in profiting from extant water bodies. In methodological terms, we decided to select five gardens in Portugal and the same number in Spain to demonstrate our point. The selection focused not only on cases of gardens of particular historical and artistic interest, but also on gardens that were highly influenced by Italian and French models so as to facilitate the comparison with their European counterparts, thereby casting light on a different aesthetic sensitivity to the usage of water.

1 Introduction

Water, as a symbol of life, has always been absolutely vital for gardens. Initially incorporated for the purposes of irrigation, water became a vital facet in garden planning, not only for watering plants and crops, but also in view of the innumerable

A. D. Rodrigues (✉)
Centro Interuniversitário de História das Ciências e Tecnologia, Faculdade de Ciências, Universidade de Lisboa, 1749-016 Lisboa, Portugal
e-mail: amnrodrigues@fc.ul.pt

C. Toribio Marín
ETSAM (School of Architecture of Madrid), Madrid, Spain
e-mail: carmentm@gmail.com

A. Duarte Rodrigues and C. Toribio Marín (eds.), *The History of Water Management in the Iberian Peninsula*, Trends in the History of Science,
https://doi.org/10.1007/978-3-030-34061-2_12

opportunities for creating aesthetical effects. Whenever gardeners and garden planners succeed in their task, thanks to the incorporation of all of the visual, aural and tactile qualities of the element of water, a visit to that garden gains the power to awaken all of our senses. Indeed, from a historically early period, these multiple uses stemming from the presence of bodies of water inside of a garden, *quinta* or *granja* (hereafter villas, even if not referring to the exact same construction)[1] had already become clear.

Steven Solomon considers the Islamic Empire to be "History's most Water-Fragile Civilization" (Solomon 2011: 126–154). Following their influence, Iberians have always avoided the wasteful use of water. Correspondingly, special water conservation techniques were developed in water-poor regions, where water had to be used as efficiently as possible and any water losses had to be minimized. As Fairchild Ruggles puts it: "Some of the most ingenious manipulations of water, both in terms of collection and display, occurred in al-Andaluz', the Islamic kingdom in the southern half of what is today Spain and Portugal" (Ruggles 2008: 18). In these water-poor areas, rather than one single solution for tackling problems of water shortage, the need arose to combine a wider range of water sources and practices that included water-saving methods, wise water management and water reuse. Moreover, Manzano Martos suggests that climate and geography determined the origins of what he considers the two greatest universes of the garden, arising in response to two primary demands: the need for water and the need for light. The southern garden, born in desert lands, with a lack of water but an excess of light, stands in contrast to the northern garden, of Central European origin, abundant in water but scarce in sunlight, due to the presence of forests and also, we might add, due to its latitude (Manzano Martos 2011: 2–3).

Among the vast literature on gardens in Portugal and Spain, few volumes have focused independently on the usage of water in these gardens, with the topic generally being addressed as a complement to the history of the gardens (Carita and Cardoso 1990; Carapinha 1995 and 2014). Most studies that are specifically about garden hydraulic systems result from the restoration projects of these same systems, and thus focus on their description (Rodrigues et al. 2009; Castel-Branco 2010). Focusing on the aesthetics conveyed by bodies of water in Iberian gardens, this chapter argues that, due to its Islamic and Mediterranean past, the Iberian sensitivity towards water in Renaissance and Baroque gardens differs from that which prevailed elsewhere in Europe. This might be approached through the role that water plays in the design of villas, the aesthetical and utilitarian usage of water mirrors, the taste for murmuring waters and slender water jets, the strategies applied to suggest the abundance of water and the advantage found in profiting from extant water bodies.

This is especially evident in Renaissance gardens, for which the Islamic legacy was not that distant. However, the principles, concepts and tastes associated with water in the seventeenth and eighteenth century gardens followed an earlier

[1]The recreational estate constitutes 48.9% of the inventoried heritage of gardens, farms, convent grounds and parks of historical interest in Portugal (Araújo 1962). The recreational estate presents a different spatial organization from the villa, since it does not result from an abstract understanding of space, but rather grows and develops along the water lines, resulting in a less rational, asymmetric, and almost labyrinthine organization (Carapinha 1995).

tradition, despite the renowned Italian and French influences (Rodrigues 2009, 2011b). Water then possessed a continuous and discreet presence that gently traversed all spaces, whispering while crawling across the floor, or murmuring, rather than splashing, from a fountain. Furthermore, beauty and utility co-existed in most water features.

This paper is divided into four sections in which we highlight some of the most desired water effects in Iberian gardens, through a comprehensive study of both their points in common and their divergences.

Focusing on water mirrors, the first section takes, as its starting point, the Islamic legacy and the taste of desert people for still water as if it were a vision of an oasis. We show how bodies of water that were already present in villas served for aesthetical and recreational purposes.

In the second section, we examine fountains, water games and water jets to underline not only the importance that they held in Baroque gardens, but also how, even in this context, this usage of water stemmed from Islamic influences in the Iberian case. For example, even the slenderest splattering of the waters launched from Baroque fountains provided a murmuring sound, rather than the splashing sound typical of Central European fountains.

In the third and fourth sections, we address the importance of bodies of water such as lakes and cascades highlighting their unique features in the European context. Moreover, we want to stress the adaptation of a natural stream as an ornamental garden feature by covering it with tiles, rather than constructing huge lakes, as occurred in other parts of Europe.

Finally, the fourth section tackles ways of conveying water abundance in cascades that, in fact, are simulations that use rustic stones with short water flows.

To illustrate these ideas, we have chosen five Portuguese examples (Bacalhoa, Quinta das Torres, Fronteira Palace, the Royal Villa of Queluz and the Royal Villa of Caxias) and the same number of Spanish examples (the Palace of the Marquis of Villena, the Real Alcazar of Seville, the gardens of the Monastery of El Escorial, Buen Retiro and the Royal Site of La Granja of San Ildefonso). They span the period between the sixteenth and eighteenth centuries and are sometimes subject to Italian or French influences. They all display aquatic features that serve to illustrate the concepts presented and are furthermore representative of the solutions that generally arose in the Iberian gardens during the period addressed. They were chosen to bring to the fore the Iberian aesthetic sensitivity towards the usage of water in contrast with their European counterparts.

2 Water Mirrors

Reflection is one of the main aesthetic values that water provides to a garden, emphasizing and amplifying its architectural and natural qualities. When at rest, the water surface acquires a bright aspect, due to its reflective properties. In view of this, some tanks, lakes and channels have earned the epithet of “water mirrors.”

Their polished surfaces reflect and duplicate objects, making these tranquil water mirrors appear as if they were true pictures, varying only in accordance with the time of day and the season.

Large tanks stand out as the most important feature in Renaissance Iberian gardens. We usually encounter them in the highest areas of the ensemble, as part of gravity-based irrigation systems. This arrangement is characteristic of the extensive water surfaces of the Iberian gardens, maintained down throughout history, while the bodies of water in Central and Northern Europe often resulted from reclamation works, and are therefore located in the lower section of the enclosures (for example, the Grand Canal of Versailles, built over a marshy area; this thus also solved the problem of the waterlogged terrain and collected the water from the garden fountains located at a level higher than the great cruciform pool).

Tanks were necessarily present in Mediterranean estates for practical irrigation needs; however, extant irrigation pools also became essential elements of Renaissance Iberian gardens. Sometimes placed in courtyards, the pool repeatedly appears as a fundamental structure of the water network, enabling both irrigation and the placement of fountains in the respective setting. We can find this solution repeatedly in the ensembles that evolved out of the ancient Roman villas that underwent transformation during the Middle Ages into *almunias* and *alquerías*, and later into *carmenes, cigarrales, pazos* or *quintas*.

Often placed up against a building, the size of these tanks grew throughout the sixteenth century as they became a vital element in the expression of power. The fascination with the reflective effects of water explains the wish to build the tanks up against the walls of their palaces so as to duplicate their image, and thus their beauty and grandeur. In Renaissance Portugal, large tanks were built according to Italian architectural influences and within the context of the period of Maritime Expansion. The Quinta da Bacalhoa, in Azeitão, southern Portugal, renovated by Bras de Albuquerque, son of the Viceroy of India, stands out as a paradigmatic example of the large estates built under the influence of Italian Renaissance art and, moreover, directly connected to important figures in the Maritime Expansion (Castel-Branco 1992; Rodrigues 2019). Although the palace was essentially built in two phases—an initial phase from 1442 to 1506, when D. Brites[2] was the owner, and a second phase from 1528 to 1581 under the auspices of Brás de Albuquerque, it was the latter who endowed it with a sense of unity and a Renaissance character (Fig. 1).

At the Bacalhoa, a large square tank was strategically situated on a higher level, providing irrigation by gravity, but its location right in front of the Italian-style Fresco House—a tile decorated *loggia*—was clearly conceived in order for it to serve as a mirror. In addition to these utilitarian and aesthetic functions, there was also a recreational function, as there is evidence that the tank was used for boating as well (Carita and Cardoso 1990; Rodrigues 2019).

[2]Mother of the future king D. Manuel I.

Fig. 1 The water mirror at the Quinta da Bacalhoa, in the region of Azeitão, Portugal. Photograph by Ana Duarte Rodrigues

In the gardens, the Italian influences are clearly intermixed with Islamic influences. These are perceivable not only through the tiles that cover several portions of the villa, but also in the planting style of the orange grove, which is at a lower level than the walkway, in such a way that the treetops could be seen from above as if they were a carpet of greenery (just as in the case of Palais-Badi in Marrakesh) (Rodrigues 2019). Although the works carried out by Brás de Albuquerque were intended to honor his father, there is a lack of clarity over whether the villa's influences come from India. It has been argued that large water mirrors only appeared after Europeans had visited the gardens of India (Castel-Branco 2010 and 2017), as a result of the voyages undertaken within the scope of the Maritime Expansion. However, there is also a long tradition of water mirrors on the Iberian Peninsula that stretches back to Roman times, such as at the Roman villa of Pisões, in which a *natatio* was built alongside the house, a trend that was accentuated under Islamic rule, as happens in the Patio de las Damas in Alhambra. Moreover, within this context and territory of influences, there were the great reservoirs of La Buyara (twelfth century), Seville, and La Menara (thirteenth century) in Marrakesh. Several water mirrors in Portugal date to before the sixteenth century and are affiliated with the Islamic tradition of garden art (Carita and Cardoso 1990: 39–53).

In the vicinity of Quinta da Bacalhoa, another Renaissance villa—Quinta das Torres—contains another huge square tank with an island in its center that is accessible by boat. Built by D. Diogo de Eça, the Portuguese ambassador to Italy, the strongly classical character of the palace follows the models of Sebastiano Serlio, correspondingly placing this tank among the series of water mirrors typical of Portuguese Renaissance villas.

The taste for large water mirrors endured throughout the seventeenth and eighteenth centuries, their grandeur enhanced by large tile panels and sculptures that seemingly floated on the water. In the late 1660s, within the post-Restoration

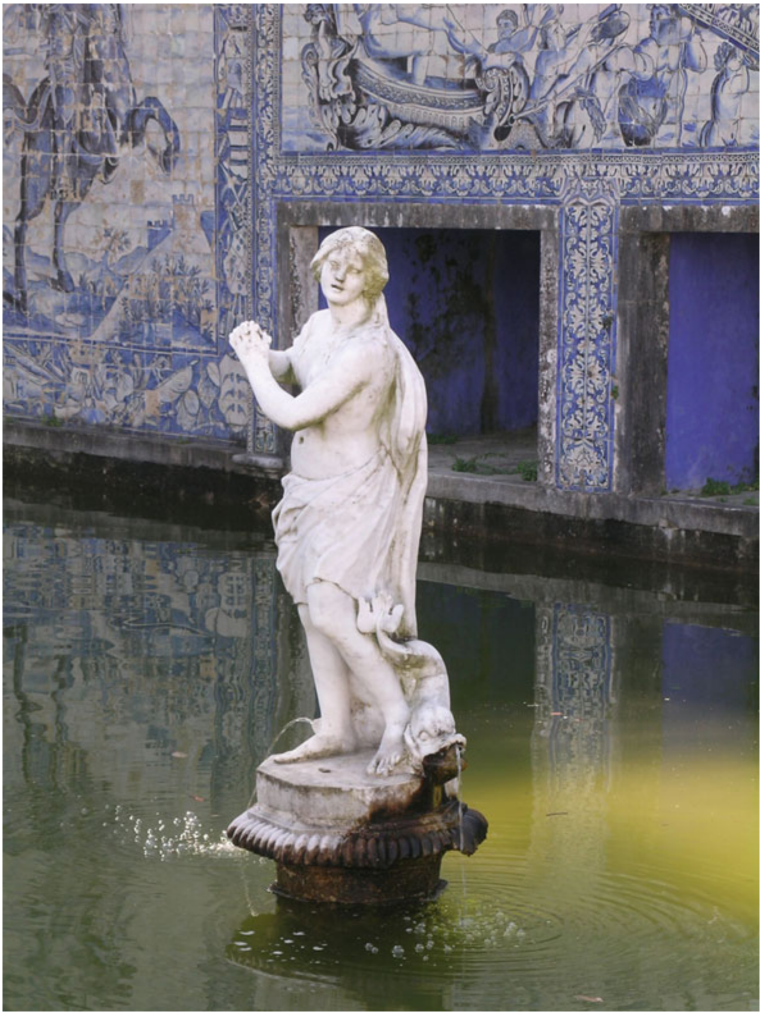


Fig. 2 A nymph floating on the water mirror of the Palace of Fronteira, Lisbon, Portugal. Photograph by Ana Duarte Rodrigues

context,[3] the exquisite gardens of the Fronteira Palace were built by D. João de Mascarenhas (Castel-Branco 2008 and 2010: 25–37; Julien 2011; Rodrigues 2014: 44–61).

Built against spectacular blue and white knight panels, the Frontier Palace's water mirror was revitalised by jets of water projected by stone nymphs in the middle of the lake that seem to glide over the water. This water mirror marries brilliance and movement to the reflective properties of still water. The water duplicates and exaggerates the gestures, movements, colour and brightness of the nymph sculptures and the figures on the panels (Fig. 2). Following the water lines of this estate on the outskirts of Lisbon, the water features were fed by three different independent systems. A reservoir placed on the water mirror's structure at an upper elevation generated sufficient pressure to power the tank's water sets. The *parterre* fountains, in turn, were fed by other sources, noting that the central fountain was exactly on the water line. It was cases such as these that led Carapinha to argue that water is the matrix guiding the design of Portuguese villas, which sometimes lack the symmetry and rationality of their counterparts in central Europe and where the rational use of water seems to be the primary guiding principle (Carapinha 1995).

In Renaissance Spain, the relocation of the Court from Toledo to Madrid during the reign of Philip II encouraged hydraulic experimentation that resulted in the construction of great dams for the irrigation of extensive agricultural lands. This type of structure was also employed at Royal Sites and on courtly estates to ensure the availability of water, not only for irrigation, but also for garden water displays.

In Spain, the large tanks often served as mirrors to reflect the surrounding landscape, rather than being systematically located up against buildings, as we observe in Portugal. As Sanz has pointed out, in some Spanish cases, the so-called *selvatico*, part of the prescriptive gradation of spaces of the classical villa, was replaced with or completed by a large tank, as in the Palace of the Marquis of Villena (Sanz Hernando 2009: 91). The palace and its formal garden, located in Cadalso de los Vidrios (Madrid), may have been built for Diego López Pacheco (third Marquis of Villena) by an unknown designer along the lines of Covarrubias, characteristic of the Spanish Renaissance under Charles V.[4] In this early work, the extraordinary tank, formerly a water reservoir meant for irrigation and located on the highest part of the property, was conceived of as a transitional element between the orchard and the hunting forest.[5] It stood at the highest point in a walled orchard, structured into terraces with granite retaining walls. The tank was constructed at a

[3]The War of Restoration (1640–1668) ended the 60-year period of Spanish rule over the Portuguese kingdom (1580–1640).

[4]In this example, the formal garden is located in a courtyard with an arcade and a gallery in the west facade of the palace. This is one of the most beautiful examples of Spanish Renaissance civil architecture (Lampérez y Romea 1922: 482). Already completed in 1534, it anticipated the later accomplishments of Philip II in establishing a gradation between the architecture and the landscape, while being otherwise still dependent on a layout of Hispanic Muslim origin (AA.VV 2004: 175).

[5]Already completed in 1534, this pre-empted solutions that were later applied in the gardens of Philip II.

Fig. 3 The now empty pool of the Palace of the Marquis of Villena, Spain. Photograph by Carmen Toribio Marín

date later than that of the building (possibly around 1550), the period when Francisco Pacheco, son of the third Marquis of Villena, boosted water availability by tapping the spring of Fuente Techada, located several kilometers away, at 1000 m of altitude. The pool, a solid architectural construction made of carved granite, was a representative piece of the whole hydraulic system (Fig. 3). Thus, its sober contours were adorned with five elements: two beautiful classical arbors in the corners and three benches that faced the water's surface. Probably surrounded by dense trees, this reflected both the landscape and the architecture. It also had other relevant recreational purposes, in addition to serving as a fishery and a site for celebrating aquatic-themed parties.

From the sixteenth century, we assess the transformation of what were originally devised as simple water reservoirs into ornamented tanks. We may take the case of the numerous pools in the gardens of the Royal Alcázar of Seville.[6] The walled

[6]The Royal Alcazar of Seville contains perhaps the most complex and interesting landscaped ensembles in Spain. Located in a privileged place, the site has been occupied by the different cultures that have inhabited the city since ancient times. The gardens to which we will refer are those constructed by the Austrian dynasty. They were laid out progressively over the old yards and orchards of the Hispanic-Islamic era, taking advantage of a great proportion of their hydraulic structures. These gardens were the subject of an exhaustive study by Ana Marín Fidalgo (1990), which, nonetheless, places greater emphasis on the architecture than on the hydraulic system.

yards and orchards were first restructured by Philip II, preserving the primitive structure of small, juxtaposed spaces. Defined by walled boundaries with superior walkways to allow for the contemplation of the whole from above, they resulted in an asymmetric composition, organized according to broken right-angle axes of Hispano-Muslim origin. The walled gardens were adapted to the slope, with terraces at decreasing heights. On the highest of these, a primitive water tank was transformed into a Renaissance pool, the Estanque de Mercurio, a very finely adorned structure that, located at the top of the site, endows the rest of the hydraulic structures with water drawn from the Roman Caños de Carmona aqueduct, whose waters fall loudly from above into the pool.[7] The renewal works also involved the reconstruction of a viewing point on top of the north wall and the construction of an arbour that sheltered a fountain close to the pool. Thus, from above, one can see the hydraulic system as a whole and the axial arrangement of the descendant terraces can be appreciated, and from the gazebo, in a protected setting that brings one close to the water. From the Estanque de Mercurio, water arrived at the fountains within the walled gardens. In the Jardín de las Flores, it fills what is probably an old, sixteenth century ornamented irrigation tank. Visible from the contiguous Jardín de las Galeras through an arched window, this was adorned with two facing banks that overlooked the water's surface. The characteristic way of viewing the gardens, from above and from ground level, was enhanced in the early seventeenth century through the work of the architect Vermondo Resta. At that time, following the announcement of a visit by Philip III (which never came to pass), the architect reconverted the old enclosing wall into the Grutesco Gallery, perhaps the most Mannerist feature of the Real Alcázar, creating one of the few period examples of pool-attached galleries in Spain.[8] Centred on the Estanque de Mercurio, this also served as a balcony that looked out over the pool and the adjacent gardens (Fig. 4).

There is another relevant example, also belonging to the Real Alcázar: the Cenador del León. Located in the old Huerta de la Alcoba, further away from the main building than the walled gardens, this was built between 1644 and 1645 to take advantage of an extant irrigation pool, according to the plans of the master, Diego Martin Orejuela.[9] The water reservoir, with clear Muslim reminiscences, was transformed into the so-called Lion pool with the addition of a beautiful pile, adorned by a stone lion from which water is conveyed to the pond through three masks carved into its circular outline.

[7]The Roman aqueduct supply was restored in the Almohad period to irrigate the orchards.

[8]There is yet another example in the orchard pool in the Monastery of El Escorial. This was built in 1598 by Francisco de Mora and placed under the Convalescent Gallery at the western end of the Jardín de los Frailes, at a lower level, but higher than the surrounding terrain. Water was tapped from springs in the hills and fed along an elaborate hydraulic system to serve the kitchens, the ornamental cloister fountains and the gardens. The surplus, also arising from the numerous cisterns for rainwater storage, went to the Estanque de la Huerta, a large rectangular structure with a walkway and niches along one side.

[9]The Huerta de la Alcoba contained an old and extensive orange orchard, along with the Pavilion of Charles V, possibly rebuilt from an old qubba (Muslim oratory).

Fig. 4 The Estanque de Mercurio in the Real Alcázar de Seville, Seville, Spain. Photograph by Carmen Toribio Marín

The parameter that most characteristically conceptualises the large tanks of this period is the inclusion of architectural features next to the water's surface (Fig. 5). Constructed from imaginative solutions, whether in the form of arbours, fisheries or galleries, they produce an extensive repertoire of combinations that establish different relationships between architecture and water and shape the perimeter and the interrelationship between the water and the ground, as well as facilitating the presence of fountains and other ornaments. The numerous islands that, in the gardens of the period, emerged out of the still water of the large pools also deserve special mention. Distant and reachable by boat or nearby and accessible by bridge, each has its particular characteristics. The installation of fountains and arbours on the surfaces of the islands or around the perimeters of the water mirrors adds even more variation to a panorama already packed with imaginative solutions. In the gardens of Buen Retiro, we also encounter these two solutions. The oval island located in the middle of the Estanque Grande was the scene of the theatrical performances that typified the Golden Age court of Philip IV. Although lost today, it is depicted in Texeira's map of Madrid (1656). The major and minor angle diameters, measuring 70 and 40 m, respectively, gave enough space to place a small building at each end of the two crosswalks that divided the island into four parts. According to the Texeira plan, there was another pavilion built in the centre. We can find another example near the Estanque Grande, in the lobed Estanque de las Campanillas. Small in dimension, each of its eight lobes was decorated with stone masks and demarcated by a simple iron railing. Again, there was an island in its centre—reachable by a bridge—that housed a pavilion adorned with bells that sounded whenever blown by a breeze, perhaps denoting an early Oriental influence.

We argue that water mirrors constitute a typical feature of the sixteenth and seventeenth century Iberian gardens, not because they did not exist then in their European counterparts, but rather because, although large lakes were built elsewhere, they still privileged moving waters. For example, although the French gardener André Le Nôtre had mastered the utilisation of water for reflection in the gardens of Versailles (c. 1660), he privileged effects of moving waters as he was well aware of the laws of geometrical optics and light propagation and refraction. When Dézallier d'Argenville wrote the treatise *La Théorie et la Pratique du Jardinage* (1709) on the French formal garden, clearly inspired by Le Nôtre's works for the Sun King, we perceive a sentiment that is diametrically opposed to the enjoyment of still waters. Furthermore, he advocates in favour of the advantages of moving waters over water mirrors. This author warns that still waters are more likely to become corrupted, especially in the summer, due to the prevailing warmth. He also recommended against placing tanks and ponds near or against buildings, due to the harmful effects and dangers of evaporation to the health, the potential to attract animals that would make noise during the night, as well as the possibility that humidity seeping into the building's walls might cause irreparable damage to the paintings and furniture inside (Rodrigues 2011a: 319–322). Furthermore, in the middle of the eighteenth century, the French hydraulic engineer Belidor stated that still waters failed to stimulate the imagination in the same way as moving waters, mentioning the need for variety in the spectacle conveyed by water. Even pleasure gardens, as well cultivated as they might be, apparently did not seem pleasant to the eye unless stirred by moving waters (Rodrigues 2011a: 327).

3 Murmuring Water

Water in motion lends its own colour to all of its surroundings, due to the unique property of resplendent light, endowing architects and artists with infinite means and resources to enrich scenes of nature and to vary its expressions. This continuous movement also allows water to be conserved in its total state of purity, transparent and crystalline. In addition, water in motion creates sound effects, ranging from a murmur to a strong splash, both equally sought after. If a single sheet of water falls, the sound produced is simpler, but also stronger than when, for example, it is subdivided into several nozzles, in this case, producing a composite sound effect similar to that of rainfall. The intensity of sound becomes all the greater with greater flows of water and the steepness of the existing gradient.

In the Iberian Peninsula, the preference for murmuring water was fostered within the context of al-Andalus. Channels of water that crossed courtyards like rippling snakes were common in al-Andalus and held a utilitarian function, as well as being an aesthetical feature in early modern Portuguese and Spanish villas. The water lines are first drawn from the water's source to the reservoir tank and then distributed through gutters and a network of open-air channels at the ground level so as to irrigate the different levels of the garden's terraces while simultaneously contributing enormously to the bountifulness and sense of peace that prevails in the garden. They were certainly a means of distributing water, but their role in refreshing the space and providing a certain musicality was equally important. Therefore, in Iberian gardens, with some exceptions, murmuring water crosses the spaces as a serpent that scrools through the grid, emitting whispers of freshness and bestowing continuous music on the landscape.

Nevertheless, murmuring water was not only spread about at ground level, but was also launched into the air, thereby creating the same effect of cooling the environment, as well as fostering particular aesthetical effects by taking maximum advantage of a minimal water flow.

At first sight, these fountains and jets of water in Iberian gardens would seem to approximate those in their European counterparts. Dézallier d'Argenville warns that water distribution accounts for one of the most difficult facets of tending to gardens, as it requires great knowledge and talent to convey the illusion of abundance when just a small amount of liquid is available. Moreover, the French author stated that "following the plants, fountains are the principal garden ornament," as, without the vitality of water movement, the scenario dies (Rodrigues 2011a).

Water also provides a fundamental feature in the projection of garden sculptures, due to the innumerable possibilities for creating aesthetic effects. Whether made of stone, metal or wood, the success of garden fountains is ultimately determined by the mastery with which water is allowed to play with the available light. These effects were so desired that, in certain cases, they even led to the construction of large aqueducts and machinery to transport water to the garden site, as was the case of the Marly machine in Versailles. There was a need to feed the splash effect of the Versailles fountains with the required amount of liquid and to ensure the pressure needed to raise the water to a certain height. Although some aqueducts may be identified as infrastructures built in Iberian villas to bring more water to the site, such as at the villa of Aranjuez or the villa of the Marquis of Pombal in Oeiras, they also nurtured agricultural purposes. In Iberian gardens, the water was raised to produce only slight jets, therefore, it is clear that water was supposed to murmur, and not splash.

During the sixteenth and seventeenth centuries, fountains and grottos were subject of multiple interpretations, both thematic and compositional, enabling murmuring water in gardens. The improvement in hydraulic techniques brought about a growing interest in fountains that, inspired by Classical Antiquity, were then adorned with mythological statuary to form part of complex iconographic programs. The classical gods entered the garden not only as deities, but also as symbols of virtues or allusions to the natural cycles that were so perceptible in the garden. The fountains, whether made of marble, clay, bronze, brass (gilded and sometimes painted) or even glass, were adorned with coloured stones, seashells and, sometimes, coral branches. On the Iberian Peninsula, the classical influence

Fig. 5 The Estanque de la Huerta in the Monastery of Escorial, surroundings of Madrid, Spain. Photograph by Carmen Toribio Marín

merged with Islamic tradition. Classical fountains with numerous basins, decorated with statuary, coexisted with those flushed to the ground level and displayed against the profusion of colours and brilliance provided by decorative tiles.

The mastery of hydraulic technology and, in some places, the scope for ensuring water with enough pressure allowed for the creation of increasingly complex water games, and even for automata and hydraulic organs. However, in many cases, the soft murmur of water that springs close to the ground, as in oases, was preferred to the sonority of the high jet. We have only to consider the terrace fountains of the Monastery of the Escorial.[10] The serial rhythm of the garden was defined, in this case, by a module formed by a small square tank, located almost at ground level, surrounded by four floral compartments. The water spouted from a central pinecone made of stone, a symbol of resurrection, spilling, rather than rising, into a small water jet that, according to Father Sigüenza, looked like a crystal plume (Sigüenza 2010 (2010): 192). Moreover, in the Cloister of the Evangelists, the centre of the

[10]The monastery was built between 1562 and 1584, according to the original layout by Juan Bautista de Toledo. Upon his death in 1567, Juan de Herrera continued the work. The great unevenness of the ground in the NO-SE direction led to the creation of two terraces. The pensile gardens are located on one, limited by the building and the Convalescent Gallery and open to the landscape (Sanz Hernando 2009, 124–127).

Hieronymite community that inhabited the southern Monastery section, we find the same taste for murmuring water. The cloister, following a traditional layout, is cross-shaped, with an octagonal pavilion in its centre, designed by Juan de Herrera. The pavilion forms a unitary structure, with four raised water tanks, filled with the water that spills softly from the statues of the Evangelists, placed on the chamfers. Once again, water combines aesthetics and utility: on the one hand, the pools were part of the gravity-fed cloister irrigation system; on the other hand, their layout exemplified a new water feature in which four basins form part of a cross-axial garden (Toribio Marín 2016: 1–15). This displays a resemblance to the Cloister of the Manga in Coimbra, which was once considered its model, although recent interpretations argue that they both follow the archetype of the *paradisus claustrali* (Rodrigues 2015: 99–107). Just as these bodies of water convey the shared culture between the two Iberian countries, they also reveal the connections with Italian Renaissance art.[11]

Ludic mechanics constituted another of the great water-linked themes of the Mannerist garden. Among all of its uses, that of providing movement or sound to an inanimate object may be water's most enigmatic. This represents a meeting of two separate worlds: one belonging to the sphere of science, mechanics and knowledge; the other arising from the world of the game, simulation and paradox (Aracil 1998: 60). Perhaps their ability to link opposing concepts accounts for the reason for their repeated presence in all known cultures, at least through to the beginning of the Enlightenment in the West.

Greek knowledge merged with the cultural legacy of Ancient Egypt in Alexandria under the Ptolemaic dynasty. Later, the Byzantine Empire was the repository of Greco-Roman science, of which the automata were a sample. The knowledge necessary to make these artefacts quickly spilled over into the Islamic world, thanks to translations of works of Byzantine origin into the Greek and Persian languages during the Abbasid Caliphate in Baghdad (eighth and ninth centuries), and from there into Islamic Spain. Therefore, their presence in the gardens of the Iberian Peninsula in the modern period is not strange, given that they were subject to the influences of both the Italian Renaissance and the Islamic tradition. The great proliferation of ludic mechanics in all Mannerist courts produced numerous examples in the Spanish court. According to Morán Turina, they are also the most coherent and imaginative (Morán Turina 1986: 116).

In a relevant hydraulic treaty of this period, *Los 21 Libros de los Ingenios y las Máquinas*, we find an early reference to this type of artifice.[12] In the following century, the remodelling of the Jardín de las Damas of the Real Alcázar of Seville

[11]This water feature appeared at the same time in Villa Lante. For more information, please see Toribio (2016).

[12]The codex, held in the National Library of Madrid, is a treaty on what was then called hydraulic architecture that almost completely covers the field of civil engineering. At first attributed to Juanelo Turriano, a watchmaker in the service of Carlos V, its authorship seems to correspond to Pedro Juan de Lastanosa, a sixteenth century Aragonese author (García Tapia 1984). Ladislao Reti, Alexander Keller and García Diego agree on the magnitude of this work in its pre-emption of works that would only appear centuries later. In his numerous papers on the subject, García Tapia attributes the manuscript to Pedro Juan de Lastanosa.

included a water organ in the garden's main fountain, the so-called Fuente del Peñasco, designed by Vermondo Resta (Marín Fidalgo 1990: 403).[13] Built in the seventeenth century on the express wishes of Felipe IV, the nearby Jardín de la Cruz (later called Jardín del Laberinto) housed a characteristic combination of water features with strong symbolism: the nymphaeum, the grotto, the waterfall and the Mount Parnassus. A multi-linear tiled pool, with a Mount Parnassus in its centre, formed part of a surprising composition that included hydraulic automata that moved over the water. This feature was in the middle of an intricate labyrinth of myrtle, where the feeling of danger and loss of orientation was enhanced by the inclusion of myrtle topiary figures of lions, deer, hunters and giants with monstrous heads and hands made of clay that appeared by surprise around the bends and turns in paths (Marín Fidalgo 1990: 455). At the Palace of Fronteira, a similar set was designed. Although lacking automata, the stone nymphs still seem to crawl along the water while simultaneously spouting jets of water, against a background formed by tile panels and accompanied by statues on a grotto-recreated Mount Parnassus (Castel-Branco 2008).

4 Unique Bodies of Water: The Most Shining Canal

The harnessing of extant bodies of water stands out as a major difference between Iberian gardens and their European counterparts. This is reflected in comparisons between the huge lakes of Versailles and the massive works undertaken to manipulate water for the *Lago Grande* (hereafter Great Lake) of the Royal Villa of Queluz, built in the eighteenth century.

The Royal Villa of Queluz, located in the surrounding areas of Lisbon, was originally an estate with lands, orchards and vineyards on the banks of the Jamor River. It was only in 1746, on the initiative of D. Pedro, future King D. Pedro III, that this estate was transformed into a proper villa for the recreational pursuits of the royal family. In 1794, the Palace of Queluz became the official royal residence, as it was the only structure available with the magnificence to perform such a function. Among its various pavilions, *parterres*, lakes and cascades, the Great Lake stands out. It shines due its uniqueness—it is the only totally tile-covered canal in the world (Figs. 6 and 7).

Besides its aesthetical quality, the rational underlying its projection illustrates the utilitarian way in which Iberians then thought about beauty. Still stemming from Islamic influence, as Ibn Luyum puts it: "the utilitarian is necessarily beautiful, and beauty is necessarily useful" (Carapinha 2016: 47–63). In Portugal, the trend was clearly to take advantage of extant water resources: If there is already a body of water on the property, what is the point of building a new one?! Contrastingly,

[13]The Jardín de las Damas, separated from the former Huerta de la Alcoba and converted into the main garden area of the Real Alcázar in the 17th century, contained several mural fountains placed at the ends of the main axes, with the largest being the Fuente del Peñasco.

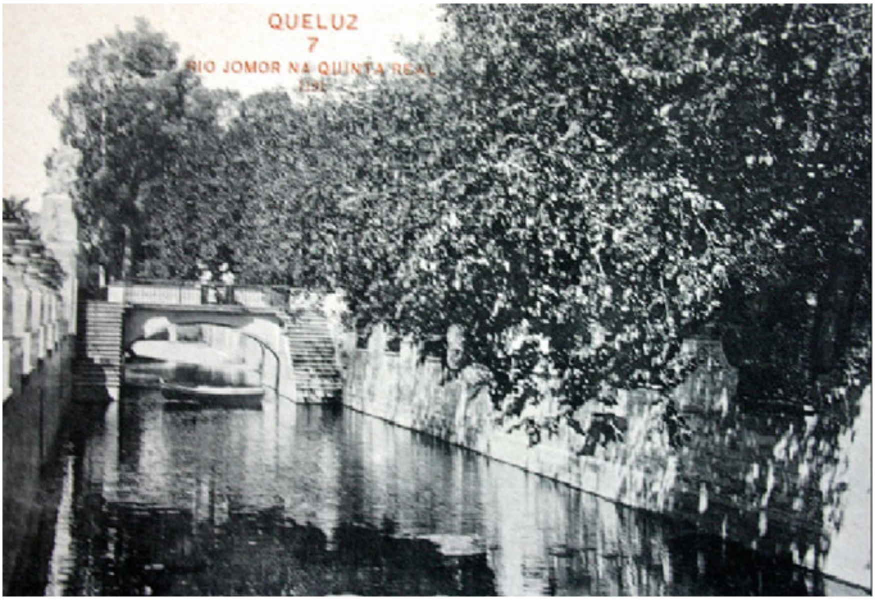


Fig. 6 The Great Lake at the Royal Villa of Queluz, 1920. Archives of the National Palace of Queluz

Fig. 7 The Great Lake without water, National Palace of Queluz, surroundings of Lisbon, Portugal. Photograph by Ana Duarte Rodrigues

elsewhere in Europe, where there was real manipulation of space and water to supply villas. Large lakes built from scratch became typical of the French and British gardens of this period. However, instead of building a huge lake at the bottom of the main axis of the gardens of Queluz, the option was to take advantage of the Jamor River, which ran through the villa.

The Great Lake essentially was the Jamor River. Its transformation for aesthetic and recreational purposes constitutes one of the most remarkable works of eighteenth century Portuguese garden art. Its uniqueness derives from being totally garnished with figurative tile panels over a length of 115 ms: 35,199 blue and white tiles were applied on the inside walls of the lake, depicting mainly sea ports, galleons and gondolas, as well as nobles being led to land; 15,939 coloured tiles depicting hunting and courtly scenes were subsequently applied to the exterior walls in 1756 (Pires 1925–1926: 293–294). In the warm season, the waters of the river were dammed using iron gates so as to form a huge lake upon which the projection of the tiles offered a lively picture in motion.

The river was channelled from the moment that it entered the gardens through to its exiting, simultaneously allowing for the controlled discharge of torrential flows and the formation of a water surface. Boating and listening to music were both common practices on this lake. The sculptures, garden furniture, musical instruments and gondolas described in the 1763 Royal Estate inventory of the Royal Villa of Queluz depict the imaginary recreations of exquisite gardens in which the water ran incessantly through fountains, spouts and cascades.

Certainly, little gondolas slipped by to the sound of music played in a small garden pavilion. Although there is no known picture of a gondola on the Great Lake, a c. 1920 postcard produced within the context of the tourism industry does depict a boat on the lake.[14] On a bridge crossing the Jamor River, the Music House, also known as the Chinese House, was built to accommodate the orchestra that played there, whether for the king's private parties or the great festivals staged in the summer (Pires 1925–1926: 298).[15] By the beginning of the twentieth century, the Music House was already in poor condition, as its main wooden structure was not humidity proof and its location over the bridge fostered its deterioration. The bridge, however, continued to stand and was re-decorated with groups of sculptures. Currently, the lake is empty for the purpose of heritage protection, as previous water flows have damaged the tiles.

Only on rare occasions do we find artificial canals as key features in Spanish gardens of the sixteenth and seventeenth centuries. However, the Buen Retiro gardens in Madrid are a unique and relevant exception (Fig. 8). The project, a seventeenth century proposal from the Count-Duke of Olivares as a suburban villa for Philip IV, also entailed the construction of a new water supply, solely for the palace complex, something that, as we have seen, was a rather infrequent

[14]PNQ, AHS, no. 1588, cx. 22. In this postcard, the level of the water is above standard.
[15]When Caldeira Pires wrote his text, the House of Music was still on the top of the bridge.

Fig. 8 The Buen Retiro in the topography of Madrid, 1656 (PPOBL (1656) 1881 CC-BY4, IGN.ES)

development on the Iberian Peninsula. Even more so, the technique employed stemmed from Muslim wisdom: in the Buen Retiro, we thus encounter the construction of two Viajes de Agua, called Alto and Bajo, a water supply structure that shared common features with the ancient *qanāts*, formed by mines and underground conduits that used gravity to convey the groundwater tapped a long distance from the point for supply.[16] Once delivered to this site, the water served both for utility and for aesthetics, recreation or representation. The Río Chico ("small river"), the first garden water feature, irrigated part of the lands of the ensemble. The greater flow rate after 1636, following the construction of the Viaje Bajo, provided for the building of the so-called Estanque Grande, a large water mirror with a central island, used both for boating and as scenery for theatre performances, as well as for irrigation. From here, a navigable canal, the Río Grande, made its way to the hermitage of San Antonio de los Portugueses, one of the many that adorned the site. It was neither designed as a straight canal to emphasise perspective, as in the later solutions of Le Nôtre, nor did it function to limit or border different areas of the gardens, as in many Central European examples. The whole water layout of the Buen Retiro appears to be a metaphor of the numerous navigation projects for Spanish rivers that were ongoing since the times of the Catholic Monarchs, reaching a peak in Aranjuez with Philip II. Overall, the water features appear to be an allegorical representation of the Philippine territory and the prevailing desire to unite the court capital with Lisbon through a waterway. Thus, the canal starts from a large pool with a central island, which might symbolize the Island Garden in Aranjuez, then follows a course that adapts to the topography, perhaps also symbolic of the tortuous course of the Tagus, finally ending in the larger scaled hermitage, of Portuguese dedication and perhaps a metaphor for the city of Lisbon.

Even in the most French-influenced garden of the Spanish Baroque, La Granja, we find a canal that constitutes a particular interpretation of the natural site, radically different from the Grand Canal of Versailles. Built in the eighteenth century for Felipe V, the first Spanish Bourbon king, his palace and gardens are located on the northern slope of the Sierra de Guadarrama, in Segovia, on a landscape crossed by numerous mountain streams (Sanz Hernando 2009).[17] One, the Morete stream, was channelled as a staggered river and displaced from the main axis to create several ornamented water lines and the Ría, which borders part of the garden and, after several breaks, disappears through an aquatic door located next to the Fountain of the Selva.

5 Illusion of Water Abundance: Monumental Cascades

Triumphal waterfalls have featured in Italian gardens since the Renaissance, and had an impact on seventeenth and eighteenth century gardens across Europe. As a result of strong French and Italian influences, some monumental cascades were

[16]This water supply system is treated in detail in Pinto Crespo, Gili Ruiz, Velasco Medina 2010, 83–90. El Retiro has been studied by, among other authors, Ariza Muñoz (1990), Blasco (2001) and Brown and Elliot (2003).

[17]On La Granja, please see Bottineauu (1986), Callejo Delgado (1988), Morán Turina (2002) and Sancho Gaspar (1996).

built on villa properties in the surrounding areas of Lisbon over the second half of the eighteenth century. They occupy, within the composition, a space equivalent to the great lakes that prolong the views towards the horizon, but providing an opposite effect. In French and British gardens, a guiding axis for the entire garden was drawn starting out from the main palace window (from the king's chambers at Versailles and Hampton Court), with the aim of endlessly extending the view along a water channel until reaching the horizon. On the contrary, in Portugal, the monumental cascades were placed at the top of the structural axis of the garden layout, thus acting as large focal points for the landscape arrangement into which they were inserted. Furthermore, science and technique were applied to suggest abundances of water when in fact the flows were only restricted in amounts. The clear intention was thus to visually amplify the flow of water as in the case of *Los Veintiún Libros de los Ingenios y Máquinas*: in drawing a cascade, the author provides recommendations "to make a small fountain look like a lot of water" (vol. II, book VII, Fig. 104: 245).

Monumental cascades constitute one of the most spectacular visual garden effects. Filled with stone sculptures of figurative size, monumental cascades provide amazing visual effects due to their scale, location and stone composition as well as their interactions with water. They direct perspectives when glimpsed at from a certain distance and provide a unique scenario when the visitor approaches.

The effects generated by free falling water depend on the forms by which this is discharged. In view of the configuration of the section over which the water falls, the height, thickness and surface of the ridge or threshold and the level of the water downstream from the threshold site, is able to return the most unexpected effects. For example, more whitish and less clear-looking water sheets are achieved by increasing the roughness of the threshold surface.

At the bottom of the Royal Villa of Queluz, D. Pedro built the first artificial cascade ever in the surrounding areas of Lisbon. Although Portuguese historiography has dedicated several studies to the Royal Palace of Queluz, only a few concern the restoration of the hydraulic system that conveys the history of water in this royal summer villa.[18] The construction works of a system for capturing, channelling, storing and distributing water were established in the landscape around the property, the adoption of which required millenary technical solutions. Although the Jamor River constituted an important water resource, it did not ensure the pressure necessary for the functioning of the water games intended to adorn the gardens. Hence, it became necessary to resort not only to opening and exploring the mines located in the surroundings of the villa, but also to the construction of tanks.

[18]The urban expansion in the area around Queluz, which has become a suburban suburb of Lisbon, was the direct cause for the degradation of the entire hydraulic system. From the early 1990s, the gardens were subject to several protective actions that had, as their main objective, halting the process of decay of the entire constructed environment and its surroundings and resolving problems concerning the garden's water supply.

The first of these mines to be built was that of Pendão,[19] followed by Carenque and Gargantada, due to the increasing water requirements. We would note that these mines were located several kilometres away from the palace and gardens, so the construction works needed to channel the water involved serious financial and technical investment. From the mines, the water was conducted through gutters, under closed galleries, and protected from the incursion of eventual impurities. These gently sloping aqueducts ran at ground level, underground, or were even detached from arches. Most of the water-conducting galleries had vaulted ceilings in stone or brick, and their dimensions allowed for a man to stand and move inside. In order to ensure the upkeep of this system, numerous inspection towers were built. They fulfilled the functions of providing access to the galleries and settling boxes. The water collected was then conducted into several tanks. The most important tank for system operation was the Miradouro Tank, which received water mainly from the Pendão mine. Other reservoirs were built, not only for water storage, but also for irrigation, a practice achieved exclusively through gravity. It is interesting to note how one of these deposits was located under the main garden—the Pênsil Garden (hanging garden)—receiving water from the lakes and fountains there, as well as from the adjoining Garden of Malta.

In most cases, the water used in the cascades and fountains would be discharged into the river; the system operated as an open circuit. This also reflects how the operation of the waterworks was conditioned both by restrictions in flows and their accumulated volumes, with the water sets therefore not always working and dependent on the opening and closing of their valves to increase pressure for water games during special events.

A 10-metre high monumental cascade stands at the bottom of the garden's main axis, which departs from the Robillion façade and is designed to be the focal point. The slope of the land, however, prevents the palace view from reaching the waterfall. This cascade was built with rustic stones from Cascais, and a great lake with whelks of stone stands as its basis. At the top, there was a large water tank with a complete surrounding balcony, decorated with statues (Pires 1925–1926: 293).

Significant gaps between the Miradouro tank (located on one of the highest hills around the estate) and the gardens (set on the banks of the Jamor River) ensured the running of the waterworks and the supply of the tank built at the top of the Great Cascade at 11 m above the soil level. Currently, water for the cascade also comes from the Curro tank, through pipes outfitted with the pressure necessary to raise the water over the 5 m gap. The tank at the top served to stabilize the water pressure and to keep the water in the veil steadier, something that is now impossible, and the

[19]Only the Pendulum mine meets the conditions for complete restoration, that is, of its function (capture and provision of water) and the physical features composing the system. The water in the mine would, however, be insufficient to meet the needs of the estate. In this context, two groundwater abstraction wells were drilled, between 1992 and 1994, within the boundary walls of the gardens from which an appreciable flow rate was obtained (AC1 bore flow rate: 3.5 l/s, AC2-5 l/s).

The 1992 draft envisages that the water collected from the boreholes be conveyed to the Belt Tank to provide for the distribution circuits to operate in a closed circuit in order to reduce water losses to a minimum.

water currently only comes out of the scowl and the eagles. Below the cascade, there is a gallery—of crypto-portico type—that has no water, but was used to maintain the tubes and the basin located below the waterfall.

The gardens are now fully supplied by the Curro tank through gutters (made out of U-shaped stones and covered with slabs) and then, closer to the fountains and sculptures, through lead pipes (at later stages, some were made out of iron before stoneware was then resorted to, but these were much wider than those made out of lead, about 5 cm wide). Currently, there is a water recycling system with boxes near each lake that collects surpluses before sending them into a reservoir, which then forwards them back to the Curro Tank.

At the Quinta Real de Caxias, near the coast, D. Pedro decided to build magnificent gardens *à la française* of a size and magnificence far superior to those at the palace, which seemed to be no more than a support house for the large living room that looked out onto the show that was the gardens (Rodrigues et al. 2009). Work must have begun in the late 1770s, with construction of the three-story cascade (Fig. 9). Located at the top of the main axis of the garden, the cascade guides the overall composition. Here, a powerful theatrical effect is generated by using the cascade as the setting for the actions of talking statues and water games. From 1782, the king's sculptor, Joaquim Machado de Castro, began work on 22 naturally-sized clay sculptures, painted white to simulate stone.

Fig. 9 Cascade at the Royal Villa of Caxias, surroundings of Lisbon, Portugal. Photograph by Ana Duarte Rodrigues

The cascade projects water that falls from the top, first into a rustic set and then into a structure composed of two marble bowls positioned at distinct levels, creating water curtains that are collected in the lake where a group made up of Diana and her nymphs stands, inspired by the episode of Diana's Bath in Ovid's *Metamorphoses*. Following the same iconography of the spectacular cascade of the Royal Palace of Caserta, near Naples, headed by the sculptural groups of Diana and Acteon at the basin of the cascade, a group of dozens of clay sculptures are ditributed throughout the cascade. Diana and her nymphs bathing in the lake are displayed at the bottom of the waterfall, while Acteon, his dogs and satyrs are spread across the various cascade levels. The water from the Queijas natural spring was channelled to the Tanque da Vinha (115 m^3). From this tank, three valves led the water through different channels and to different destinations. One arrived at the aqueduct that carried the water to the tank located just behind the top of the waterfall. The other valve led the water to a shackle installed inside of the aqueduct, reaching the fountains of the pots and two fauns placed at the top of the cascade that issued water through cornucopias. The third valve carried water both to the fountain that emerged from Diana's spear at the foot of the waterfall and to the Lakes of the Four Seasons (Beloto and Faria 2009: 138–143).

Diana bathing also features in the cascade of La Granja de San Ildefonso, in Spain (Fig. 10). Expressive jets of water spout from several points of the cascade, recalling the strength of water in the French and Italian gardens, and thus in a manner completely different from the fine water springs issuing forth from the Portuguese sculptures. However, at La Granja, a totally different cascade was

Fig. 10 The Cascade of La Granja gardens, Segovia, Spain. Photograph by Carmen Toribio Marín

placed in the main axis. Surmounted by the Cenador de la Reina, a small pavilion that blocks the open perspective typical of classical French gardens, the waters of the cascade glide smoothly from the Fountain of the Three Graces above to the group of Amphitrite at the bottom.

Moreover, as the hydraulic system of the Royal Villa of Caxias has been subject to restoration, we gain the opportunity to observe how the waterfall differs from that depicted in the *Archivo Pittoresco* (Rodrigues 2009). The effect conveyed, caused by successive interruptions in the water sheet due to several intermediate platforms, was only dynamized by jets of water thrown in the opposite direction, outlining diagonals that contributed greatly to the construction of a particularly Baroque setting. In a rustic cascade, the water flows through the stones so as to appear natural or is projected in different directions by fountains until it reaches the collector lake. While refreshing the environment, this also creates a pleasant noise and dilutes the shape and colour of the sculptures, sometimes accentuating this effect through variations in the flow rate that thus alter the degree of transparency through which the cascade design emerges. Given the longer periods of water shortage in southern Portugal, it would have been more likely for water to drip off of the rustic stones of the waterfall, as this implied the existence of a smaller flow of water. In fact, rustic stone cascades simulating natural waterfalls acted as artifices for saving water.

6 Final Remarks

Different aesthetics, influenced by differences in the cultural heritage, hydric resources, tastes and rationales that prevailed, dictated the construction of the hydraulic works of Iberian gardens. The growth and development of recreational estates along pre-existing water lines make up a great number of examples, both in Spain and in Portugal. As Carapinha states, the "only rules it obeys are dictated by the rational usage of water" (Carapinha 1995). Therefore, water becomes the structuring and dynamic element of the Iberian garden. Moreover, the orthogonal pattern derives from the irrigation techniques determined by gravity (Carapinha 2014). When estates were extended to a considerable size, and in order to minimize the risks of drought, the water feeding sources were diversified. Finding, conducting and storing water, and, later on, its usage in water games, required a certain expertise that was developed empirically on the Iberian Peninsula. In fact, gardens only employed independent hydraulic systems on rare occasions and were usually subject to territorial water infrastructures linked to agricultural developments to which their layouts were subordinate to a greater or lesser extent. The relevance of these water-related infrastructures on two different scales, one related to the territory and the other to the garden, is clear in the large number of dams associated with the Royal Sites in Spain (Valsaín, Aranjuez, Casa de Campo, El Escorial, La Fresneda).

Following principles of sustainability, although probably without such an awareness, not only did the most important bodies of water follow natural water lines, but water also served different purposes along its path. For example, in the Fronteira garden, waters from the *parterre* fountains and the water mirror subsequently served to water the boxwood garden, the vegetable gardens, the orchard and the orange grove.

The interest in ancient Roman techniques converged with the Islamic tradition on the Iberian Peninsula, resulting in the appearance of important hydraulic expertise that fostered a particular aesthetical usage of water. Water mirrors not only provide reflecting qualities to the scenario, reflecting both the architecture and landscape, they also enhance the certain quietness desired in Iberian gardens. The only interruption allowed might be the singing of a bird or the murmuring of water from water games or, alternatively, from water flowing along open air channels on the ground.

The compositional resources applied to water mirrors, which are superior in importance, function and the richness of their layout to other contemporary Italian and Central European examples, are remarkable on the Iberian Peninsula. The motif came to the Iberian garden after a long journey: Mesopotamia, Egypt, Greco-Roman culture, the medieval Hispano-Islamic garden architecture and the mediaeval Christian garden. Nevertheless, for the people of the desert, the oasis was a vision of *pairidaeza*—of a garden. The vision of still water reflecting the sky clearly recalls the oasis, and paradise on earth then seems possible, whenever there is water.

References

AAVV. 2004. *Arquitectura y Desarrollo Urbano. Comunidad de Madrid*. Tomo VI. Madrid: Dirección General de Arquitectura, Conserjería de Política Territorial, Colegio Oficial de Arquitectos de Madrid.

Aracil, Alfredo. 1998. *Juego y Artificio. Autómatas y otras ficciones en la cultura del Renacimiento a la Ilustración*. Madrid: Cátedra.

Araújo, Ilídio. 1962. *Arte Paisagista e Arte dos Jardins em Portugal*. Vol. I. Lisbon: Ministério das Obras Públicas. Direcção Geral dos Serviços de Urbanização.

Ariza Muñoz, Carmen. 1990. *Los Jardines del Buen Retiro*. Barcelona, Lunwerg, Madrid: Ayuntamiento de Madrid, Área de Medio Ambiente.

Blasco, Carmen. 2001. *Un proyecto hacia el pasado: el palacio del Buen Retiro de Madrid.* Madrid: COAM.

Beloto, Carlos and Faria, Paulina. 2009. "Recuperação do sistema hidráulico". *In* Rodrigues, Ana Duarte *et al. Quinta Real de Caxias. História, Conservação, Restauro*. Oeiras: Câmara Municipal de Oeiras, pp. 138–150.

Bottineau, Yves. 1986. *El arte cortesano en la España de Felipe V 1700–1746.* Madrid: Fundación universitaria española.

Brown, Jonathan, y Elliott, John H. 2003. *Un Palacio para el Rey: el Buen Retiro y la Corte de Felipe IV.* Madrid: Taurus.

Callejo Delgado, María Jesús. 1988. *El Real Sitio de San Ildefonso*. Madrid: Universidad Complutense.

Carapinha, Aurora. 1995. *Da Essência do Jardim Português*. PhD dissertation on Landscape Architecture. Évora: University of Évora.

Carapinha, Aurora. 2014. “The Guardian of the Mediterranean Matrix—The Portuguese Garden”. *Gardens and Landscapes of Portugal*, nº2: 6-15.
Carapinha, Aurora. 2016. Sucursal del Paraíso: o Libro del principio de la belleza y fin de la sabiduría que trata de los fundamentos da arte de la agricultura, de Ibn Luyum. *In* Ana Duarte Rodrigues (ed.). *Uma História de Jardins. A Arte dos Jardins na Tratadística e na Literatura*. Lisbon: Biblioteca Nacional de Portugal, pp. 47–64.
Carita, Hélder and Homem Cardoso. 1990. *Tratado da Grandeza dos Jardins em Portugal ou da Originalidade e Desaires desta Arte*. Lisbon: Círculo de Leitores.
Castel-Branco, Cristina. 1992. *O Lugar e o Significado. Os Jardins dos Vice-Reis*. Ph.D. dissertation on Landscape Architecture. Lisbon: University of Lisbon.
Castel-Branco, Cristina. 2008. *Os Jardins dos Vice-Reis—Fronteira*. Lisbon: Oceanos.
Castel-Branco, Cristina (ed.). 2010. *A Água nos Jardins Portugueses*. Lisbon: Scribe.
Castel-Branco, Cristina. 2017. *A Índia nos Jardins Portugueses*. Lisbon: Verbo.
Chuchi et al. 2005. “Roca y agua. El condicionamiento del entorno y el desarrollo histórico de la ciudad de Huesca”. *In Saldvie*, no. 5: 159–175.
Fernández Talaya, Mª Teresa. 1999. El Real Sitio de La Florida y La Moncloa: evolución histórica y artística de un lugar madrileño. Madrid: Caja Madrid Fundación.
García-Diego, José Antonio and Laín Entralgo, Pedro. 1996. *Los veintiún libros de los ingenios y máquinas de Juanelo Turriano*. Madrid: Biblioteca Nacional.
García Tapia, Nicolás, 1984. “Los 21 libros de los ingenios y de las máquinas: su atribución”. *Varia de Arte*. Valladolid, 434– 439.
García Tapia, Nicolás, 1989. *Ingeniería y arquitectura en el Renacimiento español.* Valladolid: Universidad de Valladolid.
Insausti Machinandiarena, Pilar de. 1998. “Los jardines del Real en Valencia”. *In Felipe II, el rey íntimo. Jardín y Naturaleza en el siglo XVI.* Madrid: Sociedad Estatal para la Conmemoración de los Centenarios de Felipe II y Carlos V: 380–399.
Julien, Pascal. 2011. “La Bibliothèque du Marquis de Fronteira et la conception du jardin de son Palais”. *In* Rafael Moreira and Ana Duarte Rodrigues (eds.). *Tratados de Arte em Portugal/Art Treatises in Portugal*. Lisbon: Scribe, pp. 145–152.
Lampérez y Romea, Vicente. 1922. *Arquitectura civil española de los siglos I al XVIII*. T. I. Madrid: Saturnino Calleja.
Llewellyn, Roddy. 1987. *Water Gardens—The Connoisseur's Choice*. London: Ward Lock Limited.
Marín Fidalgo, Ana María. 1990. *El Alcázar de Sevilla bajo los Austrias.* Sevilla: Guadalquivir.
Manzano Martos, Rafael. 2011. “El Jardín Musulmán. Origen y evolución”. In *Actas del III Encuentro Hispanoárabe de Jardinería*. Córdoba, 5 y 6 de mayo de 2011.
Marías, Fernando. 1986. *La arquitectura del Renacimiento en Toledo (1541–1631).* Madrid: CSIC.
Merlos Romero, Mª Magdalena. 1998. *Aranjuez y Felipe II. Idea y forma de un Real Sitio.* Madrid: Dirección General de Patrimonio Cultural de la Comunidad de Madrid y Ayuntamiento de Aranjuez.
Morán Turina, José Miguel; Checa Cremades, Fernando. 1986. *Las Casas del Rey: Casas de Campo, Cazaderos y Jardines. Siglos XVI y XVII.* Madrid: Ediciones El Viso.
Morán Turina, José Miguel. 2002. *El arte en la corte de Felipe V: del 29 de octubre de 2002 al 26 de enero de 2003,* Palacio Real de Madrid, Museo Nacional del Prado, Casa del las Alhajas. Madrid: Museo Nacional del Prado.
Muñoz Domínguez, José; Sánchez Sancho, Juan Félix; Sanz Belloso, José Carlos. 2009. “El estanque de la villa renacentista El Bosque de Béjar, una presa holandesa en Castilla”. *In Actas del Sexto Congreso Nacional de Historia de la Construcción*, Valencia, 21–24 de octubre 2009. Madrid: Instituto Juan de Herrera: 955–965.
Pinto Crespo, Virgilio; Gili Ruiz, Rafael; Velasco Medina, Fernando. 2010. *Los viajes de agua de Madrid durante el Antiguo Régimen.* Madrid: Fundación Canal.

Pires, António Caldeira. 1925–1926. *História do Palácio Nacional de Queluz*. Coimbra: Imprensa da Universidade.

Rodrigues, Ana Duarte et al. 2009. *A Quinta Real de Caxias. História. Conservação. Restauro.* Oeiras: Câmara Municipal de Oeiras.

Rodrigues, Ana Duarte. 2011a. *A Escultura de Jardim das Quintas e Palácios dos Séculos XVII e XVIII em Portugal,* Textos Universitários de Ciências Sociais e Humanas. Lisbon: Calouste Gulbenkian Foundation and the Portuguese Foundation for Science and Technology/ Ministry of Science.

Rodrigues, Ana Duarte et al. 2011b. *The Gardens of the National Palace of Queluz*. Lisbon: Institute of Museums and Conservation/National Palace of Queluz/National Press-Coin House.

Rodrigues, Ana Duarte. 2014. "O Bom Gosto do Palácio Fronteira". *In* Ana Duarte Rodrigues (ed.). *O Gosto na Arte—Idade Moderna.* Lisbon: Scribe, pp. 44–61.

Rodrigues, Ana Duarte. 2015. "Renaissance Cloisters in the Iberian Peninsula and the American Colonies: the circulation of meanings and forms". *Portuguese Studies Review. Special Issue: Portugal inside and out*, University of Trent, 22: (1): 97–128.

Rodrigues, Ana Duarte. 2016. "Gardening knowledge through the circulation of agricultural treatises in Portugal from the sixteenth to eighteenth centuries". *In* Hubertus Fischer, Volker R. Remmert and Joachim Wolschke-Bulmahn, *Gardens, Knowledge and the Sciences in the Early Modern period.* Cham: Springer International Publishing, 305–317.

Rodrigues, Ana Duarte. 2019. "A Quinta da Bacalhoa: regularização do espaço e controlo da natureza". *In* Maria João Coutinho et al. (eds.), *O Património artístico de Setúbal e Azeitão*. Setúbal: Câmara Municipal de Setúbal, pp. 85–107.

Ruggles, Fairchild. 2008. *Islamic Gardens and Landscapes.* Pennsylvania University Press.

Sancho Gaspar, José Luis. 1996. *La arquitectura de los Sitios Reales : catálogo histórico de los palacios, jardines y patronatos reales del Patrimonio Nacional.* Madrid: Patrimonio Nacional.

Sanz Hernando, Alberto. 2009. *El jardín clásico madrileño y los Reales Sitios*. Madrid: Ayuntamiento de Madrid.

Sigüenza, Fray José. 2010 (1605). *Historia de la Orden de San Jerónimo. Libro tercero y cuarto: La fundación del Monasterio de San Lorenzo el Real*. Valencia: CMC Editor.

Solomon, Steven. 2011. *Water: The Epic struggle for Wealth, Power, and Civilization*. New York: Harper Perennial.

Stronach, David. 1994. "Parterres and stone watercourses at Pasargadae: notes on the achaemenid contribution to garden design". *Journal of Garden History, an international quarterly*, vol. XIV, no. 1 (Jan–Mar): 3–12.

Swindells, Philip. 1991. *The Water garden*, Gardener's guides. London: Ward Lock, Ltd.

Symmes, Marilyn (dir.). 1998. *Fontane, Giochi d'Acqua e Spettacolo—Acqua e progetto dal Rinascimento ad oggi.* London: Thames and Hudson.

Tchikine, Anatole. 2016. ERASE

Thompson, Ian. 2006. *The Sun King's garden: Louis XIV, André Le Nôtre and the creation of the garden of Versailles.* London: Bloomsbury.

Toribio Marín, Carmen. 2016. "The Fourfold Water Garden, a Reinassance Invention". *Gardens and Landscapes*, no. 4: 1–15.

Water and landscape. An aesthetic overview of the role of water in the landscape. 1974. Washington: Water Information Center.

Aranjuez and Hydraulic Engineering: Public Utility, Leisure Utility

Magdalena Merlos Romero and Victoria Soto Caba

Abstract
In the Spanish Modern Age, hydraulic engineering played a particularly outstanding role within the scope of the new organisation endowed upon the Royal Court and the geopolitical system associated with Royal Spanish sites. This chapter argues that the site of Aranjuez stands as a showcase for water management, exemplifying the wide variety of water uses and constituting one of the key factors in this cultural landscape. Covering three periods of works, this chapter highlights not only water management for recreational purposes, but also how Aranjuez enabled communication with Madrid via the Jarama and catered to the potential navigation of the Tagus and the consequent connection to the Atlantic via Lisbon as an alternative to Seville.

1 Introduction

In the Spanish Modern Age, hydraulic engineering played a particularly outstanding role within the scope of the new organisation endowed upon the Royal Court and the geopolitical system associated with Royal Spanish sites. This geopolitical system was brought into being by Philip II (1527–1598) in 1561, who later decided to convert Madrid, at the centre of the Iberian Peninsula, into the capital of the Spanish Empire.

M. Merlos Romero
Archivo Municipal de Aranjuez, Ayuntamiento de Aranjuez, Madrid, Spain
e-mail: mmerlos@madrid.uned.es

V. Soto Caba (✉)
UNED (Universidad Nacional de Educación a Distancia), Madrid, Spain
e-mail: vsoto@geo.uned.es

A. Duarte Rodrigues and C. Toribio Marín (eds.), *The History of Water Management in the Iberian Peninsula*, Trends in the History of Science,
https://doi.org/10.1007/978-3-030-34061-2_13

One of these sites, Aranjuez, is probably the location with the highest number and most significant concentration of hydraulic elements on the peninsula. Its engineering system has been hailed for its catalogue value, which is an echo of tradition, while simultaneously representing a starting and reference point for formal innovations. At present, Aranjuez remains a showcase model for effective water management, exemplifying the wide variety of water uses and constituting one of the key factors in this cultural landscape, as is subsequently explored in this chapter.

Aranjuez is on the banks of the Tagus and Jarama Rivers, midway between the old and new capitals, Toledo and Madrid, respectively. As we shall illustrate, the very location of this site determined its configurations and design in keeping with the usage of water resources and incorporating the channels as urbanising elements. It was this very location that determined its strategic value within the order established by Philip II (Merlos Romero 1998).[1] Not only did Aranjuez enable communication with Madrid via the Jarama and its tributary rivers, the site also catered to the potential navigation of the Tagus and the consequent connection to the Atlantic via Lisbon as an alternative to Seville.

The following provides a highly detailed description as to why Aranjuez's historical evolution spans three relevant periods, firstly, the reign of Philip II in the second half of the sixteenth century, an era that established this Royal site; and then in the eighteenth century, especially under the rule of Ferdinand VI (1713–1759) and Charles III (1716–1788). The aforementioned royals extended Philip II's project while guided by illuminated and physiocratic inspiration. Lastly, there is also the nineteenth century, which was not so much defined by any creative contribution as it was by the recovery of the Crown's patrimony as a result of the tense political instability: The War of Independence (1808–1814), the Carlist Wars and the first Republic of Spain (1873–1874). Just as the Renaissance was an age that witnessed one of the greatest surges in activity in history and gave rise to an enormously creative movement, upon which subsequent interventions would build and be sustained, thorough attention is also given to this period in this study.

Right from the beginning, the conceptual design of Aranjuez did not restrain its ambitions to construct a palatial nucleus, but rather took on a broader dimension. This far wider form of conception is reflected not only in its gardens, but also, and more surprisingly, in the layout of its territory. This featured the provision of a large enclosed area of orchards, ponds and hunting grounds, interlinked by an urban outline of tree-dotted streets and plazas (Morán and Checa, 1986). Acknowledging this unique scenery, together with the impressive landscaping of this Royal site, UNESCO listed it as a World Heritage Site in 2001 (Merlos Romero 2001).[2]

It remains quite clear that the creation, maintenance and expansion of both the gardens and the demarcated areas would never have been possible were it not for the regulation and recourse that was made to the Tagus and Jarama Rivers. These waters were channelled through a hydraulic system of dams and canals that

[1]The author's quotations are not reiterated. References for the sixteenth century follow this text.
[2]World Heritage since 2001 (www.unesco.whc.org. Exp. 1044).

counterbalanced both environmental factors and the harsh weather, including vast contrasts between torrential winter rains and scorching summer heat.

On the one hand, engineering interventions such as works of public interest were aimed at securing the irrigation of wooded areas, crops and gardens, the generation of energy (mills) and the containment of channels that sustained avenues. The potential navigability of these rivers, enabling communication and transportation, was also a key factor. On the other hand, these inventions, together with their economic and productive purposes, as well as their scientific (agricultural and botanical research) and leisurely facets, befitted a courtly place in which pleasure and business undoubtedly went hand in hand. Ultimately, such actions were subject to the political mission of the Royal site; thus, to represent and magnify the power of the Spanish Monarchy. Historically, the Aranjuez hydraulic system has been deemed to be particularly relevant, due to its magnitude, the quantity of artefacts, its typological variety and its spatial concentration.

2 The Hydraulic System Over Time: Creation and Extension

The peninsular territory south of the Tagus was undeniably incorporated into Christian Spain following the capture of Oreja Castle in 1139, an enclave in the vicinity of the territory in which Aranjuez would later be constructed. This zone was taken on as the property of the Order of St. James of the Sword until the moment when, under Ferdinand the Catholic Monarch, it was designated as property of the Crown, in 1493. By then, these lands were being used for hunting. To the same extent, the Tagus River was dotted with mills and weirs. They were essentially oriented towards serving fruit gardens, orchards and fisheries, and were already in usage for the construction of flourmills and waterwheels, linked to the cultivation of cereals and rain-fed species in Christian times. Upstream, a series of dams and canals date back to the Muslim period of settlement and are also still in use today, designed to establish fisheries and supply downstream waterwheels and mills (Segura Graíño 2009: 1337–1343). These dams include Buenamesón (with mills and canals), Aldehuela (with waterwheels) and Valdajos.[3] Following the Christian conquest of Spain, these same dams were then renovated and altered, thereby indicating how empirical knowledge circulated among both Muslim and Christian worlds in the Iberian Peninsula (Fig. 1).

In the fourteenth century, the masters of the Order of St. James of the Sword erected a recreational residence, modelled on the Hispano-Muslim scheme of a palace, garden and orchard (Alvarez de Quindós 1804: 61–62). This medieval garden was completely surrounded by water. This thus constitutes a predecessor to

[3]This channel was intended to supply mills, and would become the source of the future Colmenar irrigation channel, which entered into operation in 1528. This irrigation channel was a significantly complex device with three mills, each furnished with its own guardhouse and warehouse for storing the grain.

the Island Garden of Aranjuez (*Jardín de la Isla*), indeed, a garden on an island. In close vicinity to the palace, there remains evidence of a waterwheel that was in use during the reign of the Catholic Monarchs, Elizabeth and Ferdinand, towards the end of the fifteenth century. The modest network of ditches, later maintained by the already prominent Catholic Monarchs, would form the basis for the hydraulic complex that was later constructed in the sixteenth century. This consequently demonstrates the close connection between hydraulic engineering and the urban history of the Royal site.

In 1534, a decision was made by Charles I (1500–1558) to convert the area into a royal recreational house. Charles I headed the construction of the El Embocador (funnel) dam and the two ditches that it originated: Las Aves, also referred to as Sotomayor, on the left bank, and El Rebollo, on the right bank. Together, they constituted the main network for the hydraulic system and the outline framework for the Aranjuez plan. The construction of the aforementioned Colmenar ditch dates to around the same period. However, it was his son and successor, Philip II, who conceptualised and put this ambitious global project into practice. As a prince, Philip arranged additional courses for channelling water, one to allow for irrigation of the Sagrilla and the other to supply water to both Alpajés (a settlement close to Aranjuez) and the orchard property of Don Gonzalo, the warden of Aranjuez during the fifteenth century.

It was during the reign of Philip II that engineering played its most important role in territorial management, bringing together functionality, aesthetics and pleasure. The greatest achievements of this period occurred in both irrigation infrastructures and the water supply produced by networks of ditches, canals, dams and ponds.

In Renaissance Aranjuez, nature became subject to a process of rationalisation, with the guidelines for intervention agreed upon and goals set for the scale of the engineering work that lay ahead. This relationship varied in accordance with its application to the land that was immediately adjacent to the palace or planned within the territorial dimensions bordering the riverbeds and cities of Madrid and Toledo. It should not be forgotten that this engineering, from a practical point of view, sought to endow the comfort idealised for Renaissance cities. This was sustained by the revival of the premises of antiquity and remnants of the functional engineering projects of classical Rome. Therefore, it is not surprising that the King participated personally in these projects. By virtue of their intricate navigation and communications networks, they were bestowed with equal importance to that of the very mastermind behind them, the Spanish Empire. Thus, interventions in the environment, infallibly determined by political needs, were aimed at practical objectives such as the control and distribution of water, the containment of riverbeds and the navigability of rivers, while also contemplating pleasure, in other words, entertainment and leisure.

Both the orography, specifically the courses of the Tagus and Jarama river valleys, and the development of communication channels delimited the territorial organisation and determined the perimeter of urbanised Aranjuez. The space was rationalised by means of a complex and geometric framework that distinguished

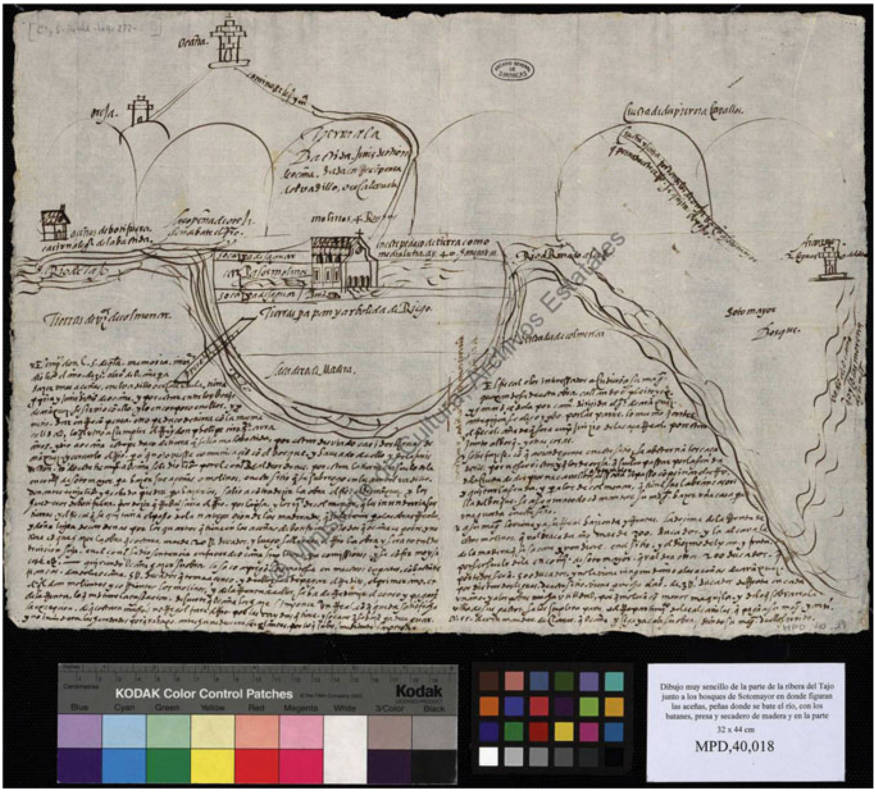


Fig. 1 Dibujo de la ribera del Tajo junto a los bosques de Sotomayor con aceñas, peñas, batanes, presa y secadero de madera; © España. Ministerio de Cultura. Archivos Estatales. Archivo General de Simancas. MPD, 40, 018

those areas for the cultivation of crops from those for hunting, and furthermore incorporated the medieval routes (the roads to Madrid and Toledo, to Ocaña and Ontígola) so as to highlight the Palace grounds and the Island Garden (Fig. 2).

The intervention zone enclosed by the Las Aves and El Rebollo ditch systems runs from east to west, from the point at which the El Embocador dam is located to an area of land that formed a confluence between the Tagus and Jarama Rivers in the sixteenth century. Today, this is the site of the meeting point between the Picotajo and Legamarejo groves.

Philip's various decisions regarding this Royal site date as far back as 1551. The process that he had envisioned was to be costly and ended up impacting upon the economic capacity of the Royal site, for which all costs were incurred by the royal household. This consisted of an experimentation phase based on what the prince had learned on his joyful journey through Europe from 1548 to 1551. Simultaneously, this decade coincided with the preparation of the territory and

Fig. 2 Domingo de Aguirre (draft.) Juan Antonio Salvador Carmona (engr.), Topografía del Real Sitio de Aranjuez, 1773; © Biblioteca Nacional de España

implementation of the earliest urban interventions, inspired by the Prince's architectural and humanistic education. This process had been enhanced by his contact with European courts (in particular, Italy, Flanders and France) and their respective contributions to the Renaissance movement. These plans matured in 1561, coinciding with the deployment of new professionals and the return of Juan Bautista de Toledo (1515–1567) to Spain. This Spanish architect (who had gained professional experience in Italy) and Phillip, then already the ruling monarch, called in professionals from Flanders, Italy and Northern Europe. They were all considered experts in their fields and rendered services in the most advanced forms of architectural planning. At all times, formal innovation was merged into the identity of the indigenous. A later phase occurred between the death of Juan Bautista de Toledo (1567) and King Phillip himself (1598), during which Juan de Herrera took on a significant role.

Juan Bautista de Toledo and Juan de Herrera implemented both the architectonic and the city planning innovation. Likewise, the Spanish Monarch, as a Renaissance Prince, displayed a passion for science, as well as for the unique and exotic. This gave rise to the diversification of water usages while simultaneously anticipating the potential challenges of the Age of Enlightenment.

In the eighteenth century, the Spanish Monarchy, then ruled by the Bourbon dynasty, perpetuated the creative path to Aranjuez. However, the sustainability plans for the coexistence of nature and the city would be reinterpreted according to different chronological and historical coordinates. The Age of Enlightenment reigns of Ferdinand VI and Charles III historically benchmark the state conception and design of Aranjuez, which was considered a courtly town 'embedded' in a *rural* settlement (Tovar 1988: 219–231). Over the course of the 1700s, a small population gradually established itself around the palace area, in conjunction with a number of agricultural colonies. This period also saw the establishment of one of Aranjuez's most symbolic green spaces—the Jardín del Príncipe (The Prince's Garden).

This city in the countryside was beautifully enhanced by other countryside cities. A rural city sought to engender a city garden, which strove to be playful yet functional. All of these enclaves, each intended for purposes of production, were dispersed across fertile lands, with each inscribed in Phillip II's conceptualisation of the logical utilisation of space. The streets that interlinked them with the pre-existing Renaissance network of avenues brought the Aranjuez project to light just as it had been imagined down through the centuries.

The leading light of this agricultural policy was the Real Cortijo de San Isidro site. This was founded in 1766, emanating from a clearly scientific and experimental vision, specifically, from the point of view of botany. These lands were ultimately dedicated to wine and olive production (Merlos Romero and Ordieres 2013). Other noteworthy farms of this period were the Casa de la Monta, a stud farm initiative in Sotomayor that pursued the Spanish tradition of horse-breeding that had been practised in Aranjuez ever since the reign of Philip II; El Campo Flamenco, whose design was greatly influenced by the Picotajo orchards, both of Nordic inspiration; and the Las Infantas and Villamejor estates, among many others. Stretching even as far as the eastern section of the city, a large area was devoted to Levantine horticultural crops, which would become known as La Huerta Valenciana. The latter was not only aimed at acclimating species, but also at promoting the Moorish tradition, deeply rooted in the Spanish Levante. Thus, there was also the production of silk integrated into mulberry cultivation and further the construction of La Casa de la Seda.

Another pivotal milestone of this era was the Prince of Asturias' Garden, implemented by the future Charles IV (1748–1819). The garden was under the care of Pablo Boutelou, who began work in 1784 with the incorporation of pre-existing landscaped surfaces and imported Anglo-Chinese patterns after his visit to England. The gardener aimed simply "to imitate the beautiful disorder of nature and hide the artifice according to the English fashion" (Ponz 1787: 377–378, in Buttlar and Soto Caba 1993: 297–298).

Furthermore, the character of the agriculture and the landscapes of the new settlements required an ever-expanding network of irrigation channels and ditches. Water needs increased with the establishment of the court city and its access roads, which required both a supply of drinkable water for the population and irrigation of the tree-lined avenues (Fig. 3).

3 The Hydraulic System in Space: Its Components

By the Renaissance, an infrastructure system had been designed aimed at maintaining the natural wealth of Aranjuez, both for productive and recreational purposes. In keeping with their purposes, the infrastructures may be classified as follows: Water containment and storage (dams, reservoirs, dykes, reservoirs and ponds, channelling rivers); water catchment and distribution (channels, canals, ditches and mines or catchment galleries, water coffers and vents); generating waterpower and elevating water (hydraulic wheels or water wheels, mills, fulling mills); supply and ornamentation (fountains); and navigation for communication and transport.

The need to manage the levels of rivers and the canal network is reflected in the construction of different containment features. Dams would allow both for the replenishment of water and the regulation of currents. They served not only for irrigation, but also for powering mills and waterwheels. The dykes would act as complementary engineering devices.

The construction of dams, dykes and palisades in Aranjuez has since been characterised by the intensity that prevailed, not only as regards the building of new facilities, but also in the need for maintenance and reconstruction. Ironically, their very creation and eventual destruction would be brought about by the same phenomenon: flooding rivers. Thus, dams, dykes and palisades were primarily deployed to contain and divert water. Any event of overflow would jeopardise the fertility and vitality of the gardens and orchards. In fact, floods themselves suffice to destroy these constructions. Not one of the three, dams, dykes or palisades, were intended to actually store water, but rather only to contain and calm it. This was a simpler and less expensive course of action than reservoir dams. The elevations on the Tagus were intended to contain floods and to preserve landscape interventions and the order of the surrounding territory.

The existing documentation enables a clarified perspective on their distribution, always adapted to the riverbed and the most oscillating stretches along their courses, the meanders. Protection and maintenance was especially concentrated on vulnerable areas that were in direct contact with the rivers, such as the Island Garden, the line of Alpajés (or Queen's Avenue) and San Remondo.

The experience gathered by Gaspar de Vega during his trip to France was applied in the field of hydraulics, both for reconstruction projects and for new projects. The new dams of San Remondo (1557) and Requena (1559) were both constructed during this period. Other dams, such as those of Islilla, Aceca, and the Requena dam itself, were rebuilt in the 1560s under the supervision of Juan Bautista de Toledo. He also constructed several dykes in 1561, such as that running between the squares on Queen's Avenue, another in El Rebollo del Borní, another in the vicinity of the bridge over the Tagus and, finally, another at El Raudal. All sought to alleviate the bursting of river banks and protect the Island Garden territory by slowing down the upstream flow so that the water near the palace would be more

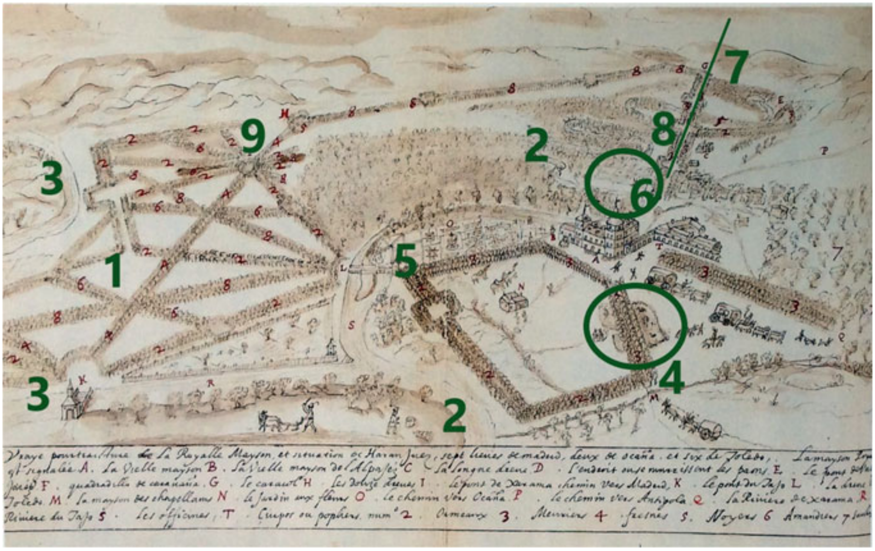


Fig. 3 Jehan L'Hermitte, Aranjuez, C. 1596; L'Hermitte, J. *Les Passetemps de… Mémoires d'un gentil-homme de la chambre de Filippe II,* Anvers, 1890–1896. 2 vols. [1. Picotajo's Orchad; 2. Tagus River; 3. Jarama River; 4. Ponds'Orchad; 5. Island Garden; 6. Up Orchad (Huerta de Arriba); 7. Embocador's Dam; 8. Queen Avenue; 9. Twelve Streets (Doce Calles)]

controlled (Luengo Añón 2008: 382).[4] Other dams, such as those at La Rinconada de Picotajo, Las Conejerías and La Huerta de Arriba, were repaired after the architect's death.

The most outstanding example is the Alhóndiga dam, restructured by Juan Bautista de Toledo between 1561 and 1562. Made of wood, this was actually a palisade designed to stop the water's momentum prior to its reaching the meander that hosted the Island Garden.[5] Today, though somewhat modified, it is known as the Palace dam and represents one of the most recognisable visual landmarks of Aranjuez (Fig. 4).

The aforementioned dyke on Queen's Avenue incorporates buttresses built by Juan Bautista de Toledo (García Tapia 1990). It established a tradition in Hispanic engineering from the sixteenth century onwards, as would later be seen in the Ontígola Sea.

Moreover, there was a project for a diversion dam on the Tagus, although it was never executed. This was designed according to Flemish tradition by the Flemish dyke builder Pieter Jansen (1567–1575). This dam would have been surrounded by a network of ponds and also involved, due to the required riverbed rectification, the

[4]AGS CSR, leg. 251.2, fol. 30a.
[5]AGS CSR leg. 251.2, fol. 33.

Fig. 4 Aranjuez (Spain) Palace's Dam, 16th century; photo M. Merlos

channelling of the Tagus River between Requena and the vicinity of the Palace, upstream of the Island Garden (García Tapia 1990: pp).

Furthermore, in 1745, during the reign of Ferdinand VI, before the changes made to the Tagus and Jarama riverbeds and the subsequent prevention projects enacted to protect the boundaries of the Picotajo orchards, the architect Giacomo Bonavía planned dams, spurs and channels (Tárraga 1991). According to his designs, an early plan for the Jarama began in the Tejeras zone, north of the Picotajo orchards, while a second channel for the Tagus would return the flow to the former riverbed. However, the most visible work of the time (1752) was that of the

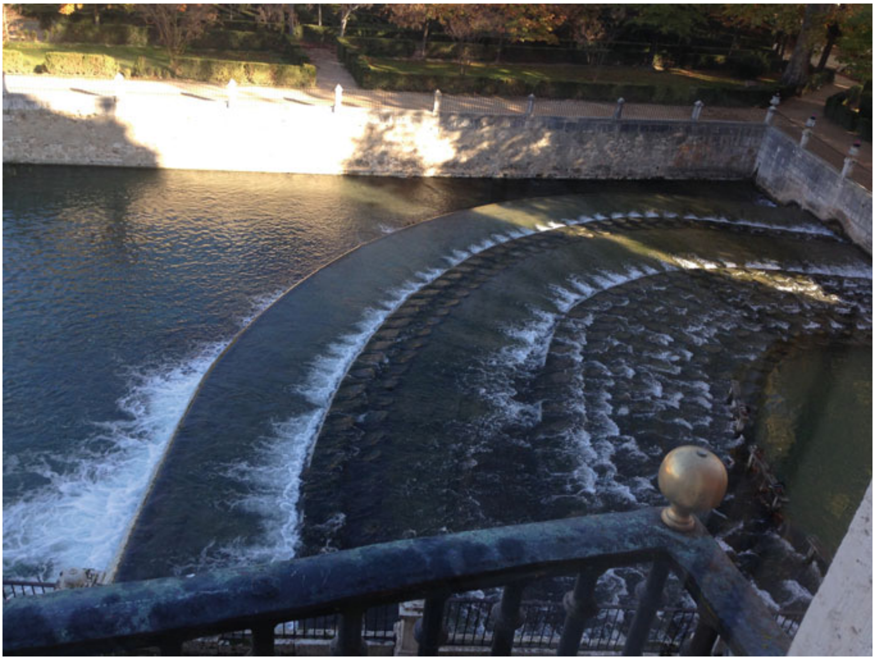


Fig. 5 Aranjuez (Spain) Las Castañuelas, 18th century; photo M. Merlos

so-called *Cascada de las Castañuelas* (the Castanet Waterfall), which interlinked with the northern palace wall located in the channel separating the Island Garden from the mainland. This echoed the ornamental transformation of a previous dam by means of the installation of fan-shaped, stepped echelons that enhanced both the water's movement and its sound (which was similar to a castanet, hence the origin of its name) (Fig. 5).

However, alongside these dams, dykes and palisades designed to divert and quieten the waters, an important system of reservoirs and dams was also implemented for the purpose of storing water and irrigating crops, gardens and the tree-lined avenues. In the sixteenth century, the most important were El Embocador and the Ontígola Sea (Fernández et al. 1984; González Táscon 1987).

The El Embocador dam dates back to the era of Charles I (around 1535). Its construction took place simultaneous to the emperor's decision to transform Aranjuez into a recreational abode. Typologically, it would emanate from the straight-dykes model. In the 1530s, this would undergo repair by the hydraulic engineer Gaspar de Vega, a member of De la Vega family, who arrived in Aranjuez in 1551. Moreover, the Ontígola Sea is the most emblematic of the hydraulic works, both amongst all of the royal residences and in the history of Spanish engineering, due its size, its survival since the Renaissance to this day and its innovative execution (García Tapia and Rivera Blanco 1985; Rivera Blanco and García Tapia 1985; Merlos Romero 1998).[6] Its novel structure—an embankment formed by two parallel walls made of stone and cemented together (running 140 m in length, 6 m in height and 10 m in width)—was an Italian-inspired construction method, emerging from Classical Rome.[7] The Ontígola Sea prototype, conceivably considered a Hispanic creation, would not only henceforth be imitated across the Iberian Peninsula, but would also set the style for the construction of all modern dams from thereon

In 1552, Flemish experts were the first to foster awareness around this reservoir project. Later, in 1561, the project commenced under the supervision of Juan Bautista de Toledo, as briefly documented in a report. Bautista took charge of the recruitment of Dutch experts, all with experience in dyke and water containment techniques. The principal dyke construction workers included Pietre Jansen and Adrian Van der Muller and the building engineer Juan de Castro, who was then later succeeded by Francisco Sánchez, an expert construction worker. However, while the preliminary construction work had been finished by 1562, the project would not be entirely completed until 1572.

Although the main role of the Ontígola Sea was the irrigation of the gardens and fountains across the Royal site, Philip II's plan to incorporate a series of islands into the pond subsequently called for additional construction work. In terms of leisure, several sixteenth century chronicles refer to the planning of naumachia (mock naval combats) and pastimes such as celebrations with bulls and hunting that later became regular leisurely pursuits. For instance, in 1635 a pavilion was built for staging shows, before the later construction of a bullring, a garden and shipyards (Álvarez de Quindós 1804: 337). It was also an ideal place for fishing, the fish having been brought there from Flanders, and walking.[8]

The other goal of the Ontígola Sea encapsulated an ecological dimension. From the moment that Philip II conceived the project in 1552, it had been planned as being a stopover for migrating birds. In addition to a leisurely aspect, this ecological phenomenon would be implemented in all of the other ponds over the course of the 1560s, and correspondingly across various areas of Aranjuez, to such an extent that it was classified as a ***Special Protection Area*** (SPA) for Birds by the European Union and featured in the Natura 2000 program.

No new dams were subsequently built until the eighteenth century. The Cavina Dam, to the west of Aranjuez, was built on the stream of the same name, an affluent of the Tagus. This is openly assumed to be an imitation of the straight-dam model, even if it lacks buttresses (López Gómez 1998: 21; Díaz-Marta 1992). Though it no longer exists today, its previous function was to irrigate La Flamenca—The Flemish

[6]See the chapter on dams by Carmen Toribio Marín in this book.

[7]The parapets that provided additional support had previously been subject to experimentation by Juan Bautista de Toledo and Pietre Jansen in the Casa de Campo. The buttresses, in particular, had already been built into another dyke in Aranjuez, located at the end of Queen's Avenue, by Juan Bautista de Toledo.

[8]Those traditions extended into the nineteenth century, as is conveyed in the Brambilla report. In the mid-nineteenth century, coinciding with the reign of Isabella II, which was, in fact, the last glorious period of Aranjuez, the sea was cleaned and again served for leisure proposes.

estate—one of the agricultural colonies founded by Charles III, and a number of meadows around the House of Serrano as far as Castillejo, the royal horse pastures. The Cavina Dam additionally took on a supportive role as a source of water for the Las Aves irrigation channel.

Other examples that reversed the distribution scoring of the dam design included the channels that were formed to feed ponds and for raft storage that, in turn, served as irrigation departure channels. The most outstanding example, as planned by Juan de Villanueva, was known as La Mina (the Mine) and consisted of channelling and storing water originating in a mine located in Valdelascasas, southeast of Aranjuez, with its role being water catchment from the mine (Álvarez de Quindós 1804: 321; López Gómez 1998: 144). This contains underground branches running at the level of the elevations south of Aranjuez until they reach El Caramillar, the eastern end of the Secano Orchard (or the Valencian Orchard), and discharge into a pond, known as the Valenciana or Secano pond. This pond was dug to accumulate and distribute water, both to the same orchard and to the Prince's Garden. The retaining wall here acted to rectify and control the Tagus riverbed, the northern limit of the garden. Otherwise, the garden design assimilated the meanders of the river in order to create artificial islands.

The ponds are a constant feature of the Royal sites. Previously a feature of the Yuste Monastery to which Charles I retired, Philip II later delighted in the ponds, whether at La Fresneda, El Pardo, Casa de Campo or El Escorial. Unlike dams, these were constructed away from the river course. Attributed many different functions, Royal site ponds tend to exhibit a geometric shape and are proportionally either closer to or further away from the residential building, in accordance with their respective size. Furthermore, they were tactically designed as imitations of nature. The tension between water in movement and replenished water engenders a landscape of high value, with the location of the ponds usually determined according to orography, thus turning them into a resource, which adds to their enhancement as a landscape feature.

The flatness of the Aranjuez plain led them to be distributed either in small valleys, such as those formed by the Ontígola stream, or in close visual connection with the architecture and the constructed urban settlement. Their functions range from the aesthetic, in which the still water surfaces not only pay tribute to the legend of the Queen of Saba, but also allow for the reflection of architecture, creating a pleasant illusion, to the functional and the essential, both for irrigation and for the containment of the force of seasonal water flows. To these previous functions, we might add a playful and leisurely dimension, beyond that of simple contemplation, enhancing recreational activities such as fishing or regular celebrations. Finally, an important additional role encapsulates the preservation of the ecosystem and the enhanced value of the surrounding landscape.

The first phase in the Aranjuez pond arrangement corresponded to the planning carried out in 1561 by Pietre Jansen,[9] who had experience in his country of origin and had already been entrusted with designing and locating those in the Casa de

[9]AGS CSR, lg. 252.3, fol. 87.

Campo, El Pardo and El Escorial. In these ponds, as in the Ontígola Sea, the islands served as stopover points for migrating birds, a pursuit featured in the Flemish tradition. The project, inspired by the Flemish aesthetic expert, was eventually abandoned, due to the scope of its ambitions. Three distribution zones were nevertheless delimited.[10] A first area was the pasture of Requena, to the west of Aranjuez, in the vicinity of the Tagus, where a dam had already been laid out. A second zone was located along the Alpajés Avenue (near the palatial area, which ran from West to East). Another pond at the end of the same Alpajés Avenue would take on diverse roles, such as for the raising of fish for the pleasure of his Majesty (García Tapia 1990).[11] Additionally, the Ontígola stream would constitute a third area of the project. From this stream, the aforementioned Ontígola Sea was formed.

This stream also provided for the establishment of other artificial lakes suitable for both fish and birds (with special attention paid to falconry) and for hydraulic purposes in this area to the south of Aranjuez. The surroundings of this zone would be complemented by the planting of meadows *in the manner of Flanders* (García Tapia 1990: n. 26).[12] The maintenance of the ponds and their surroundings was entrusted to the Flemish gardener Juan de Holbeque (-1573), also charged with caring for the Ontígola Sea and designing the Flemish-style meadows on both sides of the stream (Fig. 6).

Holbeque also took into account other ponds,[13] which may be identified with the work of another master dyke builder, Adrian Van der Muller, who headed the construction of two other nearby ponds. Eventually, the King refrained from endorsing the construction of that closest to the palace, an action interpreted as proof of respect for the already existing palace plans (García Tapia 1990).[14] The presence of two pairs of swans was intentionally referred to, for instance—reiterating the slightly artificial nature and ornamental aspect of ponds. In any event, these ponds contributed to the landscaping of the immediate palace vicinity. We may wonder whether any of these artificial lakes would be as entitled as the Orchard of the Ponds, running along the Toledo Alley, and, if it were the case, might we then assume that Juan de Holbeque was the designer of this garden, given that he carried out the botanical approach to the Island Garden.

These ponds appear in the aerial view, sketched by Jean L'Hermitte, on both sides of the Toledo Alley, with the birds depicted in great detail (L'Hermitte, 1890–1896).

The 1567 construction by engineer Benito de Morales would begin a new era in the wake of the death of Juan Bautista de Toledo. This phase was characterised by the symbolic replacement of Flemish professionals with Spaniards and witnessed the planning of new ponds, strategically distributed around the neighbourhood of Aranjuez. Morales revisited the idea of placing a pond in front of the palace. The project, considered "a plant so certain that [the fish] can enter and not leave from the

[10]AGS CSR, leg. 251, fol. 133.
[11]AGS CSR, lg. 251/2, fol. 33.
[12]AGS CSR, leg. 251, fol. 133.
[13]AGS CSR, lg. 247.1 fol. 30.
[14]AGS CSR, leg. 252, fol. 28.

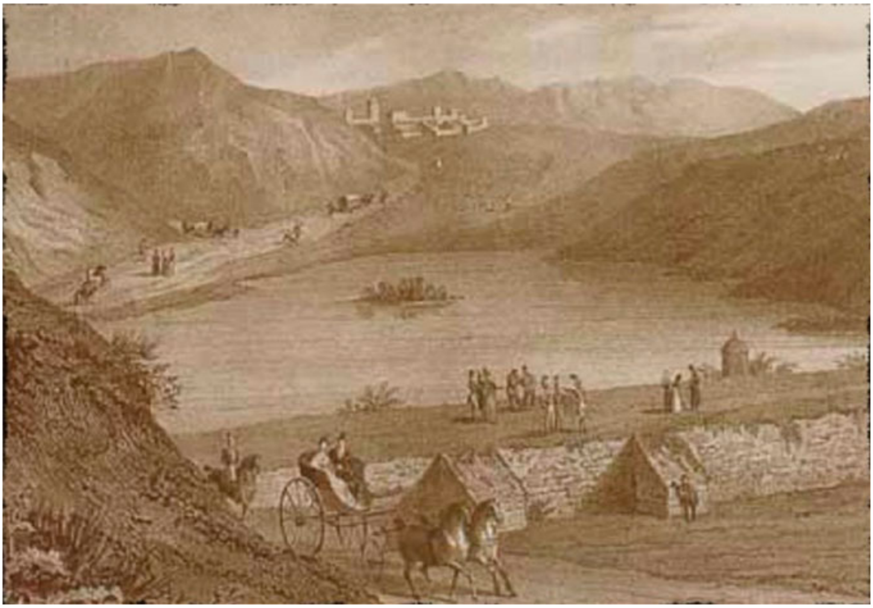


Fig. 6 Fernando Bambilla (paint.) Léon-Auguste Asselineau (engr.), C. 1830; Real Establecimiento Litográfico de Madrid (impr.) Vista de Antigola, con el estanque como es conocida © Museo de San Telmo. San Sebastián, Spain

Jarama" (García Tapia 1990),[15] involved the conjecturing of a pond for the western section of the palace. The reflection of architecture in water features was not alien to the Islamic tradition, as commented upon by Morales during his trips to Andalusia.

Morales furthermore intended to build another pond, "the most beautiful pond and fishery you can imagine," at the estuary's entry between the Island Garden and the palace.[16] To slow down the waters, aesthetic and ludic components were added, including a gazebo and galleries. Restricted access would be ensured by a walkway to the Island Garden, from which fishing could be carried out. The influence of the Hispano-Muslim garden on the work of Benito de Morales is undeniable. This aesthetic component may indicate a deliberate change in Philip II's own personal taste, which was more related to Flemish influence.

Throughout the course of time, the theme of pond construction would again be taken up for eighteenth century Aranjuez. Such was the case of El Deleite (*the Delight*), an agricultural farm near El Regajal and the Ontígola stream, south of the town and built by Charles III. This farm hosted the El Vergel (*the well-stocked garden*), which was oriented towards intensive and specialised agriculture. Around 1790–1791, Charles IV would provide a stimulus to this estate in mirroring the

[15]AGS CSR, leg. 253, fol. 125.
[16]AGS CSR, leg. 253, fol. 83.

project attributed to Pablo Boutelou (Álvarez de Quindós 1804: 312–320; Tovar 1988; Buttlar and Soto Caba 1993: 295–296) that enhanced the values of the surrounding landscape. A belvedere was installed to foster a new framework of reference for contemplating Aranjuez, and was baptised Mount Parnassus. This also provided for an increase in the supply of water. There were two ponds: the upper, in a rectangular shape typical of the Hispanic tradition and feasible for capturing water from the Ontígola stream; and the lower, irregularly shaped and connected to the English garden while playing a more ornamental role (Fig. 7).

This aforementioned imitation of natural lakes would reappear in most of the landscaping interventions that took place in the Prince's Garden under Juan de Villanueva, specifically, in the so-called Chinescos. In fact, the Prince's Garden was under the responsibility of Pablo Boutelou himself, who started out in 1784 by incorporating the pre-existing landscaped surfaces, alongside Anglo-Chinese garden patterns that he had brought back from his stay in Britain. The Prince's Garden is not a conceptual garden like the Island Garden, but rather resulted from the juxtaposition of several gardens that were added over time while surrounded by the Tagus River and the Queen's Alley. Juan de Villanueva designed all of the Chinescos, including a pond with sinuous edges that was enlivened by a grotto, a tholos, an obelisk and a Chinese pavilion, and even had small boats for leisurely trips.

The conformation of such an extensive garden, the largest in Aranjuez, would require the omnipresent and essential control of the Tagus river waters. In this instance, however, in the initial phases of the garden, the meanders formed artificial islands with a large dyke that was built to channel the riverbanks and edges of the garden, and which was given the name of Solera's promenade.

With the exception of the Ontígola Sea, the Palace surroundings—specifically, the dam, the canal and the Castanets Cascade—and the more modern interventions in the Prince's Garden, no further remains of the aforementioned dykes, dams and ponds have survived through to this day.

4 Leisure Utility: Water Management for Production, Science and Leisure

Water then had to be channelled, both for production and leisure purposes. The original channels connected to the mills and dams dotted along the Tagus, whose origins date back to the time of Muslim rule, with their flows, had, first and foremost, a functional character. Furthermore, the channel layout developed by Philip II conveyed a structural function upon the territory. They defined the surface area over which the Aranjuez project had been executed in order to expand the area under irrigation. We should not forget how these channels were intended not only to serve the immediate environment of Aranjuez, but also to supply the entire Aranjuez valley, where economic interests prevailed beyond the Crown properties, ones

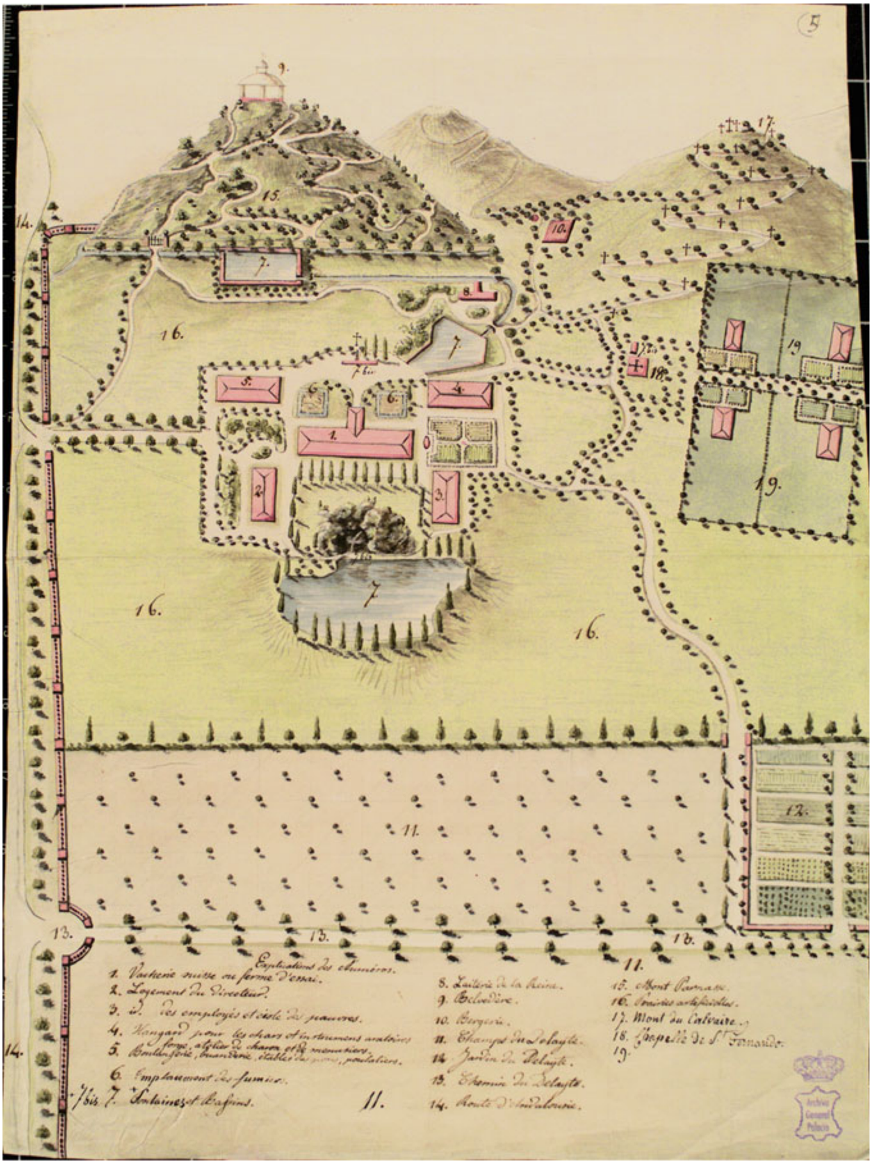


Fig. 7 Pablo Boutelou. Proyecto para El Deleite, 1790–1791; Archivo General de Palacio. Planos, Mapas y Dibujos, © Patrimonio Nacional. Spain

that united neighbouring communities. Petitions addressed to the King dating back as far as 1562 reflect the popular demand and need for a network of canals oriented towards agricultural exploitation, hitherto a characteristic of Aranjuez and one of the earliest hallmarks of this Royal site.

However, the subsequent expansion of this network also contemplated uses that were focused on enjoyment, with leisure activities such as fishing, boat trips on the water and strolls along the river banks. A number of reconstructions occurred, such as the rebuilding of the old irrigation canal and the original source of supply for the Castillejo canal alongside a new channel (the old Requena canal riverbed). All sought to prioritise irrigation in areas where the river's floods had previously caused changes to the river's course, severely damaging the crops along the way (Llaguno 1829, II: 161–162, doc. 1, 6).

At this time, the innovation with the greatest impact was the construction of two irrigation channels or catchment zones on either bank of the Tagus River. Both start at the El Embocador Dam, which was built at the time of Charles I. At first, the Las Aves irrigation channel, also dubbed Sotomayor, took shape south of the river course. Immediately afterwards, the El Rebollo irrigation channel was laid out. In the 1560s, with the assistance of Juan Bautista de Toledo, these two lengthy channels were redesigned to accommodate the irrigation of either fields of crops or the tree-lined avenues. They also provided shaded paths of aesthetic value, designed to facilitate pleasant strolls, along their borders.

The irrigation system was planned in 1581, with important factors at stake, especially economic issues, requiring good project management. However, such factors would also provoke a series of widely documented conflicts, essentially with the town of Colmenar, which later became one of the system's great beneficiaries. While they saw their demands met, they would also be burdened with the cost of canal maintenance.

Historiography has turned the Colmenar irrigation canal into one of the most interesting channelling initiatives of Renaissance Hispanic engineering, as its execution involved the implementation of the most advanced technical principles of this period (Fernández Ordóñez 1991; Corella Suárez 1999). The starting point of the Colmenar canal had been fixed many years before, in 1528, was above the El Embocador dam, near the town of Colmenar, with a section running from the Valdajos dam to the beginning of the Rebollo irrigation channel. The project's great scope not only demanded the collaboration of Spanish professionals, but also that of their international peers. Therefore, this project, originally effected by Esquivel and inspired by the utopian project conceived by Pacciotto for the navigation of the Tagus River between Toledo and Aranjuez, was also worked on by the Spaniards Juan de Herrera, Juan de Castro, Mariano Azaro, Juan Miguel de Torrijos, Jerónimo Gilí, and Francisco de Montalbán, and the Italian Juan Francisco Sitoni.

In the eighteenth century, the connection of this canal with the El Rebollo irrigation channel was extended, due to stipulations from the Real Cortijo in keeping with the subsequent irrigation needs of this experimental agricultural colony. To achieve this, two branches were planned, specifically, the Cola Alta and Cola Baja irrigation channels, which would join together, not at the beginning, as was originally planned, but rather further downstream.

Another important development involved channelling the waters through the Royal Acequia, which was one of the substructures of the water supply system, to the fertile meadow of Aranjuez. Moreover, the Ontígola Sea bore witness to two projects: one contemporary to its construction and another later in the eighteenth century, coinciding with the agricultural expansion policy. In 1572, to bring an end to the construction of the dam and reservoir, a complementary pond for the decantation of water was arranged. This pond may be identified with the precedent established by the Mar Chico (*Small Sea*), the latter dug for water distribution in 1735 (Álvarez de Quindós 1804: 320).

The ditches or irrigation channels around the palace were enhanced by their ornamental function, linked to the garden theme, as a complement to their utilitarian purpose, specifically for the irrigation of vegetal spaces. However, these were small channels that do not have the technical complexity of those such as Las Aves and Sotomayor. Somehow, these channelled aquatic fences, according to a project by Etienne Marchand, not only anticipated the French baroque model that came to be known as *ha-ha*, but are also one of a kind in Aranjuez and in Spain. Dating back to the time of Philip V, the ditches at the Parterre Garden held both playful and enclosure purposes for the exclusive use of the court.

Moreover, the mills also constituted the organising elements of the same physical space, and hence were imitated during the sixteenth century (Arroyo Ilera 1990, 1998). The mills and fulling mills along the Middle Tagus were the foundations of the medieval economy in the Aranjuez region. Besides the mills, the *azudas* (waterwheels) also signalled the course of the river during the Middle Ages and into early modern times. In the eighteenth century, the Azuda de la Montaña would be redesigned and equipped with a channel.[17]

Another purpose of water involves its use as a playful and artistic resource. Water constitutes one of the most suggestive cultural contributions of Aranjuez. This time, it was the laws of mechanics that would serve for the purposes of entertainment. Philip II designated the Ontígola Sea as both an ecological area and a festive destination. The Ontígola Sea had an island, used, as mentioned earlier, as a resting point for migrating birds, and a gazebo, reachable by gondolas and small boats. The earliest examples of water work for leisure date back as far as the sixteenth century interventions overseen by Juan Bautista de Toledo on the Island Garden. The space therein, divided into rectangles, created perpendicular axes into which small open-sky squares were intersected, alongside the installation of ornamental fountains, constituting the most perfect expression of the value of water in a garden. The distribution and location of the fountains was re-conceptualized between 1577 and 1582, which made good use of the variety of types and styles. For instance, there are fountains without sculptural decoration, based on geometric or vegetal themes, with other made of tiles and demonstrating clear Spanish-Muslim influences.

However, the original iconographic program intended for the Island Garden is lost today for a number of reasons, such as the renovation of fountains and the incorporation of various others from other locations. Nevertheless, one can find there the so-called Espinario's and Vertumno's fountains, as well as Hercules' fountain, inspired by the mythological tale of the hero that takes place on an island. Additionally, hydraulic devices that piqued the curiosity of visitors were

[17]Vid. Merlos and Soto, Gardens and Landscapes (forthcoming).

Fig. 8 Aranjuez (Spain) Jardín de la Isla, Irrigation Channel’s Vent.; photo M. Merlos

subsequently built into the garden: sounds inserted into the fountains imitating birdsongs, or court games with hidden jets of water. One of the most striking was the one known as the fountain of four trees, in which the jets, hidden in the tree trunks, reached a great height thanks to the elevation of the Ontígola Sea, the source of its water (Fig. 8).

Recreation on the river became a stimulating experience for the senses, fluctuating between the chromatics of the vegetation and the sounds of water. The origins were undoubtedly sought in the mythical character attributed to the Tagus River. Those who had once enjoyed this river were mythological and fantastical beings living in the groves along its riverbanks, in the Arcadian forests and still surviving in rural written accounts.

Stories by travellers and artistic images document the activities that were ongoing throughout the early modern period, such as fishing, walks along wooded banks, contemplation and bathing (Merlos Romero 2014, 2019).

Navigation became a peculiar source of entertainment. The displacement of the water provided one of the most fascinating ways to allow for contemplation of the landscape, with ever-changing views from new perspectives. The river allowed the idle wanderer to get a closer look at vegetation in its wildest states, such as those visible in groves and along riverbanks. Such an image of nature in motion was incorporated into the staging of courtly events and celebrations that took place on the river, as well as the regular daily boat rides. The latter, in appearance, conceived as simple entertainment, actually resorted to an artistic and aesthetic component that revolved around the design of the boats. For example, Juan Bautista Antonelli's navigability project enabled boat trips from Vaciamadrid to Aranjuez along the Jarama River that provided a delightful cruise centred around festive stopovers along the way and enjoyment of the landscape. Moreover, the navigability achieved by Juan Bautista de Toledo on that stretch of the Tagus River, as it passes through Aranjuez before the rivers again converge, was designed for party celebrations and calm boat rides that allowed people to enjoy the very rich and delightful gardens, vegetation and groves (Soto Caba 2001).

Dance and music also livened up the rides on the Tagus River, which even Philip II participated in. Evening soirees on the water sometimes included music or theatrical plays. As paradigmatic examples, Philip II's walks with his family were enlivened by the music of the *negrillos* (jester dwarves) brought by Sebastián de Santoyo, who played "from the entwined branches and other [musicians] from the riverside" (Cabanes 1829: pp.); or we can note the welcome given by the previously ruling Hapsburg dynasty to Isabel de Farnesio in 1723, with the traditional elegant reception and, in this case, the alleys adorned with triumphal arches, with the centrepiece being a mock naval battle between Turks and Christians (Soto Caba 2001). The boats were luxurious. For these festivities and river trips, golden boats are described by D'Aulnoy (1692).

This culture of water for recreation reached its most sophisticated period in the eighteenth century. The most spectacular boats were those belonging to the Royal Fleet of the Tagus River (Broschi 1758; Morales Borrero 1987), consisting of longboats, frigates and galleons. These heralded remarkable interest, thanks to their unique designs, their organisation as a fleet and the shows in which the boats featured as part of the scenography that acted as a support, not only for the audience, but also the actors, in a magisterial hodgepodge of Italian tastes.

Farinelli, the stage name of Carlo Maria Michelangelo Nicola Broschi, the most celebrated singer of the seventeenth century, was responsible for impressive parties that integrated nature into the musical evenings and moved the scene in conjunction with the waters of the Tagus. Within this context, he designed the parade of royal longboats. Moreover, boat rides consisted of a succession of lighting effects (lampposts, reflections in the water), hunting, fishing, the provision of refreshments and snacks, music, singing and games, all designed to awaken each and every one of the senses (Torrione 1998; Merlos Romero 2019). The banks were lit up by several layers of lights, specifically arranged to form images at certain points, and with the timing of the show announced by cannon salutes. There were public spectators who followed the celebrations and the boarding of the monarchs. The monarchs, Bárbara de Braganza and Ferdinand VI, and Farinelli travelled in the royal longboat, which simultaneously acted as both a stage and seats for the audience while allowing the *Il Castrato song* to be enjoyed by the occupants of the other longboats and frigates.[18]

At the time of Charles III, the royal family actively participated in these river trips (Ponz 1787: 385), be they walks or boat rides, with curious onlookers gaining passing views from the shores (Swinburne 1779: 131–132). Charles IV reoriented the fleet towards another usage, evoking bygone battles between the Turks and the Christians inspired by the war myth of Lepanto. The boats were thus his toys, a children's game worthy of kings, fantasies of past glories that enlivened his times of leisure. Isabella II and her family still enjoyed the longboats for rides, as did Alfonso XII and Alfonso XIII. Indeed, this tradition continued well into the twentieth century.

5 Public Utility: Communication and Transport

The plans that Philip II had for Aranjuez were not limited to the network of utility ditches and the decoration of the gardens around the palace or to the provision of dams, ponds and irrigation channels, or even to the surrounding regional plains and their hidden corners. They also involved a large-scale projection and scope of action, which would be applied across a broader territory. From 1561 onwards, more ambitious proposals were put on the table, such as channels for irrigation that were also navigable, supplied by diversion dams along the Tagus and Jarama Rivers.

The channel system and the transformation of river courses were inspired by existing construction projects in Lombardy and Flanders that strove to achieve a new goal: navigation. This required actions of greater technical complexity, such as the distribution of dams and locks to level out the flow. Both the dams and locks would have to overcome the difficulties deriving from the orographic condition of Aranjuez itself. The scope of the intentions may be understood from the full

[18]For all of these reasons, infrastructures were built in the so-called Sotillo, the future site of the Prince's Garden, including: two navy arsenals, a covered and closed pier, dockyards and barracks for the sailors, a chapel dedicated to Saint Cecilia and a hospital (Broschi 1758).

proposal, dated 1562, that included specifications on the construction of dams, dykes and channels. The solution to drawbacks such as meanders, displacements in the river courses, mills and water wheels would only become possible following the arrival of a group of professionals from Italy in the 1560s. Their extensive technical knowledge put them at the forefront of then-contemporary engineering and their contributions were in addition to those of the Spanish professionals.

The challenges would only be overcome in the medium term, even while some plans would never come to fruition. Its own scope would be determined by the different phases of achievement. Thus, such plans included a court walk in the immediate surroundings of the palace, the displacement between Aranjuez and the capital, through to navigable rivers on the peninsula scale. The navigation project between Toledo and Aranjuez went as far as responding to a higher aspiration, that of reaching Lisbon and forming a model susceptible to application to the entire Spanish hydrographical map. The strategic motivations (commercial, political, military) of Philip II had already been conceptualised by Maximilian of Austria during his brief regency in Spain (1548–1550).

Nevertheless, the first and most modest navigation project was entrusted to Juan Bautista de Toledo in 1561. The project, which was not completed until 1565, stretching between the Alpajés (or Queen's) avenue and the confluence of the rivers, in addition to safeguarding the palace from flooding, was intended to promote the organization of boat rides and court parties. For this purpose, tree-lined promenades were installed along the Tagus and a jetty was built in 1563. The embankment could be reached via an avenue that departed from the end of Alpajés. This project was connected to a previous endeavour, specifically, the aforementioned palisade on the Tagus next to the Island Garden. The system used, of mitre-type locks and *calatoras* gates, was not only a technique that was in effect in Italy and Flanders during the fourteenth and fifteenth centuries, but, with the founding of Aranjuez, served as a precedent for inventions that would take place in seventeenth century France, England and Germany. This navigable section was only one phase in a larger project that the passing away of Juan Bautista de Toledo definitively truncated. It had sought to use the river as a means of transport and communication.

In 1562, the most ambitious navigation project on the Peninsula began. Its scope brought forth the development of one of the great themes of the Renaissance, experiencing its first phase in the formation of a navigable canal between Oreja and Toledo. This would become the starting point for a necessary renewal of the fluvial communications network, which would interconnect the Royal sites with the capital and, on a larger scale, would seek to build connections between Spanish cities. However, this project also responded to a broader concept by Philip II, within the historical context in which Portugal was under the rule of the Spanish Crown. The connection via the Tagus River to Lisbon opened up a route from Madrid, linking it to the Atlantic Sea, and thus to the New World. By encompassing—beyond the limits of the site itself—a broader territorial scope, the project gained a higher value when compared to the prevailing geographical limitations of the Spanish Empire.

The person in charge was a military engineer, Francesco Paciotto, who had arrived in 1562, taking the navigability of the channels of Lombardy as his reference. The inspiration for this task area can be explained by the existing concerns over the landscape and rendering the plain fertile. Among the project's goals, the economic factor, including both agrarian and livestock dimensions, stands out. Such purposes were obviously favoured by the irrigation and transport activities that the canal facilitates. Besides, the recreational functions are assumed, as directly reflected in the fishing and river walks or indirectly by the pleasant walk along the riverbank. Pacciotto sought to enhance the latter with trees and ponds. Unfortunately, the engineer did not delve into any of the project's technical issues, such as those derived from the winding course of the river. By painting an idyllic image, the project did not extend beyond utopia, and correspondingly did not come to fruition. Consequently, Philip II, after requesting opinions from a wide group of experts—Pelegrín, Jansen, Gilí, Juan Bautista de Toledo and Master Esquivel—dismissed the project, especially because, in spite of claiming that it would control the river, it would actually entail an excess of intervention in both nature and the river itself.

The idea of expanding the navigation network through incorporating the Jarama would come from the work of the Italian military engineer Juan Bautista Antonelli in 1581. Although Paccioto's project had already been dismissed, the same political and economic interests propitiating these initiatives prevailed in the mind of Philip II. Made possible by reconnaissance of the course of the Tagus between 1581 and 1582, Antonelli travelled between Lisbon and Madrid before concluding that the provision of dams would render such a project possible. In 1584, documented royal voyages were organised by this engineer's nephew, Juan Antonelli, along the Jarama and Tagus Rivers (Cabanes 1829: 87). Despite being feasible from the technical point of view, it would never be undertaken. The main problems were the towpaths and the prevailing lack of resources. This did not, however, prevent this plan from becoming the benchmark for a series of interventions that continued into the nineteenth century. The first was immediate: the aforementioned Jarama's Canal. In 1641, during the reign of Philip IV, a new reconnaissance of the Tagus, this time led by Martelli, took place in order to survey the navigability of the river between Lisbon and Toledo (López Gómez 1998).

Approximately one century later (1755), another exploration of the Tagus, broadly in keeping with the Carlos de Simón Pontero project, obtained the approval of the engineers José Briz and Pedro Simo. The project was then promoted by minister Ricardo Wall and significantly coincided with the reign of Ferdinand VI and his wife, the Portuguese Bárbara de Braganza. Thus, this project may be placed into close context with the founding of the *Tagus Fleet*, a symbolic *internal/local/short-ranged* stretch of navigation in Aranjuez, aimed at courtly entertainment, featuring the famous boat trips and longboat concerts organised by Farinelli (Torrione 2000).

During the reign of Charles III, this utopia was again revisited under the guidance of the Company for the Navigation of the Tagus. There would be still more attempts, including a thorough inspection of the downstream river section by Juan de Villanueva. The last attempt was that of Cabanes, who, in 1828, in pursuing the recognition of architect Agustín Marco Artu and the projects and experiences obtained by all of his predecessors, wrote a feasibility report that conclusively turned out to be positive (Cabanes 1829: 342). The diary of the round-trip between Aranjuez and Lisbon determined the necessary interventions. Firstly, it proposed alleviating the river course's slope through recourse to the pre-existing dams (some sixty were counted between Aranjuez and Abrantes) (Cabanes 1829: 12), with improvement works to backwaters and the formation of an alternative channel in difficult areas, such as that of the Tiétar River. Furthermore, there were also talks about protecting the dams and mills through *carrerones*, or inbuilt canals, and their corresponding system of sluice-gates, with double gates or side channels for sites hosting large dams (such as the passage through Toledo).

This project unearthed the causes of certain problems, brought about by previous failures, such as the supposed damage to mills and private landowners. Moreover, the feasibility of navigation was also contemplated in conjunction with boosting agriculture and trade in Talavera, Toledo and Aranjuez. Aranjuez still remained both the starting point and the destination. The project, which had even guaranteed the involvement of Portugal (de Cabanes 1829: ap. 176),[19] was nevertheless left paralysed by Spain's internal political situation.

6 Conclusions

Aranjuez requires interpretation as a scenario that is open not only to utilitarian, scientific and technical creativity, but also to playful and artistic originality, in which the antagonistic *otium* and *negotium*, as expressed by Alberti, are able to harmoniously coexist. In this scenario, the lead protagonist is water.

Clearly, the economic and productive function of this great hydraulic system determined the conformation of Aranjuez. In addition to the agricultural products and the fisheries, the same gardens assumed a utilitarian function, which reached beyond the selection and arrangement of species, their care and maintenance. Ever since the Philippine era, not only was the stimulation of the senses and production sought, but also, alongside scientific experimentation and practical applications, strikingly evident in the botanic and vegetable gardens.

Ever since the sixteenth century onwards, the confluence in each and every one of the eras of aesthetic movements, fostered by both Spanish and international professionals and artists, has endowed a cosmopolitan atmosphere on Aranjuez, making it an exception in early modern Spain. Simultaneously, the patronage of the Crown meant that this Royal site would bear witness to the arrival of some of the most outstanding artists, both national and from other European courts.

[19]August 31st, 1829, Lisbon. Tratado concerniente a la navegación del río Tajo, celebrado por los Soberanos de España don Fernando VII, y de Portugal don Miguel I.

Philip II's development of Aranjuez might only be comparable with that carried out by Charles III in the eighteenth century. Phillip II would correspondingly be remembered for benchmarking an important antecedent of the spirit of the Enlightenment era. It is thanks to every construction project since the sixteenth century that the survival of Aranjuez has been possible to date, first of all, as an heir to the medieval legacy, and then as a departure point for early modern age innovations. The transcendence of this system, still in usage today, remains a key factor in understanding the water management of the Tagus River.

The technical innovations made in Aranjuez both opened and closed a cycle that still remains, not especially due to having fulfilled its utilitarian purpose, nor even because of the modern image that it transcends, but particularly because of the ongoing and lasting recreational facet of this site. Nowadays, the hydraulic system represents a benchmark in water and cultural heritage management.

Reference Works

Alvarez de Quindós, J. A. 1804. *Descripción histórica del Real Bosque y Casa de Aranjuez.* Madrid: Imprenta Real.

Arroyo Ilera, F. 1990: "Los molinos del Tajo en el siglo XVI según las Relaciones Topográficas de Felipe". *Estudios Geográficos.* XI, pp. 259–272.

Arroyo Ilera, F. 1998. *Agua, paisaje y sociedad en el siglo XVI, según las Relaciones Topográficasde Felipe II.* Madrid: Ed. del Umbral.

Aulnoy, M. C. (Comtesse d´). 1692. *Relation du Voyage d'Espagne*. La Haye: Chez Henri van Bulderen.

Broschi C. (Farinelli). 1758. *Descripción del estado actual del Real Teatro del Buen Retiro de las funciones hechas en él desde el año 1747 hasta el presente: de sus individuos, sueldos sin cargos, según se expresa en este primer libro. En el segundo se manifiestan las diversiones que anualmente los Reyes Nrs. Sres. En el Real Sitio de Aranjuez. Dispuesto por Dn. Carlos Broschi Farinelo Criado familiar de S. M. Año de 1758*, Madrid, Biblioteca de Palacio, Mss.

Buttlar, A. & Soto Caba V. 1993. *Jardines del Clasicismo y el Romanticismo. El jardín paisajista*. San Sebastián: Nerea.

Cabanes, F. J. de. 1829. *Memoria que tiene por objeto manifestar la posibilidad y facilidad de hacer navegable el río Tajo desde Aranjuez hasta el Atlántico, los… de esta empresa, y las concesiones hechas a las mismas para …la navegación.* Madrid: Impr. de D. Miguel de Burgos.

Corella Suárez, P. 1999. *La real acequia de Colmenar de Oreja en tiempo de Felipe II y sus relaciones con el entorno*, Madrid: Instituto de Estudios Madrileños.

Díaz-Marta, M. 1992. *Cuatro obras hidráulicas antiguas entre la Mesa de Ocaña y la Vega de Aranjuez.* Toledo: Caja Toledo.

Fernández Ordóñez, J. A. et al. 1984. *Catálogo de noventa presas y azudes españoles anteriores a 1900.* Madrid: MOPU.

Fernández Ordóñez, J. A. 1991. *Catálogo de treinta canales españoles anteriores a 1900.* Madrid: MOPU.

García Tapia, N. 1990. *Ingeniería y Arquitectura en el Renacimiento Español*. Valladolid: Universidad de Valladolid, Secretariado de Publicaciones.

Garcia Tapia, N. & Rivera Blanco, F. J. 1985. "La Presa de Ontígola y Felipe II"en el siglo XVI", *Revista de Obras Públicas,* 236, pp. 477–492.

González Tascón, I. 1987. *Fábricas hidráulicas españolas.* Madrid: MOPU.

L'Hermitte, J. 1890–1896. *Les Passetemps de… Mémoires d'un gentil-homme de la chambre de Filippe II.* Amberes.
Llaguno y Amirola, E. 1829. *Noticias de los arquitectos y arquitectura de España desde su restauración.* Madrid: Imprenta Real.
López Gómez, A. 1998. La navegación por el Tajo: el reconocimiento de Carduchi de 1641 y otros proyectos. Madrid: Real Academia de la Historia.
Luengo Añón, A. 2008. *Aranjuez. Utopía y realidad. La construcción de un paisaje.* Madrid: CSIC, IEM, Doce Calles.
Merlos Romero, M. 1998. *Aranjuez y Felipe II: idea y forma de un Real Sitio*. Madrid: Consejería de Educación y Cultura de la Comunidad de Madrid.
Merlos Romero, M. 2001. *Aranjuez, paisaje cultural Patrimonio de la Humanidad.* Madrid-Barcelona: Lunwerg.
Merlos Romero, M. 2014. *Aranjuez, imagen de un mito romántico*. PhD diss. Universidad Nacional de Educación a Distancia, Facultad de Geografía e Historia, Departamento de Historia del Arte.
Merlos Romero, M. 2019. "Imagen festiva de Aranjuez: los cambiantes escenarios del rey". In: *El Rey festivo: Palacios, Jardines, Mares y Ríos como escenarios cortesanos (siglos XVI-XIX). IMAGO. Anexos, Revista de Emblemática y Cultura Visual*, 7, 2019, pp. 175–208.
Merlos Romero, M. & Ordieres, I. 2013. *El Real Cortijo de San Isidro y su integración en el Paisaje Cultural de Aranjuez.* Madrid-Aranjuez-Alcalá de Henares: Comunidad de Madrid, Ayuntamiento de Aranjuez, Universidad de Alcalá.
Morales Borrero, C. 1987. *Fiestas Reales en el Reinado de Fernando VI.* Madrid: Patrimonio Nacional.
Morán Turina, J. & Checa Cremades, F. 1986. *Las casas del rey. Casas de campo, cazaderos y jardines. Siglos XVI y XVII.* Madrid: Ed. El Viso.
Ponz, A. 1787. *Viage de España, en que se da noticia de las cosas más apreciables y dignas de saberse, que hay en ella.* Vol. VI. Madrid: Vda. de Ibarra, hijos y cía.
Rivera Blanco, F. J. & García Tapia, N. 1985. "Juan Bautista de Toledo, Jerónimo Gili y Juan de Herrera, autores de la mar de Ontígola", *Boletín del Seminario de Estudios de Arte y Arqueología de la Universidad de Valladolid*, 51, pp. 319–342.
Segura Graíño, C. 2009. "Construcciones hidráulicas en el río Tajo en la actual Comunidad Autonoma de Madrid. Siglos XV al XVII". In: *Actas del Sexto Congreso Nacional de Historia de la Construcción* (Valencia, 21–24 octubre 2009). Madrid: Instituto Juan de Herrera, pp. 1337–1343.
Soto Caba, V. 2001. *Aranjuez, un paisaje para el recreo*. Aranjuez: Ayuntamiento de Aranjuez.
Swinburne, H. 1779. *Travels through Spain, in the years 1775 and 1776.* London: P. Elmsley.
Tárraga, M. L. 1991. "Santiago Bonavía, arquitecto hidráulico". In: *Cinco siglos de Arte en Madrid (XV–XX).* Madrid: Alpuerto. pp. 97–106.
Torrione, M. 1998. *Crónica festiva de dos reinados en la Gaceta de Madrid (1700–1759).* París: Ophrys.
Torrione, M. (ed.) 2000. *España festejante. El siglo XVIII, Actas del Congreso Internacional* celebrado en Málaga, 6–8 de noviembre de 1997). Málaga: Universidad de Málaga.
Tovar, V. 1988. "Consideración al valor de lo "rústico" en los Sitios Reales (reinado de Carlos III)", *Fragmentos,* 12–13–14, pp. 219–231.

The Water that Passes Through Alcoa and Baça: The Hydraulic System of the Monastery of Alcobaça

João Alves Puga

Abstract

This monastery, with its presence effectively defining the town of Alcobaça, provides an exemplary case of the Portuguese territorial layout, both in its balance and in the relationship between the genius loci that the local territory offers and the new, human-constructed landscape. Adopting water as the key natural resource, the monks of Alcobaça applied its use with wisdom and mastery in the most diverse fashions. Water not only becomes a frequent presence on the macro-agricultural scale of the *Couto Alcobacense*, but also appears in places of symbolic meaning, such as the cloister's *lavatorium*. The members of the religious community were referred to as farmer-monks, also deriving from the core Benedictine principle of "*Ora et Labora*" that was in effect at this Cistercian monastery; furthermore, they applied the empirical knowledge of agronomic science and improved the techniques that would subsequently change the territories of their application.

1 Introduction

The English aristocrat, politician and travel writer William Beckford gave a clear description of the beauty and excellence of the Alcobaça environment, alongside the prominence of water as an intrinsic factor:

> Here every object smiled; here every rood of land was employed to advantage, the Lombard system of irrigation being perfectly understood and practiced. Every cottage, apparently the abode of industrious contentment, had its well-fenced garden richly embossed with gourds

J. Alves Puga (✉)
Centro Interuniversitário de História das Ciências e Tecnologia, Faculdade de Ciências, Universidade de Lisboa, 1749-016 Lisboa, Portugal
e-mail: joaopugaalves@gmail.com

A. Duarte Rodrigues and C. Toribio Marín (eds.), *The History of Water Management in the Iberian Peninsula*, Trends in the History of Science,
https://doi.org/10.1007/978-3-030-34061-2_14

and melons, its abundant waterspout, its vine, its fig-tree, and its espalier of pomegranate. (Beckford 1835: 164)

Although not unique in Portugal, Alcobaça represents one of the most relevant examples of national monastic heritage and, perhaps, also the best expression of its centuries-long relationship with its surrounding territory and its symbiosis with the natural resources contained in this landscape.

The Monastery of Alcobaça thus represents a relevant case study on Cistercian communities within the scope of Portuguese history. This especially arises due to a prevailing series of atypical factors interrelated with its topography, its vulnerability to floods, especially the great flood of 1772 (Tavares 2003), and the sediment-alluvial deposits and landfills created by the monks that also altered the river's course. All of these changes in the landscape brought about episodes in the monastic complex settlements that were not intentional. The recourse to irrigation processes and the hydraulic energy used in the mills during the Cistercian and post-Cistercian periods derived from adapting the hydraulic knowledge applied to changing the territory that determined the prevailing structure of Alcobaça in an inheritable way. Hence, from around the end of the seventeenth century and throughout the following century, a period that characterized the Modern Age, the Cistercian monks embarked on this genuine transformation of the landscape in adapting it to human permanence. They transformed unproductive lands into remarkably productive agricultural fields. This regenerative capacity of the agronomist monks achieved notice and recognition by the order's chroniclers, who proposed it as an example of excellence, as opposed to the generalized state of abandonment that then afflicted the country.

The history of the Monastery of Alcobaça was initially written by two leading protagonists. Firstly, Afonso Henriques, who led the armies at the Battle of Ourique in 1137, had also recently conquered the cities of Santarém and Lisbon (1147), and, in 1143, with the Treaty of Zamora, gained recognition of its independence from the Kingdom of Leon and Castile before then seeking papal recognition. Secondly came Bernard de Clairvaux, the French abbot and great reformist leader of the Cistercian order, who held remarkable power in the Christian world at the time of the monastery's foundation. The historic coincidence stemmed from the Duchy of Burgundy, the birthplace of the paternal ancestors of Afonso Henriques, being interlinked with the founding of the order.

The Alcobaça complex was established in the coastal zone of central Portugal, more specifically, in the district of Leiria, located about 110 km from Lisbon, in the Lusitanian Basin, a sedimentary basin of clays, limestone and sand (Rebelo and Cunha 1991).

The building of the monastery and all of its other secondary support structures duly took into account the existing territory. Examples of such planning include the Quinta da Chiqueda, planted with oaks and cork oaks and with the presence of water then enabling the installation of gardens, workshops and mills and the monastic fences (in the fourteenth century, there were two, the interior and exterior walls) that provided access for the monks to enjoy the waters along the course of the irrigation channel on the south and west sides of the river, which later came to be called Baça.

Fig. 1 Main Facade of the Monastery of Alcobaça. Photos by the Author, 2016

1153 marks the beginning of this Couto, with the construction of its abbey occurring a quarter of a century later, in 1178, prior to an existence marked by extreme natural phenomena over the course of centuries. Such examples would include the 1329 earthquake that caused the partial destruction of the monastery, especially the kitchen and dining room. However, the eighteenth century saw the two events that had the greatest impact on this region: the 1755 earthquake that "… manifested itself in all the lands of Alcobaça and especially in Chiqueda, where the sources of the Alcoa River and beautiful Poçoão were completely dry." Secondly, the great flood of 1774, which, in his contemporary description, Friar Viterbo portrays as follows: "… a memory of the breathtaking inhabitants and never forgotten: it has done terrible damage to men, animals, walls, bridges and paths. In fact, this flood was responsible for the disappearance of many of the remains of the Roman settlement of Helcobatice" (Fig. 1).

2 Hydrography

The geography of this municipality is defined by its enormous hydrographic network, with numerous crisscrossing water lines, rivers and streams flowing down to the Atlantic Ocean, especially the Alcoa and Baça rivers, the two main rivers of this region. The first is characterized by its source, which varies across different locations in narrow and deep valleys (Tomé 2016), while the Baça River, smaller in scale, flows in the opposite direction to the Alcoa.

It is therefore not surprising that, at the time of its founding, the *Couto de Alcobaça* operated four seaports, which later disappeared due to the retreat of the Atlantic that consequently brought about the end of these shipping channels.

The routes of the rivers in contemporary Alcobaça differ from those of the medieval period. On the one hand, the Alcoa River was deviated in the seventeenth century to allow for the construction of the Cardinal's Cloisters and the Rachadouro, with an abrupt change in the river's direction when it arrived at the present district of the Lameirão, taking a 90° turn, with the river having since adopted a straight course, as opposed to its irregular layout elsewhere. The Baça River is also believed to have been diverted to its present course, leaving the left bank running in parallel with the Monastery facade. As we look closer, we become more aware of the confluence between these two rivers. On the eastern side of the monastery, the Alcôa River joins the Baça River on the western side, ultimately meeting and merging into the Alcobaça River, which crosses its path on route to the Atlantic coast.

The extent of the Alcôa River, within the scope of the Pederneira Lagoon, once played a much more extensive role in the landscape than that which we observe today. It ran through the territory for a few kilometres, almost reaching the Maiorga area.

In order to minimize the effects of flooding, downstream work took place to regularize the river flows, alongside controlling irrigation processes, particularly in the extensive Campo do Valado fields.

New watercourses were established, particularly in the sixteenth century, with the movement and containment of the Alcoa River and, in all likelihood, the Baça River as well.

This extensive and dedicated work was implemented in the eighteenth century with knowledge from the field of hydraulics, its applicability resulting in the conversion of coastal areas and wetlands into highly productive agricultural farmland.

3 The Monks of Alcobaça

Also known as agronomist monks, they performed remarkable work that had first started out in close collaboration with King D. Dinis in the last quarter of the thirteenth century within the framework of his agrarian policy (Gonçalves 1997).

This collaboration between the Cistercian community and the king was an effort to claim dominion over the formerly inhabited territories of the region of Extremadura, developing them in both agrarian and economic terms, with the establishment of villages and with the associated objective of highlighting the presence of the Portuguese Kingdom in lands that had, in the past, been occupied and dominated by different enemies. The Alcobaça monks initially began to implement the settlement, with the help of Letters of Population issued by King Dinis, in Extremadura, hitherto a region of polycultures, and particularly in the Couto de Alcobaça domains. The monks, with the help of the new settlers of Alcobaça, thus contributed to implementing and improving the cultivation of vines in conjunction with olive trees (Natividade 1942).

The monks also defined which crops would be grown and where, recording them on settlement maps. Furthermore, whenever these places did not feature on the Couto Charter, the monks would study the soils and their qualities to decide as to whether they were better suited to vines or cereals, with the latter being a tradition that dated back to Roman times, in this case, wheat and barley (Caldas 1998).

For all such reasons, the monks of Alcobaça played a highly important role in regional development through their way of life and their interactions with their lands in agronomic and agricultural terms, as well as their capacity to convey all of this knowledge, in terms of cultivation techniques, to the settlers of this region (Fig. 2).

Fig. 2 Cistercian monks mowing the field under the protection of the Virgin and St. Bernard. Detail (Painting—Portuguese School, 1620; Authors: Domingos Vieira Serrão & Simão Rodrigues)

All of the aforementioned qualities of the Cistercian monk prevailed in their choice of location and the setting up of the extensively built structures of the Couto of Alcobaça.

According to the Order's constitution, in its definitive version issued in 1119 at the assembly denominated the First General Chapter of Cister (Martins 2011), the monastery was to be built in such a manner that its internal organic structure was to contain everything necessary to their existence, specifically: water, mills, orchards and gardens, and workshops for the respective trades, in order to ensure that the monks did not need to emerge from their domains.

From the perspective of Ellen Arnold, "the desire to encounter an isolated landscape was accompanied by a sense of importance around converting that desert so as to ensure it was apt for human purposes." Additionally, these premises that guided the Order, as well as the desire to build a system of resources that would enable the monks to be autonomous in accordance with these basic guidelines, required solid and widespread technical support from many fields of knowledge.

Furthermore, in order to put all of this knowledge into practice, the common sense or accumulated experience of a particular group of monks would not be enough. There would also be a need to attain scientific knowledge beyond that which was passed down orally, making recourse to the specific scientific literature that had been acquired over decades to enrich the collections of its libraries. While the most notable students of the Franciscans, Dominicans and Augustinian hermits were able to continue their studies at universities outside of the country, in particular, in Oxford and Cambridge, the Cistercians of Alcobaça and other monasteries, by determination of the Order's General Chapter, went to Paris and Salamanca. Alcobaça was to become the center of education for all Portuguese Cistercian monks. In 1458, a studium was founded for the teaching of Grammar and Logic. However, it has since been verified that the Cistercian monks dominated other areas of knowledge as well, in particular, agronomy, architecture and hydraulic engineering, with this latter field being reflected in the drainage and drying works of Paul de Ulmar in Leiria, supervised by Friar Martinho, the king's deacon, in 1291 (Gomes, 2000). In the tradition of Lombardian irrigation practices, this system consisted of the drainage of previously occupied areas by rivers that, through a system of dams and channels, allowed for the exploitation of these lands for agriculture. Beginning in Italy in the twelfth century with works on the River Ticino, these irrigation schemes gradually extended to other rivers that drained into the Po from the northern lakes (Smith 1976).

There is no clear current recognition of the rules, statutes and instructions necessary for the execution of such complex works alongside all of the technical procedures deployed that incorporate the field of hydraulics for its in praxis application. Furthermore, without the application of arithmetic and geometry (belonging to the Quadrivium), undertaking such technical exploits would never have been possible. Furthermore, understanding how the knowledge that circulated orally among the craftsmen involved in the construction of these monastic complexes took place would lead us to a better perception of all of these dynamics.

These doubts around the dissemination of the knowledge acquired by Cistercian monks led Joaquim Vieira Natividade to posit one possible hypothesis as being the oral diffusion of knowledge among the pilgrims or monks from different European countries or on pilgrimages to Rome. This may represent the most consensual hypothesis in which the empirical knowledge of the monks was not only disseminated as a result of their pilgrimages between monasteries and convents across Europe, but also because of their knowledge of the works that existed in their bibliographic collections. Translations of works by Democritus, Xenophon and Theophrastus or the treatises of authors such as Cato, Varro, Columella, Palladio and Vergilus contained the knowledge necessary for the application and development of the agricultural techniques applied by the monks (Caldas 1998). Such is the example of the "Agriculture Treaty" of Abu Zacaria-Iahia, known as Ibn al-Awwam (twelfth century), which would become one of the fundamental works for the development of many agricultural techniques due to its richness and diversity of content. According to Eugenio de Castro Caldas, "Abu Zacaria, to elaborate his treaty, according to declarations, drew from texts by more than thirty authors from the Middle East, Greeks, Romans and Arabs…".

On the one hand, the Arab tradition reveals a new scientific perspective. In the field of hydraulics, it discloses innovative solutions, in particular, the devices powered by animal traction, the wind-powered water pumps, storage in reservoirs, and the establishment of irrigation channels with their consequent diversion of flows for irrigation, in addition to the application of the cogwheel in the milling systems that functioned in the factories located alongside the watercourses.

On the other hand, the scientific knowledge developed initially by the Romans was fundamental to the extraordinary levels of agricultural productivity achieved by the farms belonging to the "Couto" of Alcobaça. This incorporated theoretical agronomic knowledge into the practical actions that included: soil preparation being considered and segmented in several phases, including breaking the soil up and sanitizing it, the systematization of solar observation practices and the successive distribution of crops. With the rise of the Cistercian Order, as a consequence of the counter-reform of the Benedictine Order, their monks began to specialize and diversify, especially in the agronomic field. All of this knowledge drove the initiative of the monks who settled in contemporary Portugal, firstly, in the monastery of Tarouca, then in Salzedas and Lafões, Aguiar, Fiães, Ermelo, Bouro and Júnias, thus establishing the farms that attained the highest rates of productivity among all of those in the Alcobaça region. These same farms also functioned as general agricultural schools, perfecting all of the activities that then underwent application. Through wisdom and the mastery of the existing water resources, they were able to fully apply their knowledge to the most diverse aspects. Such knowledge became a frequent presence in the macro-agricultural scope of the Couto of Alcobaça, as well as in places of predominantly symbolic meaning, for example, in the cloister lavatory. These were the "agronomist monks," applying the core Cistercian principle of "Ora et Labora" alongside unprecedented recourse to the empirical knowledge of science applied to transforming the landscape, and consequently improving the techniques that were in effect, which would then change the territories of their application. It thus proved possible to tangibly implement the knowledge learned from agricultural or hydraulic treaties, giving rise to a very late historical period when the productive capacity surpassed expectations, the fruit of the work of both these dedicated monks and the surrounding community that adapted to their management becoming an exemplary case of sustainability and autonomy.

4 The Structure of Couto of Alcobaça

The Couto de Alcobaça had a well-defined functional structure (Fig. 1). As a macrostructure, it first extended across the so-called Couto[1] (Enclosure), which contained other substructures that constituted part of its functioning and sustainability. Considering that most of this territory was initially occupied by forested areas, these agricultural farms were only created gradually, functional units that allowed for administering the entire monastery complex. Contained within this initial structure, there later appeared a monastic fence, composed of a larger exterior and then an interior, the latter in greater proximity to the buildings adjoining the gardens. Finally, there was the complex nucleus that contained the main structures (monastery and church) (Fig. 3).

Fig. 3 Categorization of Monastic Domain Spaces. Infographics by the author, 2016

[1]The word "Couto" defines the perimeter that contains all of the lands of the monastic territory under study and that we here refer to as the monastic enclosure.

Having been signed by Afonso Henriques in 1153, the Couto Charter formalized the donation of its territorial boundaries, delineated to the north by Leiria, to the south by Óbidos and to the west by the Serra dos Candeeiros, spanning an area of 108,680 acres (44,000 ha).

The diversity of activities within the Couto would allow for the range of production that contributed to its quasi-self-sustainability. The proximity of the Atlantic Coast, through the Pederneira Lagoon, gave rise to structures that were directly linked to the sea. Examples include the seaports that ensured the shipment of products or the landing of certain otherwise unattainable raw materials. Naval yards were also set up for the construction or repair of ships and salt production. As a result of these dynamics, the landscape was bountiful. The olive trees provided the olives that, through their transformation in the mills, gave rise to excellent quality olive oil. The production of large quantities of wine led to the construction of cellars to provide storage and the abundant cereal crops gave rise to thirty-seven barns. In addition, the mills, known as "booms," were used to give greater consistency to fabrics or tanneries. There were also the lime kilns, the kilns that produced tiles for the construction of the buildings, the metallurgical units for producing tools and, finally, the pottery production facilities. Joaquim Vieira Natividade drew a map featuring a total of 14 farms in the municipality of Alcobaça (Natividade 1885).

The agronomic sciences applied on these farms derived from the deep knowledge of the classical and modern treatises of agronomy associated with a network of information exchanged among both the Order's abbeys in Portugal and at the European level. This enabled the fostering of excellence and innovation throughout this area. This knowledge was reflected in improvements to the techniques for working the earth and the introduction of new species of cultivation that generated significantly increased harvests (Natividade 1922). This was then complemented by the plantation of olive groves of such importance that the 1314 letter of settlement of Turquel contained specific guidance on them.

The parish of Vallado dos Frades hosted one of the best agricultural schools, and its population was almost entirely dedicated to working the land. With the abolition of the religious orders in 1834, this was then transferred to the Royal Estate.

Located in Évora de Alcobaça, one of the first agricultural schools was set up to meet the initial needs of the Couto of Alcobaça, even though it only existed for a short period of time.

Ataíja de Cima and Ataíja de Baixo delimited the great olive grove of the monks and Cella, one of the extinct villages of Couto, had, in the early days, hosted its own agricultural school.

In the parish of Maiorga, next to the St. Vicente hermitage, there was a fountain "…whose waters were effective in eye diseases, specializing in ophthalmic conditions."

In turn, Fervença parish stood out for the quality of its waters, not only in their agricultural applications, but also at the medicinal level, especially in regard to treating herpes infections to the detriment of the hot springs in Caldas da Rainha.

Quinta do Vimeiro, located in the parish of the same name, included an extensive forest of oaks (Matta Coutada), and the Granja de Turquel, on a larger scale, was described as having woods, vineyards, olive groves, orchards and fields.

Located near the source of the Alcoa, the population of Chiqueda was especially dedicated to milling, taking advantage of the river's water, which was subdivided in order to power the water mills.

In this parish, the estate spans an extensive forest of cork oaks, which was a dependence of Quinta do Vimeiro that belonged exclusively to the monastery of Alcobaça.

The Granja de Turquel was greatly renowned for its vineyards, olive groves, orchards, fruit farms and, especially, for Quinta do Orjo, with its lands returning generous harvests of cereals.

5 The Monastic Fence[2]

In the fourteenth century, there was both an outer fence and an inner fence. The alteration in the location of the Santa Maria de Alcobaça Monastery came about due to the increasing presence of fugitives from justice in the vicinity of the fifteenth century monument. In 1506, King Manuel I passed a decree authorizing these fugitives to go to the parish of Vestiaria while still under the same legal protection. However, either because they distrusted the validity of this guarantee or because they benefited from the resources of the bakery (eating the bread that they produced), as well as the opportunity to visit the monastery pharmacy to cure any illnesses that they may have contracted, the fact is that the fugitives did not leave this site. Out of desperation, and already into the seventeenth century, King Afonso VI decided to re-implement the fence, giving rise to the city of Alcobaça, with some vestiges of the original fence still being observable today. These provide examples of what remains of the Obelisco and Murtas gardens. The installation of these monastic fences allowed the monks to draw water from the course of the irrigation channel running to the south and west sides of the river, which later came to be called the Baça.

The monastic fence, despite its supposed monumentality, did not escape changes over the course of time, both in terms of its area and its uses. Everything becomes even more complex at this point, due to the difficulty of obtaining documentation from this time that is capable of transmitting information about the organization of this monastic space in Alcobaça. However, in keeping with better preserved models, such as the Clairvaux Abbey in France, it is possible to ascertain an approximate working model of the historical past of the Monastery of Alcobaça.

[2]The landscape feature denominated in Portuguese as the "*Cerca Monástica*."

6 The Main Building

The Mother House of the Cistercian Order in Portugal, this huge building, with 47,000 m^2, is one of the largest Portuguese monastic complexes. Its construction began in 1178 and continued for several decades, with monks moving into the building in 1223.

This structure contains the most extensive Gothic church in Portugal, running 100 m in length and with its layout taking the form of a Latin cross. The chapter room, the refectory, the monks' rooms and the dormitory date from the thirteenth and fourteenth centuries, while the famous kitchen was built at a later date, in 1752. Classified as a UNESCO World Heritage site since 1989, Alcobaça is a structure that now displays a different configuration to that initially constructed, having undergone numerous modifications throughout its existence, especially in the sixteenth and seventeenth centuries. Firstly, the sixteenth century saw the expansion of the monastery eastwards, while the complete reform of the west wing took place in the late sixteenth and early seventeenth centuries with the transformation of the converts' wing and the completion of the church's frontispiece in 1725. This latter set of significant changes was only completed in the second half of the eighteenth century with the construction of apartments for the Abbot General of the Congregation of Alcobaça, located in the Southwest section (Maduro 2015).

Furthermore, a set of vicissitudes occurred over time and served to profoundly alter the monastery's existence. The earthquake of 1755 caused severe damage to the monastic complex, before the already mentioned great floods of 1772. No less serious was the destruction brought about by the French invasions in 1811, which consequently led to a financial crisis from which there was no return. The culmination of all of these ruinous events came in 1834 with the abolition of religious orders in Portugal that first triggered the looting of its collections by the inhabitants of Alcobaça, before its subsequent conversion, firstly into a prison, then into barracks, before finally into administrative offices.

7 The Monastic Garden

The gardens constitute an integral component of any monastic complex while being categorized into two distinct types. On the one hand, there are gardens circumscribed within built spaces, the so-called garden cloister, with a central focus, generally a fountain or well, marking the division of the space into four equal parts, analogous to the Four Rivers of Paradise. The gardens of the Alcobaça cloisters fall into this framework, with William Kinsey describing to us that "the square garden in the center of the cloisters is planted with cypresses, orange trees and a variety of beautiful shrubs, and contains the fountain which supplies water to the washbasin immediately in front of the cafeteria" (Kinsey 1828: 432) (Figs. 4 and 5).

Fig. 4 D. Dinis Cloister. Photos by the Author, 2016

Fig. 5 Cardinal Cloister. Photos by the Author, 2016

On the other hand, there are the much larger-sized gardens, with their spaces enclosed by walled features that contain orchards planted with several different fruit trees (especially lemon and orange trees), small woods, gardens and medicinal gardens that adjoin the infirmary areas that were generally located near what we call here the monastic fence. As the cloister garden held a much more thoroughly defined symbolic and contemplative character, the forbidden garden served as a space for the development of thought while the monks enjoyed their daily walks, simultaneously playing a therapeutic role for those who fell ill and needed healing. These were the places where monks grew vegetables to satisfy their food needs, but also where they planted the flowers that served to adorn the altars, in spaces where the beauty of the gardens reflected the splendour of Paradise (Macdougall 1986).

Over time, some gardens disappeared, both in their designs and boundaries, as is the example of the Myrtle Garden, "which was above all, the most artistic garden of the monastery, adorned with caves, of good marbles" (Natividade 1885: 98), and which today hosts a cemetery.

We should also emphasize the care with which the larger areas and the paths that interconnected the various spaces within the monastic fence were treated in landscaping terms, in particular, the 899 m long space between Rua Grande and Levada, "…a vast and exquisite garden, composed of long avenues of weeping, acacia, cedar and ailanthus, erected on a long tablecloth of plants and flowers, embellished by statuettes" (Macdougall 1986: 97).

8 Kitchen Gardens and Orchards

The kitchen gardens and orchards were areas of excellence and were fundamental for the sustainability of the monastic complex, ensuring the production of numerous vegetables and fruits, which particularly required, especially in the kitchen gardens, constant daily care and the application of numerous horticultural techniques that enabled intense cultivation and excellent crop yields (Martins 2015). These kitchen gardens, unlike other forestry crops, required an efficient and bountiful irrigation system for the intended level of production, which was generally ensured by the presence of a waterwheel or irrigation channel, alongside abundant tree growth that benefited from proximity to plentiful water. Among Beckford's numerous descriptions, he stated that, "From this immense sea of green leaves rose a number of plum, pear, orange, and apricot trees; the latter procured by the monks directly from Damascus, and bearing, as I testify, that most delicious fruit of its kind called 'eggs of the sun' by the Persians" (Beckford 1835: 29).

9 Vineyards

The Alcobaça monks also made an enormous contribution towards viticulture through applying and perfecting several ancestral techniques, including means of digging, cutting and pruning. The rigor and care in planting the vineyards turned them into places that reflected a splendid image of the landscape and were described at the time as follows: "The wide latticed windows of the apartment allotted to me commanded the view of a boundless vineyard in full luxuriant leaf, divided by long broad tracts of thyme and chamomile, admirably well-kept and nicely weeded" (Beckford 1835: 29).

10 The Meaning of Water and the Hydraulic System

The entire structure of the Couto of Alcobaça, however, depended on an element that was at its genesis and without which nothing could be accomplished: water.

As water has always represented a determining factor conditioning the existence of all humanity, it has, through its redirection and reconditioning, similarly enabled communities, particularly the monastic communities of the Middle Ages, to meet their basic needs, whether for hygiene or the production of everything else necessary for their existence and continuity in built complexes.

> The stratification of the Cistercian Society and the hierarchy of its spaces were paralleled in their management of water and its separation between rivers, channels and pipes, each with its own physical characteristics, its own flows, quotas, controls and risks and different purposes. (Tavares 2014: 210)

In addition to the physical dimension, water has also always held a spiritual meaning, and the utilisation of mechanisms associated with the hydric resources that existed in the monastery fashioned this cultural connection. Medieval Christianity, for example, associated water with spiritual fertility, healing, and religious conversion (Arnold 2007). All of this water-based symbolism led to the location of Cistercian monastic complexes in places "near streams, where, by channels or dams, they used the driving force or channelled the waters to fertilize lost lands" (Korrodi 1929: 26). This magnificence of the relationship with water described here also implied responsibility for respecting the will imposed by this element, hence also adaption to the episodes of flooding caused by the nearby rivers or streams. Correspondingly, the monks often had to build landfills or artificial platforms for such situations so as to avoid buildings collapsing and, when the water courses were farther away, the work carried out would be the reverse: diverting water lines, building dams, raising levees, drainage and regulation of the currents (Tomé 2016).

The application of the "good triangle" rule implemented the three vertices that were deemed fundamental for any monastic complex. The first vertex was that the area should contain good foundations that were able to secure the buildings, without any danger of the constructions coming to a precocious end. The second vertex demanded that the site should be well served by rivers or other water lines able to cope with the hydraulic mechanisms that would contribute to the desired productivity rates. Finally, there needed to be an area of relatively flat zones for the implementation of the Cistercian Plan (Tavares 2014).

The Alcobaça hydraulic system was thus established and consolidated through the intervention of the monks, involving the implementation of a network of channels spanning several categories of watercourse. There would be the "channels for the adduction of community buildings and for the evacuation of water, channels for the production of the hydroelectric energy necessary for mills, sawing mechanisms, pumping stations, forges and other industrial equipment, channels related to the diversion of rivers and streams, with two basic purposes: field drainage, and a view to their recovery for agriculture" (Maduro et al. 2017: 96).

Upstream of the monastery, the water supply system extended over two kilometres. This spanned two fundamental elements: the irrigation channel, which experienced major flows, and the channelling of drinking water via limestone pieces, carefully placed, whether on the surface or in underground galleries, so that they might be periodically maintained. While the irrigation channel served industrial production, washing and power generation facilities, the pipeline met needs that required better controlled water quality.

The water mills, which once totalled forty in number, are now almost all extinct. However, one or two well-preserved examples of this very specific heritage have been safeguarded, so that we can today observe the richness of these lands in their peak years.

In the center of Alcobaça, there are also traces of this heritage related to water, perceptible, to a greater or lesser extent, as interrelated with the presence of the Alcôa and Baça Rivers. From the imposing stone gutters that run along the streets of downtown Alcobaça, the channel then passes underneath one or another building in the center of the village, or even supplies a fountain discreetly located near a particular building.

The natural resources of the region, and, in particular, the two waterways, Alcôa and Baça, became fundamental, firstly for the building of the monastic complex and, from there, for disseminating the interconnected structuring poles that created the Couto of Alcobaça (Figs. 6 and 7).

One of the driving forces of the Alcobaça monastic domain was the Alcôa River. This was the river that, after changing its course, then divided in two, near Alcobaça, with one section passing through the middle of the monastery cloister before arriving in the village. The local hydrographic structure clearly delineated the richness and diversity of Alcobaça, rendered visible in the monastery's structures, with the parishes distinguished by their functional specificities.

Monastic hydraulic engineering reached well beyond the diversion of streams or springs, instead being characterized by the implementation of intricate channel and drainage systems that sustained these monastic complexes and guaranteed their habitability by providing drinking water and disposing of waste waters. Ellen Arnold provides the example of the Maulbronn monastery in Germany, with a water channel that runs through the whole complex, and with its subterranean,

Fig. 6 The Baça River. Photos by the author, 2016

open-air canals containing at least one mill along their course, one of many examples in Europe (Arnold 2007).

All of the activities developed by the monastic communities had to be delineated in keeping with the hydraulic system and, therefore, designing a viable and efficient scheme across the different functional requirements constituted a great challenge. It

Fig. 7 The Alcôa River. Photos by the author, 2016

was first necessary to set up a drinking water network through recourse to extraction via mines or wells, the water then being channelled through an externally insulated plumbing system that was stored in cisterns or tanks before its final distribution throughout the various zones of the complex, such as the fountains, washbasins and kitchens. Alcobaça thus incorporated a base structure enabling the utilisation of water, whether for domestic purposes, fish farming, agriculture or the powering of hydraulic mechanisms.

Alcobaça was itself supplied by an underground system of running water beginning 3.5 kilometres away on the site of Chiqueda de Cima, southwest of the village, although there is also some uncertainty over the existence of a spring well within the monastic fence that may have contributed to the decision to construct the complex there. However, the most important water line created was the irrigation channel that was connected to the Alcoa River, which not only provided a greater flow for the irrigation, but also powered the forges. Due to the irregularity of the flows, which rose in the winter before falling away in the summer, the monks needed to build a dam to regulate the water levels. Although this dam still remains in perfect condition, other sections of the water system have changed over the years, whether as a result of programmatic changes in the complex or due to landslides (Tomé 2016). These descriptions, resulting from observations made locally (Maduro et al. 2017), are, in many cases, difficult to decode, as the passage of time has modified these constructions, and the lack of written documentation, in some cases, forces us to formulate purely hypothetical solutions. However, the descriptions of the Alcobaça hydraulic system deserve our analysis and study of the various constituent parts, thus enabling a line of reasoning based on the available information that may more accurately gauge the reliability of the monastic hydraulic system structure. One of the most important facets of this structure was the irrigation channels that supplied water to the existing fields, orchards and kitchen gardens. There were synergies arising from these irrigation channels, specifically, the link with the fruit trees that benefited from the irrigation of the kitchen gardens. These spaces often contained, and Alcobaça would be no exception, a water point, a waterwheel (of Arab design), a dam or irrigation channels arriving directly from the river and designed and implemented by specialist monks called "openers" (Martins 2015). These devices constituted the primary structure of irrigation that then gave way to the farmers who administered the secondary channels. Finally, it was the task of the peasants to maintain these functional channels, which would become blocked during the winter as a result of the strong currents and debris carried by the heavy rains of that season. The level of water circulation in the channel network was insufficient, and retention correspondingly fundamental for times of greater scarcity, especially the drier summer period. This led to the installation of sinks or cisterns that would hold this water for farmers to use when needed. Two important sinks still remain visible today, both on Quinta de Vale de Ventos, which was once one of Alcobaça's monastic farms. The first, called Pia da Serra, covered an area of 15.00×9.00 m and was 3.00 m in depth, built out of blocks of limestone and covered by a cradle vault. This cistern is particularly interesting in terms of construction, given how it takes full advantage of the function for which it was built: it includes a small window in the smaller walls to obtain water via a bucket and a small exterior sink in a limestone block for the cattle to drink from, alongside a patio to collect rainwater for this same cistern through carved grooves on the floor. This would have served as a watering point for the livestock and, eventually, for the irrigation of sweet lime and orange orchards

(Maduro 2015). The other tank, called Pia do Olival, located about 800 m from Pia da Serra, was built in masonry and spanned 56.00 × 29.00 m, with a maximum depth of 3.50 m. We know that this was built in the third quarter of the eighteenth century by Luiz Pereira (Ribeiro 1908: 154) and with the key function of irrigating the extensive olive groves planted in the previous century, as well as some vegetable gardens and orchards (Souza 1929). Also forming part of this structure were the Alcoa river mills established on some of the Couto de Alcobaça farms. Such was the case with the four-stone mill and the six-sided mill of Quinta da Chiqueda, the three-stone mill of the Quinta das Freiras de Cós, and the Fervença factory. With the abolition of the monastic orders in 1834, these hydraulic engineering works were sold at a public auction, and many had been destroyed or had their uses changed by the end of that century. As we approach the interior of the monastery, the path of the waterways soon becomes clear, especially in the cloisters.

In the four existing cloisters, and although water remains the consistent source for the magnificent lavatory, it is in the Cloisters of the Cardinal and the Novices that the presence of water is most greatly felt, due to the channel that is fed by the irrigation channel arriving from the Rio Alcôa.

The water-related architectural details are a constant presence, be they testimony of the past, like the gargoyle mounted over the washbasin (*lavatorium*), which functions as a rainwater collection point, or resulting from contemporary interventions, such as the calcareous gutters that delimit the geometric design of the cloister's parterres.

If there is one built space that especially welcomes the water flowing through the channel, it is undoubtedly the majestic monastery kitchen, with its large sinks and famous water tank. Beckford (1835: 37–38) said, in his book *Recollections of an Excursion to the Monasteries of Alcobaça and Batalha*: "I verily believe, the most distinguished temple of gluttony in all Europe, my eyes never beheld in any modern convent of France, Italy, or Germany, such an enormous space dedicated to culinary purposes. Through the center of the immense and nobly groined hall, not less than sixty feet in diameter, ran a brisk rivulet of the clearest water, flowing through pierced wooden reservoirs, containing every sort and size of the finest river-fish."

From 1726 onwards, water made its presence felt in the Obelisk Garden, in the fountains lined with green tiles and white Moleanos stone and in the monastery kitchens beginning to fill their tanks with drinking water from the Chiqueda mine.

11 Conclusion

Over the course of Portuguese history, Alcobaça and its monastery have undergone continuous changes, a consequence of both climatic conditions and human intervention, in particular, the attempts at conquest by invading countries. The natural conditions were often adverse, especially flooding and the horrendous earthquake of 1755, which left deep marks. In relation to the direct actions of man, we encounter two destructive dynamics afflicting the monastic complex. On the one hand, the actions carried out by Napoleon's troops during the French invasions and, on the other hand, the uncontrolled looting by the local population, which, as mentioned above, following the 1834 abolition of religious orders, irreversibly stripped away the great heritage held by the monastery.

Particularly remarkable was the excellence of the monastic library, which dazzled with its richness, its bibliographical content rigorously described by Manuel Vieira Natividade in 1885. Furthermore, today, despite all of these historical vicissitudes, it remains a respectable collection, distributed among several institutions (Giurgevich & Leitão, 2016), notably the National Library of Portugal.

Since 1989, Alcobaça has become one of the great examples of landscape and monastic architecture, with state institutions and civil society participating in carrying out a series of initiatives to recover and preserve this extraordinary monastic heritage of Portugal.

References

Arnold, Ellen F. 2007. "Engineering Miracles: Water Control, Conversion and the Creation of a Religious Landscape in the Medieval Ardennes", *Environment and History*, Vol. 13 (4): 477–502.

Beckford, William. 1835. *Recollections of an Excursion to the Monasteries of Alcobaça and Batalha*. London: Samuel Bentley.

Caldas, Eugénio de Castro. 1998. *A Agricultura na História de Portugal*. Lisbon: Empresa de Publicações Nacionais, Lda.

Giurgevich, Luane, & Leitão, Henrique. 2016. *Clavis Bibliothecarum: Catatálogos e Inventários de Livrarias de Instituições Religiosas em Portugal até 1834*. Lisbon, Secretariado para o Estudo dos Bens Culturais da Igreja.

Gonçalves, Maria Beatriz. 1997. *Os Monges de Alcobaça e a Política Agrária de D. Dinis*. MA (History), Universidade Federal de Goiás.

Gomes, Saúl António. 2000. In: Gouveia, António Camões, *et al*. (Series Ed.) *História Religiosa de Portugal: Vol 2. Vivendo a Palavra de Deus: Escolas Conventuais*. Lisboa: Círculo de Leitores.

Kinsey, William Morgan. 1828. *Portugal Illustrated*. London: Treuttel, Würtz, and Richter.

Korrodi, Ernesto. 1929. Monumentos de Portugal - Alcobaça. Porto: Litografia Nacional

Macdougall, Elisabeth B. 1986. *Medieval Gardens*. Washington D.C: Dumbarton Oaks Research Library and Collection, Harvard University.

Maduro, V. 2015. "A Construção da Paisagem Hidráulica no Antigo Couto Cisterciense de Alcobaça", *Cadernos de Estudos Leirienses*, N.º4: 29–60.

Maduro, V. et al. 2017. "O Ordenamento Hidráulico no Território Cisterciense de Alcobaça", *Riparia* 3: 95–126.

Martins, Ana Maria Tavares Ferreira. 2011. "Minimalismo Cisterciense: Del Cister del Siglo XII al Minimum del Siglo XXI". In: Cobian, Esteban (Ed.), *Proceedings of the Congreso Internacional de Arquitectura Religiosa Contemporánea*, held in Ourense, Spain, 12–14 November 2009, p. 112–117.

Martins, Pedro. 2015. *A Evolução Morfológica e Funcional dos Coutos do Mosteiro de Alcobaça – Uma Experiência De Ensino*. Internship report (History and Geography), Universidade de Coimbra.

Natividade, Joaquim Vieira. 1922. *Região de Alcobaça – Algumas notas para o estudo da sua agricultura, população e vida rural*. Lisbon: author's edition.

Natividade, Idem. 1942. *Os Monges Agrónomos do Mosteiro de Alcobaça*. Leiria: Tipografia Alcobacense.

Natividade, Idem. 1885. *O Mosteiro de Alcobaça (Notas Históricas)*. Coimbra: Impressa Progresso.

Rebelo, F., & Cunha, L. 1991. Relevo de Portugal. In: *Enciclopédia temática de Geografia*. Lisbon: Edições Portugal Moderno. pp. 13–27.

Ribeiro, José Diogo. 1908. Memórias de Turquel. Porto: Typ. Universal

Smith, Norman. 1976. *Man and Water: A History of Hydro-Technology*. London: Peter Davies Limited.

Souza, José Pedro Saldanha Oliveira de. 1929. Coutos de Alcobaça: as cartas de povoação. Subsídios para a História da Agricultura em Portugal. Lisboa: Tip. Inglesa

Tavares, Pedro. 2003. "Água e Património Construído", *Revista Pedra & Cal*, N.º 18: 16–18.

Tavares, J. Pedro Duarte. 2014. "William Elsden, O Mosteiro e Alcobaça", *Revista de Estudos Anglo-Portugueses*, N.º 23: 203–250.

Tomé, Mariana Martins. 2016. *Study of the presence of the order of Cistercian in Portugal and its relevance to landscape architecture*. MA (Landscape Architecture), Instituto Superior de Agronomia, Universidade de Lisboa.

Noras, Norias and Technology-of-Use

Ana Duarte Rodrigues and Magdalena Merlos Romero

Abstract

Focusing on a specific device used widely across the Iberian Peninsula, this paper demonstrates how *noras, norias* and water wheels were fundamental devices for irrigating fields, even while often being mutually confused and misunderstood. Based on a comparative approach between *noras* in Portugal and *norias* in Spain, we argue that these words do not refer to the exact same kind of device, highlighting the characteristics specific to each country and, consequently, reshaping the historiography that approaches the history of water on the Iberian Peninsula as a whole. Moreover, in following David Edgerton's conceptual framework of 'technology-of-use,' this paper furthermore argues for a change in perspective, as it emphasizes the role that *noras, norias* and water wheels played along an extended timeline beyond the dates of their respective invention, incorporating the new innovations that came along as they were duly appropriated, transformed, and adapted to the different situations prevailing on the Iberian Peninsula in the early modern period.

A. D. Rodrigues (✉)
Centro Interuniversitário de História das Ciências e Tecnologia, Faculdade de Ciências, Universidade de Lisboa, 1749-016 Lisboa, Portugal
e-mail: amnrodrigues@fc.ul.pt

M. Merlos Romero
Archivo Municipal de Aranjuez, Ayuntamiento de Aranjuez, Spain
e-mail: mmerlos@madrid.uned.es

A. Duarte Rodrigues and C. Toribio Marín (eds.), *The History of Water Management in the Iberian Peninsula*, Trends in the History of Science,
https://doi.org/10.1007/978-3-030-34061-2_15

1 Introduction

The word *na'ura* stems from an Arabic origin, but the devices it identifies are no the same everywhere at any point in time. Nevertheless, *noria*, the Castilian word that derives from *na'ura*, has been associated with the Iberian Peninsula as a symbol of the golden past of al-Andalus. Translated as and often confused with water wheels, the history of *nora* and *noria* still needs clarification, despite the interest of international historiography in the technology deployed to elevate water and/or produce energy, focusing especially on their origins and technical aspects (Bennett and Elton 1899; Curwen 1944; Forbes 1955–56; Reynolds 1983; Cressier 2006).

Due to the long duration of Islamic dominion and its great influence over the Iberian Peninsula, water management and practices in Portugal and Spain remained somewhat removed from those of the rest of Europe in terms of hydraulic history (Magnusson 2001: xi). The words *nora* in Portuguese and *noria* in Castilian appeared within the context of al-Andalus. As mentioned, they have since been confused with waterwheels, although they are not a perfect match. Water wheels are devices that serve to lift water no matter the source, the respective kind of energy or even the final purpose of its utilisation. The words also appear to be associated with other systems for grinding grains, such as watermills. The relevance of water wheels as the most important source of power from Antiquity until the eighteenth century is reflected in the complex legislation that was enacted in almost all European countries for the control of rivers (Derry and Williams 1960: 253). Nevertheless, their usage in the Muslim world was largely restricted to irrigation.[1] Moreover, the two words are not applied to exactly the same devices in Portugal and Spain. We would thus argue that, while both shared a common heritage and technological culture, given their heterogeneous and multi-cultured uses, they should not be understood as having a homogeneous history.

As the history of technology has been dominated by innovation, rather than knowledge transfer, Spanish contributions have remained in a subordinate position, even though recent decades have seen a shift in the focus of historiography (Maldonado 1990; García Tapia 1990; ; Glick 2005; Cressier 2006; Inkster and Calvo 2010). The Spanish case has not only gained greater attention in international historiography than the Portuguese input, the whole has also been extracted from the part. In Portugal, despite the considerable output on the history of water that has emerged in recent decades, there is still no comprehensive study on water history.[2] Furthermore, the benchmark comprehensive study on traditional hydraulic water-lifting systems stems from the field of ethnography (Dias and Galhano 1986).

[1]Except for Norway and Greece, irrigation techniques and their support devices were developed only on the Iberian Peninsula, as some crops cannot grow in the region without watering during the dry season.

[2]Some studies have been conducted on water management in monastic enclosures (Quintela 1998; Jorge; Xavier 2011), as well as on the hydraulic technology used in gardens and villas (Rodrigues 2011; Castel-Branco 2010).

Topical approaches focus on the role of technology in society, in keeping with Edgerton's conceptual framework (2011). We wish here to apply this to earlier periods in order to identify how the transfer of knowledge to different sites and cultures fostered different applications of the same technology, different epistemologies and, ultimately, different innovations. Furthermore, we argue that to analyze technological transfers, both from Antiquity and from al-Andalus, into the early modern Iberian landscape simply as a process of imitation or adaptation is to underestimate the difficulties and challenges that the builders of water devices confronted. Although the principles of these hydraulic systems are quite simple and have endured for more than a thousand years without significant changes, the adaptation to the specificities of each site, their structures, and the choices of hydric resources and distribution routes all demanded high levels of creativity that reach far beyond the concept of adaption and, in some cases, rank as innovations in their own right. Based on this viewpoint, we therefore argue that the water technology process of transfer required professionals and imitation, appropriation and adaptation, all of which together strove for innovation.

In the first section of this paper, we approach the origins of different devices for lifting water, some of which were described by Vitruvius, specifically analyzing the words deployed by the scholar responsible for translating *De Architectura* from Latin into Portuguese (Vitruvius and Maciel 2006). The second part establishes the different devices identified as *nora* in Portuguese and *noria* in Castilian. Following Pamela Smith's conceptual framework, in order to reconstruct the historical techniques of constructing, experiencing and knowing *noras* and *norias*, we gathered a wide variety of sources to counterbalance the lack of any clear nomenclature. A certain type of *nora* correspondingly stood out as the Portuguese *nora*. Therefore, we decided to discuss the specificity of the *noras* with buckets, their Moorish origin and the impact in Portugal from al-Andalus up until the twentieth-century. In the third part of this paper, we tackle the multiple devices that use similar technological concepts and that are merely translated as watermills in English. Moreover, we discuss several documents that highlight their usage and ownership. The fourth section then addresses this topic through the 'technology-of-use' concept, portraying the different uses that were based on the same technology, alongside the emergence of new devices, some of them unique to Portugal. Should empirical developments characterize innovations in this context, these inventions and novelties had already been subject to registration in the Spanish kingdom by a Book of Patents dating to the early modern period.

2 *Na'ura* Beyond Arabic Origins

The transformation of the rectilinear movement of a stream into the circular motion of a vertical wheel with blades, and with buckets in the rim, thereby raising the water to a height equal to its diameter, which may be of considerable size, constituted an important discovery of technique that had been put into practice since ancient times. *Shadufs, noras, norias* and water wheels constitute part of a wide range of devices that have been applied to lifting water in different regions of the world since the early years of human settlement.

For the early history of power, Terry S. Reynolds provides a definition of the vertical undershot and overshot wheels, the *noria*, the primitive horizontal impulse wheel and the water lever, forewarning that the relationships existing between them are difficult to grasp (Reynolds 1983: 14). Furthermore, based on the scant existing archeologic, iconographic and literary records, he concludes that the vertical undershot watermill, the horizontal watermill and the *noria* appeared at the same time in the Mediterranean in I B.C., and likewise in China (Reynolds 1983: 18–20), thereby reviewing the previous position of scholars that the appearance of these devices had taken place sequentially (Troup 1894; Bennett and Elton 1899; Curwen 1944; Usher 1954; Forbes 1955–56; Moritz 1958). Despite the several references to water-powered mills made by Roman authors—Stabo, Lucrecius and Vitruvius—, the specific identification of each device is mostly impossible (Reynolds 1983: 17).

Reynolds considers that the *noria* probably preceded the vertical and horizontal watermills, as it was probably originated in the arid regions of the eastern end of the Mediterranean (Reynolds 1983: 25). Moreover, he inscribes the vertical undershot mill as being a development that emerged out of the *noria* (Reynolds 1983: 25).

Reynolds furthermore defines the *noria* as a form of undershot water wheel, which activated no machinery (such as gears or millstones) beyond itself. The *noria* was then composed of a large vertical wheel, sometimes reaching as much as 50–80 feet (15–25 m) in diameter, "equipped with radial blades which rotated the apparatus as they were impacted by the flowing water in which the lower portion of the wheel was immersed" (Reynolds 1983: 11–13). Additionally, the bucketed *noria*, used as a metaphor to explain the rotation of the heavens by Lucretius, was commonly encountered in the rivers of that period (Reynolds 1983: 17).

Notwithstanding that the Portuguese word *nora* and the Castilian word *noria* derive from the Arabic word *Na'ura*, this leads to misapprehensions as regards the origins of these devices. Misperceived as being of Islamic origin, hydraulic systems for lifting water had, in fact, been operational ever since Antiquity.

International historiography has consecrated the Vitruvius work *De Architectura* as the first primary source describing a *nora/noria*. This does not mean that Vitruvius—or any other Latin author—was the inventor of the water wheel for raising water, as he was certainly inspired by the wheels in use in the Ancient Eastern World. Vitruvius describes a vertical water wheel with a horizontal axle and pots attached around the wheel, turned by animal power, the inspiration for which must have been the 'Persian Wheel' or *saqiya* (Derry and Williams 1960: 250). For the wheel to work, it was imperative that there be a current of water strong enough to rotate the rope and raise the water. Such devices therefore only functioned in rivers with flows that continued even during the summer, when irrigation was most necessary. As not all rivers naturally offer these conditions, the practice emerged of guiding the water towards the wheel by means of a wide, but increasingly narrowing, channel.

In Syria, one can still encounter such solid wooden devices on the Oronte River, sometimes gigantic in dimension, that raise the river water to the top of high stone aqueducts that then channel the flow to the lands requiring irrigation. Mohammed El Faïz states that there is a strong affiliation between the water wheels in Syria, on the River Oronte, and the water wheels in al-Andalus, based on their similarities (El Faïz 2005: 258). However, the fact that the first rulers of al-Andalus came from Syria means that many Arabic hydraulic machines were probably then disseminated across the Iberian Peninsula within this context.

In Chapter Four of Book 10, Vitruvius addresses the various devices that were invented to lift water and describes the way in which they were built. He points out the *tympanum*, which could be used in salines, as well as for irrigating gardens (Vitruvius and Maciel 2006: 373–374). He also describes a waterwheel, which should be as high as the level to which the water is to be conducted, while also stressing how the cups/buckets are to be fixed on the outside of the wheel (Vitruvius and Maciel 2006: 374)—and this remains a major difference when compared with the Islamic waterwheel, which has the cups/buckets affixed inside of the wheel. The device that Maciel translated as 'nora' was the one that Vitruvius described as "rotae axe involuta duplex ferrea catena," in keeping with its double iron chain and the buckets hanging in such a way that they rose above the axis before rolling over to launch the water into a reservoir (Vitruvius and Maciel 2006: 374). The device was thus appropriate for distributing water to high levels.

In chapter five of Book 10, Vitruvius then describes waterwheels, which dispensed with human intervention, as they were moved by the force of rivers. These were translated into Portuguese as *rodas de travessas* and were called *azudas* in Castilian. Other watermills, such as *hydraletae*, were identified as being *azenhas* in Portuguese, which derives from the Arabic word *as-saniya*, even though the device already existed in the Greek-Roman period (Vitruvius and Maciel 2006: 374–375). He stresses that these differ from the water mills, translated as *moinhos* in Portuguese, as they may have an exterior wheel, but their movement derives from a vertical axis based on a feather caster that rotates through the force of the water conducted along a gutter. In an eighteenth century Portuguese language dictionary, the definition given to *azenha* focuses on the same difference from mills, as the latter have wheels with reeds and the former do not. Moreover, while the mills were established near rivers, the *azenhas* were located on streams (Bluteau, Vol. I, 1718: 694), as they were in Spain as well.

In Europe, hydraulic wheel technology was largely applied in mills and mines. The physical evidence for the earliest watermill is located in Greece, which included a water wheel that used water to create energy to power a mechanical process able to grind small quantities of grain (Wikander 2000). This watermill, known as the Greek or Norse mill, featured a vertical axle, which had a series of scoops or vanes at the lower end; these passed upwards through the millstones, before turning the upper stone. Despite being called Greek, these mills might actually have originated in the Near East, even while they were unknown in Egypt and Mesopotamia (Derry and Williams 1960: 250). However, one can be certain that the Romans played a very important role in the dissemination of the watermill along both shores of the Mediterranean, with some of these devices still shaping the European landscape. The Barbegal watermill in southern France, considered the biggest ancient mill complex, included a total of 16 water wheels and stands as evidence of the complexity that such watermills attained in the Roman Empire (Sellin 1983: 91–109).

However, while we are unable to assert that water wheels were used on the Iberian Peninsula during Roman times, it is only natural that this would have happened.[3] Many authors, nevertheless, maintain that the dissemination of these devices here is due to the Arabs and, among Iberian speakers, this hypothesis receives backing from the consideration that the words *nora* and *noria* derive from the Arabic term *na'ura,* which means "la que llora, la que gime" ("the one who cries, the one who groans"), in line with the way that the constant beating of the water on the pallets produces a sound similar to someone crying (Dias and Galhano 1986: 189).

Mohammed El Faïz states that the terminology of water wheels needs clarification. He correspondingly points out how experts often confuse *norias* with other different engines for lifting water, such as the *saqiya, saniya*, known as the Persian wheel (El Faïz 2005). He argues that an Arabic text from the twelfth century has already clarified this discussion: "If the machine (the wheel) is very large," wrote Ibn Hishâm al-Lakhmî (dec. in 1181), "round and embodying the paddles that increase the action of the flow, if it moves exclusively by hydraulic energy, it is called a *noria*. This engine only functions on a river. It produces a sound when it rotates (*swwayt*) from where derives the name *noria*" (El Faïz 2005: 117–118). Moreover, the author states that it had 80 buckets hanging from it and that each of them carried 7.65 litres. Taking these numbers as his starting point, El Faïz states that a *noria* could irrigate circa 588 hectares during winter and 117.6 hectares during summer[4] (El Faïz 2005). However, we would consider that this definition based on a twelfth century Arabic text does not close the topic to such an extent that *noras* and *norias* can actually be said to refer to different devices in Portugal and Spain.

3 *Noras* and *Norias*: Not Exactly the Same

As a territory, al-Andalus acted as a springboard for developing and intensifying every water-related technique and system. Between the twelfth and fourteenth centuries, the Arabs were the "Masters of Water," as they prevailed as the world's leading experts, not only in lifting water from rivers and wells, but also in diverting, channeling and distributing water through *qanats* and canals (El Faïz 2005).

[3]They are not mentioned in Quintela et al. (1986).

[4]These numbers are described by the twelfth century author, but, as he does not include either the wheel's diameter or the speed of rotation, this calculation is merely an estimative.

The water management undertaken in Madinat al-Zahra or Alhambra, Granada, reveals an expertise that is incomparable even with that of the cities of other sophisticated civilizations (Maldonado 1990: 18). Large aqueducts, in keeping with the Roman tradition, complex water devices able to elevate the water from the Darro River up to Alhambra, the large reservoirs such as La Buyara in Seville and the open-air channels that distributed water through the entire complex in a wise and sustainable way underpin the fame and renown of the leisure and vegetable gardens of this palatine urban nucleus. Alhambra and Generalife became the paradigm for sophisticated Arabic garden art, contemplated and imitated both by Christians and Muslims on both shores of the Mediterranean.

In al-Andalus, agriculture, along with its need for irrigation, generated the driving force behind the main hydraulic projects. Following William Dunmire, the expertise in water management provided the grounds for the "Islamic green revolution" (Dunmire 2012). On the Iberian Peninsula, many crops are unable to grow successfully without recourse to artificial irrigation, particularly during the dry summer months. Control over the irrigating of fields was enabled through the demarcation of gravity flow canals from rivers or springs to fields and gardens, and especially by extracting water from wells through the deployment of technological devices such as pillories and animal-powered *noras/norias* (Quintela 1996: 16).

Moreover, we know that the study of this technology and its multiple uses constituted major concerns for Muslim scholars. The theoretical framework of the "Islamic green revolution" is mirrored both by treatises on agriculture and by books on hydraulic engineering, with both describing and explaining *noras/norias.* For example, Jazari'*s Book of Knowledge y de los dispositivos ingeniosos* (ca. 1206) includes drawings of multiple versions of water mills and *noras/norias*. Additionally, the Andalusian school of agronomy was flourishing, as demonstrated by the treatises by Ibn Wafid and Ibn Bassal at Toledo; Al-Khayr, Ibn Hadjdjadj and Ibn al-Awwam at Seville; and Ibn Beithar at Malaga.

The Muslim agronomist Ibn Al-Awwam wrote a treatise in the twelfth century through which we can trace water devices such as wells, *norias*, and running water channels (Ibn Al-Awwam 1864: 117 and 129). *Noras*/*norias* appear as a common technology for lifting water, reflecting the widespread dissemination of this hydraulic device. Ibn Al-Awwam does not mention any Roman devices, with his work referring only to the Nabataean influence and experiments developed on the Arabic peninsula prior to their occupation by the Romans (Ibn Al-Awwam 1864: 124).

While sharing a common background, *noras* in Portugal and *norias* in Spain served to identify different devices. Not only are several different devices designated by the same name, but, at other times, there are also several designations for the same devices. Therefore, we need to apply the utmost caution and try, at all costs, to avoid making the tempting error of playing with words and forgetting the strict sense that they once must have held.

In the territory that is currently Spain, *noria* served in a general way to define different kinds of systems for lifting water (Bazzana and Montmessin 2006: 236-253). During al-Andalus, the Arabic words *na'ura* and *sâqiya* were applied to identify different hydraulic systems, with one being more related to the waterwheel and the other to a lifting system that made recourse to animal force. The Albolafia of Cordoba dates from the Muslim era. Moreover, in the twelfth century, the Muslim geographer Al-Idrissi, born in Ceuta in 1100 and dying in 1164, mentions a large *noria* lifting water from the River Tagus up to the city of Toledo for the irrigating the orchards: “On the Tagus, you see a very curious aqueduct, formed from a single ring, beneath which the waters run with great violence and cause a hydraulic machine to move at the end of the aqueduct, which raises the water to 90 cubits high” (about 66 m) (Carrasco Manchado 1996). Al-Himyari (1461) mentions the water wheel at Lorca, in Murcia, as well as the *saniyas* on the Guadalentín River (Pérez Sánchez 2009).

After this period, the word *noria* came to define both systems. However, in order to distinguish between both hydraulic systems, the *sâqiya* became known as a *noria de sangre* (blood waterwheel). Moreover, the word *noria* covered diverse situations throughout this period. Whenever the water source was a river, a channel or an *acequia*, and whenever the final purpose was either irrigation or the supply of water, it was referred to as an *azuda*[5] or *noria fluvial* (Torres Balbás 1940: 195–208), and whenever the device served the mill industry, it was an *aceña* (Caro Baroja 1954). *Noria* was also applied to define systems that either lifted water from wells or saline from mines.

The Portuguese word *nora* does not encompass that many different hydraulic systems. *Noras* define the water system for lifting water from wells. The devices that are called *nora* are *nora de alcatruzes*, and *nora de sarilho*, and are divided into long- and short-shafted mechanisms.

The technology incorporated into *noras de sarilho* is clearly more archaic than that applied in *noras de alcatruzes* or water wheels. These *noras* present the singularity of not using sprockets to transmit the movement, but rather wooden beams arranged into a double cross. In Portugal, these can be found as far north as Leiria in the centre of the country, as well as in Italy, with their diffusion probably attributable to the Carthaginians (Dias and Galhano 1986: 199–200).

The *noras de sarilho*, in turn, have most of their mechanism inserted into the well and supported by wall studs. The centre contains a thick vertical axis, the *pião* (top), which rotates between a horizontal beam, the bridge, resting on two masonry blocks placed at the mouth of the well, called *moirões*, and alongside a shorter board known as an *enóra* (Dias and Galhano 1986: 60). Two long sticks emerge from the top of the *pião*, one of which, the thicker one, known as the *almanjarra*, is attached to a rocker with rods, which the animal then pulls. At the thinnest end, the guide is attached to the *almanjarra* and not to the *pião*.

The *noras de eixo comprido* probably have Roman origins. They were popularly called *calabres* or *engenhos*, and only in erudite contexts were they termed *noras*. This device is called a *calabre* in S. Frutuoso (Coimbra); an *engenho* in Almada (Southern bank of the River Tagus), Gândara, Bairro (Leiria) and Mirandela; a *roda de tirar água* in Pombal; an *engenho de ponteria* in Tomar; and a *nora alta* in Setúbal (Dias and Galhano 1986: 198). As we can see, the generic name of *nora* was a scholarly invention, easily misleading to those who are not clearly aware of

[5]In Castilian, the word *azuda* derives from the same word *al-sudd*, while holding different meanings. An azuda can also be called a ‘*noria fluvial*.’

its contextualisation. Although technologically similar to *noras*, an important functional difference separates them. While short shaft bearings can only draw water from wells, a system common in Morocco, long shaft bearings mainly work near rivers and streams. The long shaft serves precisely to enable the buckets to hang over the river's edge, while the animal works a few feet away from the edge of the riverbank.

The 1718 Portuguese dictionary by Raphael Bluteau defines a *nora* as a hydraulic machine with a wheel, ropes and buckets moved by the action of animals. Additionally, he states that there are three different types of *nora*. One applied human strength, the second water and the third weights (Bluteau, Vol. V, 1718 :745–746). Moreover, he observes the difficulties in finding a Latin name for the Portuguese *noras* (Bluteau, Vol. V, 1718: 746). He recalls the device described by Suetonio and concludes that "it is not exactly as those found in Portuguese vegetable gardens," as well as others described by Livio and Pliny, and concludes that they are also not like the Portuguese *noras* (Bluteau, Vol. V, 1718: 746). While the poet Lucretio mentions a "tympanum," which is a "machina rotunda ad rotae similitudinem," Bluteau concludes that, as there is no adequate Latin word, he will resort to a periphrasis—*Rota aquaria*—as used in the Lisbon area (Bluteau, Vol. V, 1718: 746). The Portuguese *nora* thus corresponds to the Moorish *nora* or *nora de alcatruz*, and it is always associated with a well.

Short-axis daggers are known in both Portugal and Spain as *noras mouriscas* (Moorish *noras*), in keeping with their attribution as being of Moorish origin. In fact, they are very common in North Africa, often driven by camels. However, such designations are quite random, especially as authors commonly attribute the general origins of the *nora/noria* to the Arabs, even though certain of these mechanisms for raising irrigation water may never have been known in either North Africa or the East.

The only one of these devices that is originally of Arabic origin is the short shaft *nora de alcatruz*. Therefore, *noras* de alcatruzes (*noras* with buckets) became commonly known as *noras mouriscas* (Moorish *noras*). Muslims in Morocco practiced irrigation mainly through recourse to water from wells. Except for those who lived in the vicinity of the slopes of the Atlas Mountains and foothills, and who were able to take advantage of spring meltwaters, irrigation of the flat lands, and especially the oases, took place by means of short shaft bearings. These were, in fact, the most widespread, and can still be encountered in Morocco.[6] Furthermore, Moorish *noras* are not only widespread in Morocco, but are also responsible for the nomenclature of the apparatus, with many of their parts being of Arab origin.

We may also compare the usage of both devices in al-Andalus in accordance with the comments by Abu Zacaria. He asserted that the long shaft *nora* was not commendable, for being both too laborious and prone to frequent havoc. Contrastingly, Zacaria expresses no such reluctance as regards the short shaft *nora de alcatruz*, which he describes in great detail in another chapter of his work, giving precise technical advice. The awareness of so many details indicates that this device was very familiar to him, in contrast to the long shaft *nora*.

[6]On this topic, see the chapter by Desidério Baptista in this book.

Moreover, Ibn Al-Awwam's *Treatise on Agriculture* (twelfth century) does not provide a description of the *nora/noria*, but rather of ways to improve it based on Abou'l-Khair (Ibn Al-Awwam 1864: 129). This work depicts the *nora* as a device that was very common across the Iberian Peninsula, to such an extent that the author neither had to explain what it was nor describe its means of construction, instead giving only hints and recommendations about expanding its power capacity.

These short-axis *noras* often appear in the countries of the Mediterranean basin. Apart from North Africa, as already detailed above, they appear in the Balkans, Italy, Spain, including on its islands of Ibiza and Mallorca, and Portugal. These *noras* and *norias* were specifically used for irrigation in the areas of the Southern Iberian Peninsula, such as Alentejo and Algarve in Portugal and Andaluzia, Valencia, Murcia, and Aragon in Spain.

Furthermore, while the *nora of alcatruzes* was fairly commonly used in Entre-Douro and Minho, in northern Portugal, it did not extend beyond the Galician-Portuguese border (Dias and Galhano 1986: 203). Some isolated cases, made of iron, must be of only recent introduction. In both the western and eastern parts of southern Galicia, and in the regions bordering them to the east—Sanabria, Cabrera and Bierzo—, there are no *norias of alcatruzes*, which partly stems from the general abundance of water in those mountainous regions. However, further east, in the former region of Leon, they once again make an appearance. As *norias de alcatruze*s do not appear in Galicia and Asturias, and Valadares does not register the word in his Galician-Castilian dictionary. Moreover, in Asturias, the word *noria* designates the channel that specifically conducts water to mills, and not to any water-lifting device.

Such devices inscribe the memories of the innovations and knowledge of previous generations, as well as their own; not only did their construction require very significant expertise, so did their maintenance. *Nora, noria* and water wheel construction was considered a specialized profession, both in Spain and in Portugal. In Spain, there are references to the master of the *noria* (Blázquez and Severino 1999). In Portugal, Manuel Ribeiro was the master carpenter of the *noras* for the Royal House and, for example, on March 26, 1799, carried out conservation work on the *nora* of the well located in the Quinta das Calvanas, property of Count of São Miguel.[7] Other conservation works included the *nora* house of the Royal Villa of Belém in 1895.[8] However, the actors enrolled in the construction and conservation of theses devices, as well as, their professional status, remain almost untracked.

4 Misunderstanding Water Wheels and Watermills

In Portuguese, a large epistemology was applied to identifying water wheels and watermills. Different types of water wheel, such as *rodas com alcatruzes ligados às penas* (feathered bucket water wheels), *rodas com alcatruzes presos ao aro* (water wheels with buckets attached to the rim), *rodas com alcatruzes presos aos arcos da*

[7]ANTT, Feitos Findos, Administração de Casas, mç. 166, nº 22.
[8]ANTT, Ministério das Obras Públicas, mç. 444.

Fig. 1 Water wheel at Tomar, Portugal. Photograph by Ana Duarte Rodrigues

roda (water wheels with buckets attached to the wheel's arches), and *rodas com dois aros* (water wheels with two rims) are all found in Portugal (Dias and Galhano 1986: 40–54). Examples of other water-powered devices include the *engenhos de copos* and the *estanca-rios*.

Moreover, what is described by Ibn Hishâm al-Lakhmî as a *noria* is usually called a *roda hidráulica* (water wheel). In the Portuguese language, *roda hidráulica* defines a waterwheel built near a river in order to lift water. One exception is the water wheel built in Mouchão, Tomar, in Portugal, that follows the Syrian model and is called a *nora hidráulica*. In some situations, the misperception occurs in the opposite direction. For example, the 1899 repair of a mill for raising water from an existing well in the monastic enclosure of the Recolhimento do Bom Pastor applied the word *moinho* to what was probably the well's *nora* (Fig. 1).[9]

Furthermore, a watermill might correspond in Portuguese to a *moinho*, an *azenha*, an *atafona*, or any number of other devices. Written documentary evidence about this technology is sparse at best. However, documents on watermills are more abundant than those on *noras*. The earliest written record of the usage of this technology in Portugal reaches back to the tenth century. In turn, the oldest document mentioning a *moinho* (water mill) in Portugal dates back to 906 (Oliveira

[9]ANTT, Ministério das Obras Públicas, mç. 453.

et al. 1983: 77–78), and there is another reference in the tenth century from the Monastery of Lorvão, in northern Portugal, which summoned a Muslim master to build two bridges and a water mill (Borges 2002: 72). The oldest reference to *azenhas* (another word for water mills) in contemporary Portuguese territory comes from 998 (Durand 1982: 219), with the second appearing in 1087 (Marques 1978: 193).

Documents concerning watermills in Portugal appear frequently across two distinct moments. In the late medieval period, most of the documents derive from royal authorization to build watermills. Most of the consent given to build *azenhas* and *moinhos* was granted by the kings D. Dinis, D. Duarte, D. Afonso V, D. João I, D. João II and D. Manuel I (Silva 2008). On April 24, 1592, the Monastery of Santos-o-Novo rented a piece of property in the surroundings of the village of Palmela to Francisco de Azevedo, allowing his utilisation of the mill there for the price of eight hens per year[10]; other such rental agreements have also been established in this period. For example, a water mill located on the Bucelas stream was rented by the bishop to a mason on March 26, 1453.[11] King D. João II also rented a water mill on the Alviela River on October 16, 1487.[12]

In the early modern period, however, most of these watermill-related documents are either rental agreements or lawsuits stemming from their failure. Half of the watermills located on the Alcobertas stream were purchased by José da Silva Pinheiro from Pedro da Silva on August 30, 1765.[13] The blacksmith João Ferreira, in the eighteenth century, also rented a watermill located on this stream against the payment of wheat, one hen, and barley,[14] and Joaquim Machado and his wife rented a watermill called "Rodrigo Lopes," also located on the same stream.[15] The fact that their own names were attributed to these devices conveys their importance. Another document identifying how a watermill was bestowed on the Monastery of S. João in Estremoz on June 10, 1778, also reveals that the *azenha* was named after the "Alpendres" (Porches).[16]

The Lisbon Misericórdia (a charitable institution) filed a lawsuit against Francisco Mateus for having missed his water mill income payments in 1766 and 1769.[17] The religious institution Misericórdia of Viana do Castelo, in the north of Portugal, rented the water mill to Manuel Lourenço Manso and his wife on July 17, 1854.[18] The running of a salt water mill would also constitute a privilege as duly offered to João da Costa Lima, an official in the Royal House, on March 28, 1767.[19] Salt watermills are typical of eighteenth century Portuguese coastal areas.

[10] ANTT, Mosteiro de Santos-o-Novo, nº 1896.
[11] ANTT, Viscondes de Vila Nova de Cerveira, cx. 10, nº 20.
[12] ANTT, Chancelaria de D. João II, liv. 21, fl. 40.
[13] ANTT, Casa de Abrantes, cx. 16, mç. 46, doc. 891.
[14] ANTT, Casa de Abrantes, cx. 16, mç. 46, doc. 890.
[15] ANTT, Casa de Abrantes, cx. 16, mç. 46, doc. 889.
[16] ANTT, Registo Geral de Mercês de D. Maria I, liv. 4, f. 36v.
[17] ANTT, Feitos Findos, Juízo Privativo das causas da Misericórdia de Lisboa, mç. 21, nº 8 and 9.
[18] ANTT, Registo Geral de Mercês, D. Pedro V, liv. 4, fl. 170v.
[19] ANTT, Registo Geral de Mercês de D. José I, liv. 13, f. 527.

They were tide-powered, as is the case of the example at the Palmeira villa, Seixal, in southern Portugal. However, there are also other documents encompassing the manipulation of rivers in order to activate watermills, as demonstrated by the deviation of river water into a channel to power Francisco João's water mill on May 16, 1647.[20]

The word *atafona* appears in ancient documents as a device similar in function to a watermill. To hold an *atafona*, one had to gain royal permission, and this was deemed a privilege bestowed upon someone as a reward for their services. For example, King D. Afonso V gave permission to a jurist from Évora for an *atafona* or *açacal* on May 6, 1452.[21] In the same region of Alentejo, King D. João II authorized the construction of an *atafona* in Moura, on April 15, 1486.[22] Moreover, on August 23, 1497, King D. João II bestowed on the barber Diogo Real the right to have an *atafona* in the village of Olivença, in the Alentejo district, southern Portugal, in honor of his service in the Portuguese army in a war against Castile, which left him crippled.[23] King D. Manuel I gave permission for his cook to run an *atafona* in Évora, on June 28, 1498,[24] and for his butcher on July 21, 1501,[25] as well as to a knight of the Royal House in 1517.[26]

The right to operate an *atafona* was also a privilege of colonial rulers. The ruler of the island of S. Tomé[27] and the ruler of the island of Príncipe[28] both owned the right to keep all of the bread mills on their respective islands for themselves, excluding the arm mill (*mó de braço*). Furthermore, one could only hold an *atafona* after having received royal approval. This document from December 11, 1499, identifies how the *moinho*, *mó de braço* and *atafona* referred to three different devices: the *moinho*, the most complex and productive, could only be the ruler's property; the *mó de braço*, the level of production of which hardly reached beyond the self-sustaining, could be owned by the island's population; and, finally, the *atafona* was classified as a device that was somehow in-between the other two.

As is the case with advanced technology nowadays, a device's parts were not that easy to replace back then in the distant reaches of the empire and, when they did fail, parts to replace them had to be sent from Lisbon. For example, this must have happened with the *seis pedras de mós de atafona* (six hornets of mil) sent to Martim Fernandes, the captain of a ship heading to Cochim on November 13, 1514.[29]

[20]ANTT, Registo Geral de Mercês, Mercês da Torre do Tombo, liv. 22, f. 380v.-381.
[21]ANTT, Chancelaria de D. Afonso V, lv. 3, fl. 74.
[22]ANTT, Chancelaria de D. João II, liv. 1, fl. 139.
[23]ANTT, Chancelaria de D. Manuel I, liv. 28, fl. 93.
[24]ANTT, Chancelaria de D. Manuel I, liv. 31, fl. 19v.
[25]ANTT, Chancelaria de D. Manuel I, liv. 17, fl. 65.
[26]ANTT, Chancelaria de D. Manuel I, liv. 25, fl. 161.
[27]ANTT, Chancelaria de D. Manuel I, liv. 13, fl. 6.
[28]Given by King D. Manuel I on 7th April 1500. ANTT, Chancelaria de D. Manuel I, liv. 21, fl. 18v.
[29]ANTT, Corpo Cronológico, Parte II, mç. 53, nº 31.

In seventeenth and eighteenth century inventories, *atafona* appears in conjunction with other instruments, such as that listed as a *sarilho de roda e outro de mão*, featured in the inventory of D. Francisca Teresa de Jesus, who died on June 28, 1784.[30]

Such records of practice have often been taken at face value to be merely random data, even though they play an essential role in collecting the nomenclature that was in use in the early modern period in Portugal for the purpose of identifying devices taken globally as water wheels in the English language and, therefore, illuminating the underlying structures of practical knowledge.

5 Innovation Through 'Technology-of-Use'

Following the conceptual 'technology-of-use' revolution, which forced us to broaden our horizons beyond technological innovation, beyond the invention-producing centres, and reformulate our ideas about the most important technologies, the specificity of the appropriations and adaptations of the hydraulic wheel technology in various locations in Spain and Portugal becomes an important case study for refreshing the history of technology in global terms. Edgerton points out the example of the steam engine, the flagship of the industrial revolution and, nevertheless, a device that turned out to be more important in 1900 than it had been in 1800 (Edgerton 2011, xi). Following Edgerton, we argue that *noras*, and water wheels, were just as vitally important as technologies in the nineteenth and twentieth centuries as they were in the medieval or early modern periods. Moreover, we argue their importance stemmed from their social usage and their construction in different materials rather than technological improvement.

Nicolás García Tapia deemed medieval Castilian society to be far more advanced than the rest of Europe in the field of water mills and water-elevating systems, to such an extent that he considered it a real "energy revolution" (García Tapia 2008b: 307–330). However, García Tapia also argues that there was no real technological innovation occurring at this point in time, as most Islamic models simply incorporated ancient Hellenistic and Roman models (García Tapia 1984). Moreover, Thomas Glick stresses how wise water management does not only derive from technological innovation, but also from the social usage and spread of that innovation, emphasizing the role that Muslims played in the systematic establishment of *noras, norias*, water wheels and distribution channels throughout al-Andalus (Glick 2005; see chapt. 11 in this book).

Up until the early eighteenth century, hydraulics works were based on empirical knowledge concerning gravity flow and low-pressure systems of channels and pipes. Water technology had undergone revitalisation from time to time, but there was no overall technological upgrade in the seventeenth century in Portugal, despite the circulation of a greater number of books and treatises on hydraulics

[30]ANTT, Feitos Findos, Inventários post mortem, Letra F, mç. 52, nº 7.

(Rodrigues 2011). Even though, in the seventeenth and eighteenth centuries, the Islamic past was already considered to be very distant and many other models had become available, the cultural utilisation of water in the gardens and estates of the Iberian Peninsula still owed a lot to the Hispano-Moorish legacy (see chapt. 12 in this book). In the early modern period, in Andaluzia, particularly in Almería, the farms were administrated by the community in keeping with the Islamic model. The survival of *norias* that extracted water from wells may be traced up through to the nineteenth century, with the remains still sketched into the regional toponomy, for example, Las Norias de Daza (Molina, Checa and Olmos 1998). Similarly, the Algarve landscape is still punctuated by *noras*, many of which stem from the early modern period. But the revitalization of the Algarve agriculture at the turn of the twentieth century interconnects with the replacement of wooden by iron *noras*, which are nevertheless largely the continuation of their ancestors. They can also be considered innovations attributable to the greater possibilities this metal provides in relation to wood. Later, when electricity and water supply system technologies already existed, they were not available for the more isolated and poorer regions of Portugal, such as the Algarve. In this region, farmers continued to use *noras*, sometimes associated with electric pumps for lifting water from wells (see chapt. 11 in this book). Based on Edgerton‘s conceptual framework, we would argue that iron *noras* in this context became “the new technology of poverty” (Edgerton 2011: xiv).

Engenhos de buxos or *noras de buxos*, neither term having any translation into other languages, can also illustrate how innovation was fostered by ‘technology-of-use' of *noras* in Portugal.

The *engenhos de buchos*, found in Valongo, in the north of Portugal, may not employ any technological principal that is different from the vertical or horizontal wheels. However, based on the same technology, a different device was tailored to meet the specific prevailing aims, thereby constituting a local adaptation of an ancient piece of knowledge. This consists of the material culture of technological transitions.

The Romans were already aware of this technology, and applied it to drain water from mines. As circumstances would have it, there had once been a Roman mine in Valongo. Therefore, the *engenho de bucho* emerges as a local adaptation of the machine that drains water from mines designed to fulfil the need to water the fields, as the technological principle deployed remains absolutely the same. The section designed to increase the water flow generally consists of several wooden tubes, fitted together, through which an iron chain with balls, spaced at particular distances from each other, passes. These balls are made of horsehair, lined with leather and could fit into a person’s hand. Only the purpose of its usage changed. In the Roman period, such devices were operated in mines for drainage, whereas *engenhos de buchos* were used in this region of Portugal for irrigation from the early modern period onwards. Therefore, *engenhos de buchos*, which seems to be otherwise unknown in the Mediterranean countries (Dias and Galhano 1986: 194), must therefore classify as a local innovation.

Although these 'technology-of-use' innovations took place through empirical development, Spain also established a modern way of recording innovations—in the Book of Patents.

The devices known in the sixteenth century, such as norias, the tympanum (described by Vitruvius) and the Archimedes' screw, among other water-lifting devices, became inefficient when attempts were made to raise water over a height of 30 m (García Tapia 1994: 42). How might this problem be solved so that they could lift water up to a height of 90 m? Finding a solution for this problem became the goal of Juanelo Turriano in 1564 (see chapt. 2 in this book). However, the Book of Patents shows that one was granted to the French architect and engineer Luis de Fois, who had invented machines for elevating water in the ancient Alcázar Real de Madrid, and who had, even before Turriano, tried to create another water-lifting device that ran from the river to Toledo (although he failed in this endeavor). Another patent was also granted to him on June 6, 1563, for deviating water from rivers to higher places, although we cannot ascertain precisely how (García Tapia 1994: 45). Therefore, many devices were created by inventors seeking to resolve practical problems who neither wrote treatises nor described their experiments, even when registering them in the Book of Patents.

The registration submitted by the Valencian farmer Jaime Zamora on May 31, 1572, also constituted an improvement of a pump for lifting water. A sophisticated way of lifting water via pumps, such as the Ctesíbio Machine, had already been described in Vitruvius (Vitruvius and Maciel 2006: 377); nevertheless, a patent was still granted in Spain for another pump of the same kind as those known as 'tisi-bicas,' from Ctesibio (García Tapia 1994: 50).

6 Final Remarks

In this study, we began by focusing on how certain gadgets described by Vitruvius, who wrote in Latin, were translated into Portuguese. Most of these devices were translated homogeneously into English as water wheels, because they generally corresponded to those found along the rivers in central and northern Europe. However, on the Iberian Peninsula, both for geographical reasons, associated with the drier and hotter summer climate, and for historical reasons, due to the strong Islamic influence on this region in keeping with its long al-Andalus period, the history of water-raising devices became much more complex. Several case studies enabled us to identify some of the aims and strategies deployed to appropriate and adapt that common heritage.

This study also clearly portrays how water wheels and water mills actually correspond to a huge diversity of devices, which basically apply the same technology, but that, whether due to their different uses, regions or historical periods, are attributed different names in Portuguese. It became clear that *roda hidráulica*, *nora*, or *engenhos de buchos*, in addition to a wide series of variations on each one are all translated as water wheels in English, just as watermill became the translation of *moinho*, *azenha*, or *atafona*, alongside another series of variations on these principal types. On the other hand, in Spain, the word *noria* clearly serves to identify a much wider range of devices than in Portugal, demonstrating how the Iberian Peninsula's history of technology cannot be fully grasped only by studying the Spanish case and accepting that part as the whole.

Still furthermore, this study also clarifies how those mills that appear to be of Islamic origin, in most cases, are not. The exception is a specific type of *nora*: the *nora de alcatruzes*, sometimes even identified as the "Portuguese *nora*," which is a specific type that is actually found mainly in Morocco and on the Iberian Peninsula.

This study also demonstrates how the nomenclature that we find today in the erudite context hardly features in the historical documentation, in which the nomenclature is not only reduced, but is also sometimes different from that currently in usage, thus making it difficult to specifically grasp just what kind of device was in use then. Nevertheless, this documentation is relevant to our understanding of the importance of these devices in the granting of permission for their construction, leasing or usage by someone specifically representing royal privilege. Throughout time, ownership and usage of these devices moved beyond the exclusive control of the monarch, with contracts then being established between private individuals.

Following David Edgerton's conceptual framework on the technology-of-use, we then demonstrate how the use of *noras* and *norias* on the Iberian Peninsula contributed more towards progress in farm irrigation in the early modern and modern periods than at the time of their invention. Moreover, the spread, development and impact on productivity reached its peak, not during the al-Andalus, but rather during the early modern period.

Noras and *norias* thus constitute records of practices, as well as repositories of knowledge, innovations and reinventions, providing insights through an engaging history of technology case study.

References

Primary Sources: Manuscripts

ANTT, Feitos Findos, Administração de Casas, mç. 166, nº 22.
ANTT, Ministério das Obras Públicas, mç. 444, mç. 453.
ANTT, Mosteiro de Santos-o-Novo, nº 1896.
ANTT, Viscondes de Vila Nova de Cerveira, cx. 10, nº 20.
ANTT, Chancelaria de D. João II, liv. 1, fl. 139; and liv. 21, fl. 40.
ANTT, Casa de Abrantes, cx. 16, mç. 46, doc. 889–891.
ANTT, Registo Geral de Mercês de D. Maria I, liv. 4, f. 36v.
ANTT, Feitos Findos, Juízo Privativo das causas da Misericórdia de Lisboa, mç. 21, nº 8 and 9.
ANTT, Registo Geral de Mercês, D. Pedro V, liv. 4, fl. 170v.
ANTT, Registo Geral de Mercês de D. José I, liv. 13, f. 527.

ANTT, Registo Geral de Mercês, Mercês da Torre do Tombo, liv. 22, f. 380v.-381.
ANTT, Chancelaria de D. Afonso V, lv. 3, fl. 74.ANTT, Chancelaria de D. Manuel I, liv. 28, fl. 93.
ANTT, Chancelaria de D. Manuel I, liv. 31, fl. 19v.; liv. 17, fl. 65.; liv. 25, fl. 161; liv. 13, fl. 6; liv. 21, fl. 18v.
ANTT, Corpo Cronológico, Parte II, mç. 53, nº 31.
ANTT, Feitos Findos, Inventários post mortem, Letra F, mç. 52, nº 7.

Printed Sources

Agricola, Georgius. 1556. *De re metallica*.
Balaguer y Primo, F. 1873. *Riegos por medio de Norias, bombas y otras máquinas*. Madrid: Fundación Manuel Tello.
Bluteau, Raphael. 1712–1728. *Vocabulario portuguez e latino, áulico, anatómico, arcitectonico, bélico, botânico…* Coimbra: no Collegio das Artes da Companhia de Jesus.
Carduchi, L. 1641. *Chorographia del rio Tajo: año de 1641*. 2008. M. García Ruipérez (Ed.). Toledo: Ayuntamiento de Toledo.
Ibn Al-Awwam. 1864. *Le Livre d'Agriculture*, French translation. Paris: Librairie A. Franck.
Ramelli, A. 1588. *Le diverse et artificiose machine del capitano Agostino Ramelli dal Ponte della Tresia ingegniero del Christianissimo re di Francia et di Pollonia*, Parigi: in casa del'autore.

Bibliography

Almagro Gorbea, Antonio. 1996. "Una noria de tradición árabe en Albarracín", *Homenaje a Purificación Atrián.* Teruel: Instituto de Estudios Turolenses, Diputación de Teruel, Museo de Teruel.
Ballester, Luís García. 2002. *Historia de la Ciência y de la Técnica em la Corona de Castilla: Siglos XVI y XVII*. Madrid: Junta de Castilla y León/ Consejería de Educación y Cultura.
Bazzana, André and Yves Moontmessin. 2006. "Na'ura et saniya dans l'hydraulique d´al-Andalus à la lumiére des fouilles de «Les Jovades» (Oliva, Valence)". *In* Patrice Cressier (ed.). *La Maîtrise de l´Eau en al-Andalus. Paysages, Pratiques et Techniques*. Madrid: Casa de Velásquez, pp. 209–287.
Bennett, Richard and John Elton. 1899. *History of Corn Milling*. 4 Vols. (1898–1904). London: Simpkin, Marshall & Company.
Blázquez Herrero, Carlos and Severino Pallaruelo Campo. 1999. *Maestros del agua.* Zaragoza: Departamento de Educación y Cultura del Gobierno de Aragón.
Caro Baroja, Julio. 1954. "Norias, azudas y aceñas". *In Revista de Dialectología* 10 (1): 29–160.
Carrasco Manchado, A. I. 1996. "La percepción del agua y los sistemas hidráulicos en la obra de Al-Idrisi". In *II Coloquio Historia y Medio Físico. Agricultura y regadío en Al-Andalus. Almería*, pp. 57–65.
Castel-Branco, Cristina (ed.). 2010. *A Água nos Jardins Portugueses*. Lisbon: Scribe.
Colin, G. S. 1932. "La noria morocaine et les machines hydraulique dans le monde arabe". *Hesperis* 14: 22–60.
Cressier, Patrice (ed.). 2006. *La Maîtrise de l´Eau en al-Andalus. Paysages, Pratiques et Techniques*. Madrid: Casa de Velásquez.
Curwen, E. Cecil. 1944. "The problem of Early Water-mills". *Antiquity* 18: 130–146.
Derry, Thomas Kingston and Trevor Illtyd Williams. 1960. *A Short History of Technology from the Earliest Times to A.D. 1900*. Oxford: Oxford University Press.
Dias, Jorge. 1959. *Sistemas Primitivos de Moagem em Portugal: Moinhos, Azenhas e Atafonas*. Porto: Instituto de Alta Cultura. Centro de Estudos de Etnologia Peninsular.

Dias, Jorge and Fernando Galhano. 1986. *Aparelhos de Elevar a Água de Rega*. Lisboa: Publicações Dom Quixote.
Dunmire, William. 2012. *Gardens of New Spain: How Mediterranean Plants and Foods Changed America*. Texas: Texas University Press.
Durand, Robert. 1982. *Les Campagnes Portugaises entre Douro et Tage aux XIIème et XIIIème siècles*. Paris: Fundação Calouste Gulbenkian/Centro Cultural Português.
Edgerton, David. 2011. *The Shock of the Old: Technology and Global History since 1900*. Oxford: Oxford University Press.
El Faïz, Mohammed. 2005. *Les Maîtres de l'Eau: Histoire de l'Hydraulique Arabe.* Arles: Actes Sud.
Forbes, R. J. 1955–56. *Studies in Ancient Technology*, Vols. 2–3, Leiden: Brill.
Galhano, Fernando. 1978. *Moinhos e azenhas de Portugal*. Lisboa: Associação Portuguesa dos Amigos dos Moinhos.
García Tapia, Nicolás. 1984. "Los 21 libros de los ingenios y de las máquinas. Su atribución". *In Boletín del Seminario de Estudios de Arte y Arqueología 50,* Valladolid, pp. 434–439.
García Tapia, Nicolás. 1990. *Ingeniería y Arquitectura en el Renacimiento Español*. Valladolid: Universidad de Valladolid, Secretariado de Publicaciones.
García Tapia, Nicolás. 1994. *Patentes de Invención Españolas en el Siglo de Oro*. Madrid: Oficina Espanola de Patentes y Marcas/Ministerio de Industria y Energia.
García Tapia, Nicolás. 1996. "Ingeniería del agua en los códices de Leonardo y en los manuscritos españoles del siglo XVI". *In Ingeniería del agua* 3 (2), pp. 17–38.
Garcia Tapia, Nicolás. 2003. *Técnica y Poder en Castilla durante los Siglos XVI y XVII*. Salamanca: Junta de Castilla y León. Consejería de Educación y Cultura.
García Tapia, Nicolás. 2008b. "Técnicas y usos. El papel del agua en la sociedad castellana medieval". *In* Isabel del Val and Olatz Villanueva (eds.). *Musulmanes y Cristianos frente al Agua en las Ciudades Medievales.* Santander: Pulbicaciones de la Universidad de Castilla-La Mancha, pp. 307–330.
Glick, Thomas. 2005. *Islamic and Christian Spain in the Early Middle Ages*. Leiden, Boston: Brill.
Inkster, Ian and Angel Calvo. 2010. *History of Technology: European Technologies in Spanish History*, vol. 30. London and New York: Continuum.
Magnusson, Roberta J. 2001. *Water Technology in the Middle Ages, Cities, Monasteries, and Waterworks after the Roman Empire.* Baltimore and London: The Johns Hopkins University Press.
Maldonado, Basilio Pavon. 1990. *Tratado de Arquitectura Hispanomusulana, I AGUA (aljibes, puentes, qanats, acueductos, jardines, desgues de ciudades y fortalezas, ruedas hidráulicas, banos, corachas*. Madrid: Consejo Superior de investigaciones cientificas.
Malpica Cuello, Antonio. 1996. "Análisis arqueológico de las terrazas de cultivo. El ejemplo de los albercones de la Alhambra de Granada". *In Actas del II Coloquio de Historia y Medio Físico. Agricultura y Regadío en al-Andalus*. Granada: Universidad.
Marques, António H. de Oliveira. 1978. *Introdução à História da Agricultura em Portugal: a Questão Cerealífera durante a Idade Média*. Lisboa: Cosmos.
Merlos Romero, Magdalena and Victoria Soto. 2020 (in press). "Water and Enlightened Techniques: The *Azuda* of Aranjuez, Spain". *In Gardens & Landscapes 7,* Sciendo (forthcoming 2020).
Miranda, Adriana de. 2007. *Water Architecture in the Lands of Syria: The Water-wheels*. Roma: Studia archaelogica, L'Erma di Bretschneider.
Moritz, L. A. 1958. *Grain-Mills and Flour in Classical Antiquity*. Oxford: Oxford University Press.
Oliveira, Ernesto Veiga de et al. 1983. *Tecnologia Tradicional Portuguesa – Sistemas de Moagem*. Lisboa: Instituto Nacional de Investigação Científica.
Pérez Sánchez, Cruz. 2009. "Norias de la Vega Media del río Segura. Estudio, descripción y valoración de las actuaciones". *In XX Jornadas de Patrimonio Cultural de la Región de Murcia (Cartagena,*

Cieza, Águilas, Puerto Lumbreras y Murcia, 6 oct-3nov 2009). Actas. Murcia: Consejería de Cultura y Turismo de la Comunidad Autónoma de la Región de Murcia. pp. 85–98.
Quintela, António de Carvalho *et al*. 1986. *Aproveitamentos Hidráulicos Romanos a Sul do Tejo: Contribuição para a sua inventariação e caracterização.* Lisboa: DGRAH.
Quintela, António de Carvalho. 1996. "Breve caracterização das obras hidráulicas e da utilização da água em Portugal anteriormente ao século XVIII". *In Hidráulica Monástica Medieval e Moderna. Actas do Convento da Arrá*bida. Lisboa: Fundação Oriente.
Quintela, António de Carvalho. 1998. *Hidráulica*. Lisboa: Fundação Calouste Gulbenkian.
Reynolds, Terry S. 1983. *Stronger than a Hundred Men. A History of the Vertical Water Wheel*. Baltimore and London: The Johns Hopkins University Press.
Ribeiro, Margarida. 1969. *Vasos de Barro da Nora e da Roda de Tirar Água: suas Analogias e Divergências*. Guimarães: [Companhia Editorial do Minho].
Rodrigues, Ana Duarte. 2011. "O conhecimento teórico ao alcance de arquitetos e Jardineiros em Portugal durante a Idade Moderna". *In* A. D. Rodrigues and R. Moreira (eds.). *Tratados de Arte em Portugal/Art Treatises in Portugal*. Lisboa: Scribe, pp. 119–144.
Rodrigues, Ana Duarte. 2017. "Sustainable beauty for Algarvean gardens: cross- boundaries solutions between the humanities and the sciences". *Interdisciplinary Science Reviews* 42: 3, pp. 296–308.
Rossello Verger, V. 1989. "Els molins d'aigua de l'Horta de Valencia". *In Los Paisajes del Agua. Libro Jubilar dedicado al Profesor Antonio López Gómez.* Valencia and Alicante: Universidades de Valencia y Alicante, pp. 317–345.
Sahady, A., J. Bravo y C. Quilodrán. 2011. "Las azudas de Larmahue: una singular manifestación del ingenio humano para regar cultivos en tierras de secano", in *Revista de Urbanismo*, nº 25.
Sellin, R. H. J. 1983. "The large Roman Water Mill at Barbegal (France)", *H'Techn* 8: 91–109.
Silva, Teresa Rebelo da. 1999. "Azenhas e moinhos no Algarve: segunda metade do século XIII e século XIV'. *Arqueologia Medieval* 6: 213–223.
Silva, Vasco Jorge Rosa. 2008. *Sistemas de Moagem Hidráulico: Azenhas no tempo de D. Dinis*. Porto: Ecopy.
Torres Balbás, Leopoldo. 1940. "Las norias fluviales en España". *Al-Andalus 5:* 195–208.
Troup, J. 1894. "On a possible origin of the Waterwheel", *Asiatic Society of Japan, Transactions*, 1st ser. 22: 109–114.
Usher, Abbot Payson. 1954. *A History of Mechanical Inventions*. Cambridge, Mass.: Harvard University Press.
Violet, Pierre-Louis. 2007. *Water Engineering in Ancient Civilizations: 5000 Years of History*. International Association of Hydraulic Research.
Vitruvius and Maciel, Manuel Justino (trans.). 2006. *Tratado de Arquitectura*. Lisbon: IST Press.
Wikander, Orjan. 2000. *Handbook of Ancient Water Technology*. Leiden: Brill.
Wilson, Paul N. 1952. "Origins of Water Power". *Water Power* 4: 308–313.
Wulff, Hans E. 1966. *The Traditional Crafts of Persia: Their Development, Technology, and Influence on Eastern and Western Civilizations*. Cambridge, Mass., and London.
Xavier, António Manuel. 2011. *Das Cercas e Conventos Capuchos*. Lisbon: Licorne.

Beyond Stevin and Galileo: Seventeenth Century Hydrostatics in the Jesuit Class of the Sphere

Nuno Castel-Branco

Abstract
In the first half of the seventeenth-century, philosophers and mathematicians were still trying to solve important questions on hydrostatics, like the existence of vacuum, the cohesion of matter, and pressure. Mathematicians like Simon Stevin and Galileo Galilei made contributions to these problems that became standard in the field. But Jesuit mathematicians in Portugal also provided solutions, albeit different ones. For instance, the Italian Jesuit Giovanni Paolo Lembo (1570–1618) explored the existence of vacuum and the Flemish Hendrick Uwens (1618–1667) mentioned the moment of speed in fluids to explain the hydrostatic paradox in the classes that they taught in Lisbon. This paper explores these answers to illustrate specific features of the Jesuit teaching of mathematics in early modern Lisbon. As the teaching of mathematics in seventeenth-century Portugal was centred in this school, this research is a much-needed survey of the teaching of hydrostatics in the country at that time.

1 Introduction

"If all the water of the sea were inside a siphon, … a little amount of water in a straw would still be able to raise it." So said Hendrick Uwens (1618–1667) to a mathematics class in Lisbon in the early 1640s (Uwens 1645: 192r). Uwens was explaining what came to be called the hydrostatic paradox, in which water in a U-shaped siphon remains at the same height on both sides, regardless of their

N. Castel-Branco (✉)
Department of History of Science and Technology, Johns Hopkins University, Baltimore, USA
e-mail: nuno.cb@gmail.com

A. Duarte Rodrigues and C. Toribio Marín (eds.), *The History of Water Management in the Iberian Peninsula*, Trends in the History of Science,
https://doi.org/10.1007/978-3-030-34061-2_16

respective widths. This clearly exaggerated, and yet theoretically possible, situation constituted one of the many examples deployed by Jesuit mathematicians to teach hydrostatics to students attending the "Class of the Sphere" at the Jesuit College of St. Anthony [*Colégio de Santo Antão*] in seventeenth-century Lisbon.

As with many other Jesuit mathematicians who taught in this school, Uwens did not remain known for his mathematics teaching. Indeed, history of science questions regarding the significance of his teaching have rarely been asked. The main reason is simply that Uwens did not publish any scientific works. However, the intellectual prejudices directed towards Iberia for centuries, famously known as the black legend, also did not help foster historical research in Iberian science, especially when practiced within religious institutions.[1] In the last decades of the twentieth-century, this situation began to change, with new studies of the Class of the Sphere in particular, and Jesuit mathematics in Iberia more generally, then beginning to take place.[2] However, these were mainly focused on the general context of the class, and those studies that ventured into a close reading of the sources rarely reached beyond astronomy topics.[3]

In this paper, I present a survey of the teaching of hydrostatics in the seventeenth-century Class of the Sphere. As there were almost no other schools of mathematics in Portugal at this time, and those that did exist were only minor establishments primarily focused on cosmography and navigation, this paper also provides a much-needed survey of hydrostatics teaching in seventeenth-century Portugal as a whole. This survey does not strive to be exhaustive, but does aim to convey some of the main intellectual traditions taught in seventeenth-century Portugal, as well as some of the features that made them unique, mainly due to the twofold Portuguese and Jesuit context—a very practical and Aristotelian context.

The main sources for this paper are the class notes that were dedicated exclusively to hydraulics. In particular, we will be looking at the notes from the classes taught by the Italian Giovanni Paolo Lembo (1570–1618), who addressed and expanded upon the *Pneumatics* tradition of Hero of Alexandria (c. AD 10–70 AD), and those from the classes of the Flemish Hendrick Uwens, who continued addressing Hero's tradition, as well as delving into the Archimedean work *On Floating Bodies*. Some other professors from the Class of the Sphere also dealt with studies on water, with at least one engaging in hydraulic engineering projects. These cases are also detailed briefly, as they shed light on the water management and engineering practices that were advocated by the professors of this class. These three backgrounds for the study of hydraulics—Hero's *Pneumatics*, the work by Archimedes, and hydraulic engineering—constitute the most common approaches adopted by historians of science when writing about early-modern hydraulics. For

[1]For recent discussions on the current state of research into early modern Iberian Science, see Portuondo (2017). For the historical disregard of religious institutions in the history of science, especially accentuated in the case of early modern Iberia, see Giurgevich (2016: 253–256).

[2]For Portugal, see Leitão (2003); for Spain, see Navarro (2003). The contributions of Ugo Baldini, often quoted in this article, are also important, even while harder to find in English literature.

[3]See, for example, Leitão (2001).

some, this field emerged from the engineering practices associated with rivers and the Italian heritage of Benedetto Castelli (1578–1643) (Maffioli 1994). For others, it came from studies of the *On Floating Bodies* by Archimedes, in the tradition of mathematicians such as Simon Stevin (1548–1620) and Galileo Galilei (1564–1642).[4] Additionally, for a few others, it emerged out of studies that had been made of Hero's treatise on small devices for moving water, a work impossible to disregard within the scope of seventeenth-century pneumatic studies (Valleriani 2014).

The sustained presence of these backgrounds in Portugal suggests that these sources speak to broader issues than the history of hydraulics. Just like other mathematicians elsewhere in Europe, Jesuits in Portugal were striving to explain certain phenomena that led to the development of modern concepts such as pressure and vacuum. However, whereas the solutions provided by Stevin and Galileo became standard in modern physics, those presented by the Jesuits did not. But, in some cases, the Jesuits provided more complete explanations than those of Stevin or Galileo. To this extent, it may be stated that the Jesuits reached beyond Stevin and Galileo in certain aspects of their hydrostatics teaching. These explanations proceed from important features of the early-modern Jesuit teaching of mathematics, such as their intentional pedagogical focus on applications and the influence of Aristotelian philosophy among Jesuit mathematicians.

2 The Class of the Sphere

The Lisbon school was founded at the behest of the king of Portugal in the late sixteenth-century, with the primary goal of training specific segments of Portuguese society in mathematical topics (Baldini 2000: 53–54). This training was in great demand when considering the expansion in the overseas Portuguese territories over the course of the sixteenth and seventeenth-centuries and the oceanic voyages involved. Hence, most study courses concentrated on navigation, geography and astronomy, which also held importance for navigation. Astronomy was taught in accordance with Sacrobosco's (c. 1195–1256) treatise *On the Sphere*, famously commented upon by the Jesuit Christopher Clavius (1538–1612), and hence the reason that the class became known as the "Class of the Sphere" [*Aula da Esfera*].[5] In the first half of the seventeenth-century, the range of topics broadened to include mechanics, hydrostatics, fortifications and military arts, which all fell into the scheme of early-modern mixed mathematics.[6]

Unlike other classes at this college, which were taught in Latin and were only open to enrolled students, mathematics was taught in Portuguese and was open to external participants (Leitão 2003: 235). Historians have since suggested that the purpose of early-modern translations from ancient Greek and Latin into vernacular

[4]For a recent account, see Chalmers (2017).

[5]For an introduction to Clavius and his role in the history of astronomy, see Lattis (1994).

[6]For more on early-modern mixed mathematics and the role of the Jesuits, see Dear (1995).

languages was not about reaching larger audiences, but rather different groups of people.[7] Such was also the case in the Lisbon class. Not only did most of the students who attended the Class of the Sphere not understand Latin, they were also mainly interested in these topics for practical purposes, and not due to any special interest in mathematical theory. Mathematical contents associated with practical applications, such as astronomy, navigation, mechanics or even military arts and fortifications, usually formed part of the education for noblemen, especially around the turn of the seventeenth-century. This is the kind of audience to whom mathematicians such as Stevin and Galileo taught private classes (Chalmers 2017: 28; Valleriani 2010: 72). The typical products of these classes were textbooks, written by the professors-engineers as guides to educate their patrons, with the Class of the Sphere being no different. Most of the extant sources from the Class of the Sphere are notes characteristic of early-modern Jesuit schools. In these schools, students were allocated specific scheduled times to copy from the professors' notebooks (Wallace 1984: 6–8). For this reason, many of the contents of these manuscripts are well organized, almost as if they were scientific treatises.

The first professors of the Class of the Sphere were the Jesuits João Delgado (1553–1612), who had studied mathematics in Rome under Christopher Clavius, and Francisco da Costa (1567–1604), Delgado's student.[8] In regard to the first twenty-five years of this class (1590–1615), the only manuscripts that are extant are from the classes of these two professors.[9] However, as with most professors in this Class, their notes constitute only a small sample of what was actually taught. Although this early material does not specifically address the study of hydrostatics, there are some hints that may help us gain a somewhat better understanding of what role, if any at all, water management played in their mathematical knowledge. Whereas most manuscripts associated with Delgado's classes point only to astronomy and astrology, we know that Delgado actively participated in engineering projects in Portugal.[10] He worked as the leading architect on Jesuit projects such as the buildings for the new College of St. Anthony and College of Arts in Coimbra (*Sphaera Mundi* 2008: 103). More interestingly, there is evidence that Delgado issued an opinion on the project for a new marine entranceway [*barra*] into the port of Lisbon around 1608.[11] Delgado taught in the Class of the Sphere in the 1590s, before returning there to teach again from 1605 to 1608. This means that Delgado issued this opinion while in Lisbon as a professor of mathematics, illustrating the practical side of the work of these professors. This opinion on the

[7]See, for instance, Valleriani (2014: 137).

[8]For a complete list of all of the professors in the Class of the Sphere, the years in which they taught, and their respective discussions, see Baldini (2000: 57–66; 2004: 382–465).

[9]A survey and brief description of most of the extant manuscripts and printed books related to the Class of the Sphere can be found in *Sphaera Mundi* (2008).

[10]For an initial study of Jesuits teaching astrology and other divinatory arts in the Class of the Sphere, see Leitão (2006).

[11]This information is in a codex in the Biblioteca Cadaval, and was mentioned in Albuquerque (1972: 16, n35).

port of Lisbon is particularly interesting, as it was not a project of the Society of Jesus, but rather of the official state authorities. This opinion also suggests that Delgado had knowledge of certain aspects of water engineering. In fact, this is not at odds with what was asked of Jesuits in Italy, who were often involved in water management projects, such as restructuring rivers (Maffioli 1994: 40).

As for Francisco da Costa, who taught in Lisbon from 1602 to 1604, his extant class manuscripts deal mainly with geography. Some sections of his treatises also provide information under the title of "hydrography." However, these sections deal with the locations of certain places on the seas, such as islands and shores, and do not apply any specific study of the motions of water.[12] Moving ahead some years, the same situation occurs with the teachings of Johann Chrysostomus Gall (1586–1643), who went from Ingolstadt to teach in Lisbon from 1620 to 1627, before leaving to work in the Indian missions. In his treatises, the only water-related topics are theories about the tides, which are often otherwise included in astronomy courses. In the third section of his "treatise on the material, celestial and natural sphere," Gall taught geography and hydrography in the same way that Francisco da Costa once had (Gall 1625; Albuquerque 1972: 16). The final part, on the natural sphere, deals with the physical composition of the world, among other things. However, as these were not topics usually included in treatises of mathematics and hydrostatics, but rather in philosophy treatises, I do not address them here. Gall also taught a course on Aristotelian mechanics, which were, on occasion, interrelated with hydrostatics, even though there is no reference to waters in this case (Gall 1623). As was the case with Delgado, Gall and other professors might have been involved in water management projects, even if we have no actual evidence of this.

3 Lembo's Theory of Hydraulics

The teaching of hydraulics in the Class of the Sphere therefore emerges not as a result of engineering practices, but in the teaching of mechanics and small pneumatic devices. These devices were introduced into Renaissance Europe through the works of Hero of Alexandria, whose book *Pneumatics* circulated as part of the humanist revival of ancient science (Valleriani 2014; Laird 2007).

The first treatise to be totally dedicated to these matters was the "Brief Treatise on Hydraulic Machines" [*Tractado breve das Machinas Hydraulicas*] by Giovanni Paolo Lembo, a 25-folio treatise bound with other notes attributed to the same author (Lembo 1615–17).[13] The other topics addressed include basic geometry, navigation, astronomy and the construction and utilisation of certain instruments, such as telescopes. Lembo was in Rome in the years following the publication of Galileo's *Sidereus Nuncius* (1610) and lived through the excitement that this generated among the Jesuits of the Roman College (Shea and Artigas 2003: 30–48).

[12]For an outline of Costa's class notes, see Albuquerque (1972: 25–27).

[13]The full codex has 140 folios, 30 cm in height.

In fact, he was also one of the few signatories of the letter that Jesuit mathematicians wrote to Cardinal Bellarmino (1542–1621) confirming Galileo's observations. Historians have since concluded that this came about due to his advanced skills in building and handling telescopes (Baldini 2014: 131). Lembo's practical skills with the telescope, an astronomical device, explain why he taught astronomy in Lisbon, while probably also accounting for his interest in Hero's pneumatics devices.

Lembo's hydraulic treatise is composed of 65 chapters, each of which corresponds to a single, short proposition. These are drawn from Hero's *Pneumatics* and Vitruvius' (c. 70–15 BC) *On Architecture*. The Vitruvius work was often cited in works on hydraulics, as he included descriptions of hydraulic devices, for example, the Archimedes screw for raising waters and small pumps. Lembo mentioned both of these authors by name, as well as Federico Commandino (1509–1575), who published the most widely circulated Latin translation of Hero's *Pneumatics*.[14] Ugo Baldini has also demonstrated that Lembo often made recourse to Giambattista della Porta (1535–1615) (Baldini 2014: 166, n99). Lembo never mentions him explicitly in the treatise on hydraulic machines, but he does get mentioned once in other class notes by Lembo attached to the same codex. Della Porta wrote extended commentaries on Hero's devices in his book *Pneumaticorum libri tres* (Naples, 1601). He was a famous author in the tradition of the books of secrets, and especially on natural magic. He occasionally got into trouble with the inquisition, with some of his books being prohibited by the *Index*, which probably provides the reason for Lembo not mentioning him explicitly.[15] Baldini also showed that they were in contact with each other on at least one occasion (Baldini 2014: 135).

Adopting the same structure as Hero, Lembo began his treatise with a prelude in which he addressed the structure of matter and the existence of the vacuum. Hero's *Pneumatics* represented one of the ways in which corpuscularianism and the acceptance of the vacuum entered into early-modern Europe. This was the first time that it was taught in the Class of the Sphere, and probably also the first time in Portugal. Both Hero and Lembo rejected the existence of a continuous vacuum, but they did believe in a disseminated vacuum in matter. This disseminated vacuum, sometimes also called an "interstitial vacuum," corresponded to the empty spaces inside of material substances that eventually allowed them to contract and expand.[16] In Lembo's own words "in all elements and mixtures, there are some parts of vacua

[14]Lembo mentions Hero and Commandino for the first time when he begins addressing recipients that contain water and wine, in Chapter 22 (Lembo 1615–17: fol. 103v).

[15]Della Porta's relationship with the inquisition is a little bit more complex. For a recent account, see Tarrant (2013).

[16]For a more thorough explanation, see Grant (1981: 70–74).

spread out, but they are [so] small and thin that they fit in the pores of bodies."[17] Both Hero and Lembo applied this interstitial vacuum to explain, for example, how one is able to insert more air into a vessel that is already filled with air. Moving beyond Hero, and applying his Aristotelian studies, Lembo commented that most philosophers did not believe in the existence of the vacuum.[18] Nevertheless, Lembo also drew the line between philosophers and practitioners of hydraulics [*os hidráulicos*]. He stated that philosophers explain the phenomenon of putting more air inside of a vessel by describing how the air gets more "condensed," that is, more aggregated. However, Lembo said that this amounted to no explanation whatsoever. The reference to "condensed air" represented only a description of the state of the air, but did not explain how this actually happened. Hence, Lembo applied the philosophers' own methodology against them in asking for a causal explanation. He concluded that philosophers, thus, had no option but to apply the disseminated vacuum concept, as that allowed the "condensation" of matter to happen.

Lembo's position is surprising, to say the least. His belief in the existence of the disseminated vacuum and his usage of it to explain the condensation of matter makes him no different from any mechanical and corpuscularian philosopher as regards this topic. Even Della Porta argued explicitly against Hero's disseminated vacuum (Della Porta 1601: 5–9; Baldini 2014: 176–177). Hence, Lembo's take on the vacuum, and his explicit challenge to the traditional explanation of natural philosophers, not only ran counter to Della Porta's text, one of the most up-to-date on the matter, but also seemed to go against the Aristotelian philosophy that he, as a Jesuit, had committed to following. Was this uncommon among Jesuits in the 1610s? According to the *Constitutions* of the Society of Jesus and the *Ratio studiorum*—the study plan for Jesuit colleges worldwide—, the Jesuits had to follow Aristotle whenever doubts in philosophy might arise. In the 1580s, the Society's Superior General, Claudio Acquaviva (1543–1615), recommended to all Jesuits: "[N]o one shall defend any opinion that goes against the axioms received in philosophy or in theology, or against that which the majority of competent men would judge is the common sentiment of the theological schools" (Feingold 2003: 18). In 1611, Acquaviva reissued this request for intellectual uniformity among Jesuits (Feingold 2003: 19). Although the most serious problems arose in theology, the superior's statements were general enough so as to also include philosophy. And, as there appears to have been a need to keep reminding Jesuits, this would mean that, at least by the 1610s, certain Jesuit scholars still held opinions that threatened this uniformity. Such was the case in the field of astronomy, for instance, in which some Jesuits had begun to argue in favor of the fluidity of the heavens (Feingold 2003: 20). However, not much is known with regards to the vacuum. In fact, by the 1610s, neither hydraulics nor mechanics were the main fields of study for Jesuit mathematicians, and therefore it is probable that not many scholars beyond Lembo

[17]"por todos os elementos e mixtos estão espalhados algumas partes do vaccuo, ainda que pequenas e delgadas, põem estas partes do vaccuo nos poros dos corpos" in Lembo (1615–17: fol. 95r).

[18]See Aristotle, *Physics*, Book IV, Chap. 9.

were turning their attentions to theories on the existence of the vacuum.[19] However, most Jesuit natural philosophers would have agreed that there was simply no space for any vacuum in nature.[20]

Nevertheless, we do know of one particular episode in Lembo's life that may shed light on this matter. Following the publication of *Sidereus Nuncius* (1610), Cardinal Bellarmino, the main inquisitor during the affair of 1616, asked the mathematicians in the Jesuit Roman College to confirm Galileo's observations (Langford 1992: 79–104). Five Jesuits signed the letter that was produced, including Lembo (Favaro 1901: 92). The most famous signatory was Christopher Clavius, the Society's leading mathematician. In that letter, while all of Galileo's observations were confirmed, not all of his conclusions were agreed upon. Indeed, even among the Jesuits who signed the letter, there was some disagreement on these matters. For instance, regarding the existence of mountains on the moon, the letter states that "the inequality of the moon cannot be denied; but it seems more probable to Fr. Clavius that it is not the surface that is unequal, but rather that the lunar body is not uniformly dense and that it has denser parts and others rarer, as it happens with the spots that are seen by ordinary vision" (Favaro 1901: 92). Nevertheless, some of the letter's other signatories did not share this opinion, and this was also included in the letter: "Others of us think that they truly are unequal with the surface: however, there is not as much certainty related to this so that we could affirm it without a doubt." Hence, even if Lembo was not the one who disagreed with Clavius, he was aware that such disagreements might happen.

Lembo's take on the vacuum does not imply a complete rejection of the Aristotelian system, which would probably not be acceptable to the majority of early-seventeenth-century scholars, and not just to the Jesuits. This rather conveys how, despite claims to uniformity, early-modern Jesuits did not monolithically adopt Aristotelianism. Lembo did, in fact, use a strong Aristotelian language in his introduction on siphons (Lembo 1615–17: fols. 97v–98v). He probably wrote this introduction for a pedagogical purpose, in order to ensure that his students better understood the devices contained in the subsequent propositions on different kinds of siphons. In this introduction, Lembo focused most of his attention on explaining the striking, and yet common, phenomena seen in siphons—that once water starts running out of a vessel through a siphon, it does not stop flowing until all of the water has been drawn out. He first stated that many hydraulics practitioners explained this phenomenon by analogy with a balance (Lembo 1615–17: fols. 97v–98r). The siphon section where the water goes up is one of the arms and the part in which the water goes down is the other. The latter would be heavier, and thus the part of the siphon inside of the vessel would continue to draw water into the siphon in a search for equilibrium. However, Lembo affirmed that this was wrong, for, if one were to imagine a siphon with its end drawing the water back into the same original vessel, then this would lead to perpetual motion, which is impossible.

[19]Clavius planned to write on these topics so as to include them as part of the curriculum of the Jesuit Academy of Mathematics in Rome, but ended up not doing so (Baldini 2003: 62).
[20]See, for example, *Commentariorum* (1594: 61–64).

Lembo did not actually state this, but, for continuous out-flow to happen, the end of the siphon would need to be at a height below the vessel. In fact, the omission of this information is what allowed his explanation to work.

Unlike his approach to the vacuum, Lembo's explanation of how siphons work was very Aristotelian. It relied on the fact that water, like the earth, always moves to its resting place, closest to the centre of the universe (Lembo 1615–17: fol. 98r). Thus, it only moves out of a siphon when the siphon's end is below the water surface in the vessel, and thus closer to the centre of the universe, its natural place of rest. This way of explaining how siphons work was particularly ingenious, as it also allowed him to explain another phenomenon that also perplexed most practitioners of hydraulics, such as Simon Stevin and Galileo. In two vessels connected at the bottom by a siphon, the water surface always remains at the same height, even when one of the vessels is larger and contains much more water—a phenomenon that became known as the hydrostatic paradox. However, according to Lembo, this phenomenon was just another example of the theory that he had just presented: the water surface always remained at the same height because the water in both vessels was seeking its natural place at the centre of the universe. Thus, he did not perceive it as a paradox.

The rest of the treatise deals with many different devices. For each, Lembo referenced applications, including methods of underwater defence, siphons able to bring water through hills or ways of removing wine from different vessels. This once again inserted Lembo's text into the pneumatics tradition of Hero. In fact, Lembo's text seems to be the first known Portuguese translation of Hero's *Pneumatics*, even if only a partial one. However, the differences between Lembo and Hero also emerge in the practical aspects. Hero and Della Porta introduced these useful devices without spending much time on their respective applications. However, in Lembo's text, the different usages of each device become clear in almost every proposition and in the way that the treatise is structured. For example, the first two propositions do not exist in the treatises by Hero and Della Porta. The propositions explain "how someone can cross a river without a boat, and still fight," and "how one can go underwater without getting wet," by means of human-size vessels (Lembo 1615–17: fols. 95r–96v). Finally, before entering into the theory of siphons, Lembo added a proposition for "a curly-shaped instrument with which it is possible to raise great amounts of water," which is the Archimedes screw (Lembo 1615–17: fols. 96v–97v). Lembo not only detailed what kinds of material should be used in assembling one section of this instrument, but also finished by saying that "this instrument is highly useful to irrigate small gardens that are close to rivers." Almost all of the other propositions are laid down in a similar way.

4 Hydrostatics from Flanders

The next Jesuit to teach hydrostatics in Lisbon was Simon Fallon (1604–1642). Fallon was an English Jesuit who arrived from Spain and who ended up becoming the Chief Engineer of the Portuguese king after 1640 (Baldini 2000: 65, n 47). His extant manuscripts mainly deal with astrology and the sphere. However, in one of the manuscripts on astrology, there are propositions on mechanics under the title "practical and speculative geometry," with topics including the calculus for centres of gravity and simple machines. There are also propositions on hydrostatics, especially on specific gravity.[21] These same topics appear in a manuscript dated 1638 entitled "Mathematical topics."[22] These hydrostatics topics appear when Fallon is discussing the positioning of the earth's centre. First, Fallon addresses whether the rules of gravity that he has already introduced also apply "in the seas" (Fallon 1638: fol. 198r). He then discusses the "proportion that heavy bodies have among themselves," and includes a table with proportions between the specific gravities of heavy bodies (Fallon 1638: fol. 199v). These topics were also discussed, but in much greater detail, a few years later in the classes of Hendrick Uwens. As Uwens wrote a full treatise on these topics of mechanics, we thus move directly to his sources.

Hendrick Uwens travelled to Lisbon with his mathematics professor Joannes Ciermans (1602–1648). They both left the Leuven Jesuit College in the first semester of 1641, planning to depart to the Asian missions. Ciermans began teaching in the fall of 1641. In Leuven, Ciermans had been a professor of mathematics for at least five years. Uwens, on the other hand, was finishing his studies of theology there, having completed his mathematics studies two years earlier. When he arrived in Portugal, he was only 23 years old but had already been a member of the Society for seven years. While it is difficult to ascertain the precise contents of Ciermans' mathematical classes in Leuven, in his last year in Flanders, he published *Disciplinæ Mathematicæ traditæ anno* (1640), "the mathematical disciplines delivered in a year." In this book, Ciermans showed how the different sub-disciplines of mixed mathematics could be taught in different months. For instance, he dedicated the month of January to the teaching of statics and February to hydrostatics. What he taught in Lisbon was probably no different from the contents in his book, and he may well have brought copies with him to Lisbon.[23] As Ciermans wanted to teach almost all of the mixed mathematics topics in a single book, everything had to be highly condensed. However, as Ciermans was Uwens' professor in Flanders, Uwens' classes provide a better illustration of just what and how Ciermans taught. In the year after Ciermans taught in Lisbon, Uwens began teaching in the Class of the Sphere through to the Spring of 1646. In 1647, he boarded a ship to Goa, where he was placed in the Mughal mission and became the tutor to the Mughal Emperor's son.

---

[21]This description comes from Albuquerque (1972: 37).

[22]*Materias mathematicas nas quais se contem astronometria, astrologia e outronometria*, BNP, Cod. 2127.

[23]There are two copies in the BNP: BNP, Res. 3140; BNP, S.A. 624 A.

The only source from the classes of Hendrick Uwens in Lisbon is the *Treatise of Statics*, from 1645. There are two extant copies, one in the Portuguese National Library (BNP) that is not signed, and another in the Public Library of Évora (BPE), written in a different hand and signed by João Nunes Tinoco (ca. 1610–1689).[24] Tinoco was a Portuguese architect, as his father had been, who worked on important architectural projects in seventeenth-century Lisbon (Sousa Viterbo 1922: Vol. 3, 112–116). Indeed, it would seem that Tinoco attended Uwens' classes while already undertaking some of his projects, including the construction of the Monastery of St. Vincent Outside the Walls [*Mosteiro de S. Vicente de fora*]. The fact that Tinoco was the scribe for one copy reinforces how these classes were being taught to a class of noblemen who were interested in engineering. The treatise does not seem to have been intended for publication, as there are no prefaces or forewords, but it might well have circulated among students. The importance of this treatise on statics is also illustrated by the mathematical rigor with which the pictures are drawn and the systematic framework applied to the treatise.

The differences between the two manuscripts are minimal, so I here limit the scope to a description of the manuscript from the National Library. The manuscript is physically a collection of 211 folios, bound together in 21 centimetres of parchment. The front cover provides the name *Treatise of Statics* for the manuscript.[25] It explicitly states that the priest Henrique Boseo, the name by which Uwens was known in Portugal, lectured upon the contents in 1645 at the Royal Academy of Mathematics of the College of St. Anthony. The treatise is split into five major parts: the calculus of centres of gravity; mechanics; hydrostatics; aerostatics, as a continuation of the previous chapter; and pyrostatics, dealing briefly with the military arts. This was a then-typical subdivision for the mixed mathematical discipline of statics.[26] The chapters on hydrostatics and aerostatics are the second largest, after that on mechanics, and together occupy a total of 70 folios, which is about a third of the whole treatise.

The hydrostatics section contains two major chapters, with each organized as a mathematical treatise. There are propositions containing a statement, which are then followed by corresponding demonstrations. These are followed by corollaries, which are applications of the theoretical statements. Whenever a corollary needs further development, it is split up into lemmas. As Uwens states at the very beginning, the first chapter is on "things that swim in the water and descend beneath it," with the second being on "different ways to move and raise waters" (Uwens 1645: fol. 113v).[27] The first chapter took its source from the tradition of Archimedes' *On Floating Bodies*. Archimedean mathematics, like mechanics and hydrostatics, developed in the early-modern period through works by mathematicians such as Niccolò Tartaglia (1500–1557), Simon Stevin, and Galileo. Indeed,

[24]BNP, Cod. 4333 (henceforth referred to as "Uwens"); BPE, CXXVI/2–7.

[25]The BPE copy is entitled "Mathematical treatise of statics."

[26]See, for example, the scheme of the mathematical sciences by the Jesuit Paul Guldin in Guldin (1635: 21).

[27]This sub-subdivision is also present in Guldin's scheme of mathematics.

Uwens was well aware of their contributions to hydrostatics, which he explains in his treatise while not mentioning all of these authors by name. That Uwens started out with Archimedes means that he followed a highly mathematical approach to hydrostatics, as Stevin and Galileo had done. However, this did not prevent him from addressing Hero's tradition of hydrostatics. In the second chapter, Uwens laid out his theory of siphons and other devices. Thus, the Uwens text is unique in bringing together Archimedean hydrostatics and Hero's pneumatic devices. Yet, he still addressed these traditions in different ways. Unlike Hero and Lembo, Uwens retained the Euclidean format of propositions when discussing pneumatic devices. However, he went still further, by arranging the contents in a different order. He grouped all propositions dealing with siphons first, under the title of "the way of moving waters by means of filled siphons" (Uwens 1645: fol. 130v). Those dealing with pumps and other devices he then grouped under the title "the way of moving waters by means of an exterior force" (Uwens 1645: fol. 150r).

Uwens began the chapter on siphons by addressing whether or not the vacuum existed. He agreed with Aristotelian philosophers, and therefore denied their existence. However, he did not like the philosophers' explanations. Philosophers then commonly maintained that water was raised by means of a "fear of vacuum." However, if there was no vacuum, why would nature fear it and be moved by it? To correct this, Uwens affirmed "that nature, due to its conservation, ties things among themselves; … solid bodies have this tying in their union, and so also have liquids…"[28] Nevertheless, this tying of solids and liquids still required an explanation. However, that explanation was a facet that only philosophers lacked, as he said that "whatever [explanation] it is, let the philosophers examine it."[29] As a mathematician, he simply acknowledged that the vacuum did not exist and worked on that basis. He wanted to maintain this distinction so as to avoid having to explain the cohesion of matter.

Although Uwens does not address this topic again in the treatise, there is more to this comment than there might seem to be on first reading. In *Two New Sciences* (1638), Galileo also stated that there was a "tying" between solid things, whose forces of cohesion he compared to binding by ropes (Galileo 1638/1954: 6–10). He furthermore added that this also explained the cohesion of liquids (Galileo 1638/1954: 17). The reason that Galileo put forward for this tying in liquids was the afore-mentioned fear of vacuum (Galileo 1638/1954: 13–15). However, Galileo accepted the existence of the vacuum, and so his explanation did not encounter the problems that Uwens singled out for Aristotelian philosophers. Whether or not he was thinking of Galileo, we cannot be certain.[30] Uwens did not believe in any

[28]"Digamos logo que a natureza para sua conservação ata entre sy as couzas de sorte que não se podem separar sem succeder outra em seu lugar; esta atadura tem os corpos solidos de sua união da mesma a tenhão tambem os liquidos a qual seja examinem os Philosophos." In Uwens (1645: fol. 130r).

[29]Ibidem.

[30]Uwens departed from Flanders for Lisbon in the spring of 1641, so there had been time for him to come across Galileo's book, or at least to discuss some of its contents with other readers. For a short account of the circulation of Galileo's *Two New Sciences,* see Raphael (2017: 15–19).

vacuum, but did acknowledge a major fault in the explanation applied by Aristotelian philosophers. Finally, he also declared, in his hydrostatics treatise, that the non-existence of the vacuum was confirmed "by many experiments." Thus, he was making rhetorical recourse to experiments, as was Galileo's practice, to argue against the existence of vacuums.

After these axioms on the vacuum, Uwens introduced his theory of siphons, but in a fashion different than Lembo. Uwens extended his introduction of siphons to include all types of siphons. Even though he wrote only four propositions on siphons, each had several corollaries. Indeed, the way that he discussed them also greatly differed from Hero or Lembo. For about twenty folios (130v–150r), Uwens applied different kinds of siphons to discuss what came to be called Stevin's law. He began inquiring about the degree to which the bottom of a water-filled vessel might "feel the weight" [*sentir o peso*] of that water. This "feeling of the weight" is what modern science calls "pressure." Uwens knew that this depended not on the amount of water, but rather on its height. In *The Art of Hydrostatics*, theorem VIII, Stevin had also already reached this conclusion (Stevin 1955: 412–415). In fact, in the 2nd corollary of the 3rd proposition, Uwens introduced an example that was also applied by Stevin—that of a balance with a plate free in open air, and another one at the bottom of a vessel filled with water (see Fig. 1) (Uwens 1645: fol. 133v; Stevin 1955: 492). The weight needed on the open-air plate to maintain the balance in equilibrium was much greater than the amount of water present in the vessel. And the weight needed for equillibrium was always the same, regardless of the width of the vessel or the amount of water. What mattered was the height of the water in the vessel.

Uwens never acknowledged Stevin by name in his discussion, despite having mentioned him previously when explaining the inclined plane (Uwens 1645: fol. 104v). However, Uwens also did not explain this phenomenon in the same way that Stevin did. Indeed, Stevin never attempted to explain how this happened. Uwens, on the other hand, did. As seen, he observed that, both in wide and thin vessels (i.e., siphons), the force of the water at the bottom was always the same, even though the latter might have much less water than the former (Chalmers 2017: 41, 44). Uwens described how "what they [the vessels with water] lose in quantity, they gain in the hurry of the motion."[31] Hence, he continues by saying that "where the hurry is doubled, so is the strength" [*onde dobra a preça dobraselhe tambem a força*] of the water. At first, this would seem rather obscure, but Galileo does use this approach in his book *Discourse on Bodies in Water* in a clearer way when explaining the hydrostatic paradox (Galileo 1612/1960: 17). In two vessels connected at the bottom by a pipe, the water surface always remains at the same height, even when one of the vessels is larger and has much more water than the other (see Fig. 1). Galileo applies levers to explain this paradox, but not in the Archimedean form of statics. In *Problems of Mechanics*, a disciple of Aristotle explained the lever by means of the dynamic motion of its arms (Dyck 2006: 374, 381). A longer lever

[31]"a pouca agoa EF o que perde na cantidade ganha na preça do movimento," in Uwens (1645: fol. 132v).

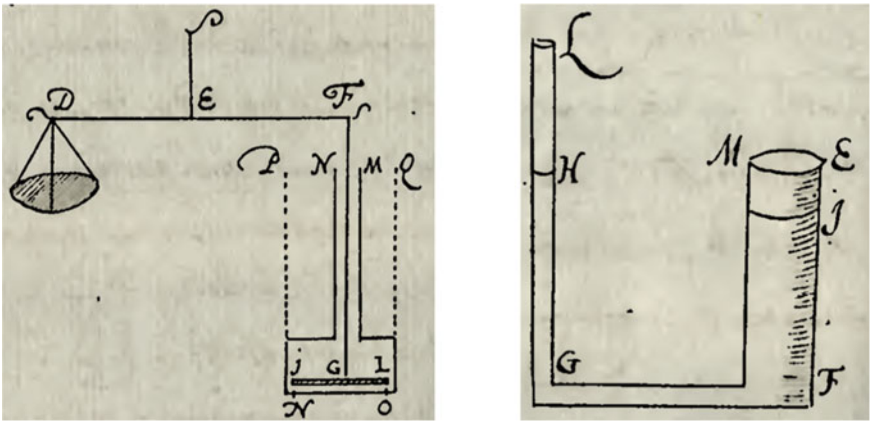


Fig. 1 *Left*: balance with a plate free in the open air and another one at the bottom of a water-filled vessel (Uwens 1645: fol. 133v.); *right*: two vessels joined together at the bottom by a pipe (Uwens 1645: fol. 139v)

arm simultaneously covers much more space than shorter arms can. The same happens in a thin siphon, where water rises much faster than in a wider siphon, even though the quantity might be the same. According to Galileo, this difference in speed is contained in the water as a moment of velocity, which Uwens called the "hurry of the motion." Hence, the Uwens explanation of the hydrostatic paradox amounted to the same as Galileo's that was discussed in detail in proposition 3 (Uwens 1645: fols. 139r–142v). Naturally, as a good teacher, he introduced this in the most dramatic way: he imagined two vessels connected by a pipe at the bottom, where a little water on the thinner side could keep all of the water of the seas in equilibrium on the other, wider side. Uwens was thus reuniting the theory of siphons with Archimedes, whose famous quote, "[G]ive me a place to stand and I will move the earth", he would often mention when teaching levers and pulleys in the mechanics section.

Much more could be said about Uwens' approach to hydrostatics. However, I shall finish this analysis here with the way in which Uwens included practicality, such an important feature of the Class of the Sphere, in a treatise that otherwise seemed more theoretical. More theory thus does not necessarily imply a disregard for applications. After proposition 2 in Chap. 1, in which Uwens explained that bodies that are less dense than water float, he laid down the Archimedes principle of buoyancy as the 1st corollary. Furthermore, Uwens then presented a series of real cases in which this theory might be applied. In the 2nd and 3rd corollaries, he reported on how objects that otherwise seem very heavy can actually float: ships, metals or even islands, he said. And he also explained how a dead body begins to float after some time in deep water. After this short proposition, Uwens explained how bodies weigh different amounts under water and provided a numerical relationship between the densities of different materials in a table similar to that put forward by Marino Ghetaldi (1568–1626) in *Promotus Archimedes*

(1603). After this, he then introduced the last and longest proposition of this chapter, on the method of how to raise sunken ships from the seabed (Uwens 1645: fols. 126r–129r). The method was explained by Tartaglia in *Regola generale di soleuare ogni fondata nave e navili con ragione* (1551) and consisted in filling the bottom of two sailing ships with water, but only to the extent that they did not sink. After filling them with water, they were then tied to the sunken ship. Then, the water in the bottom of the floating ships was gradually released. In this way, the floating ships then rose higher on the surface of the water and pulled the sunken ship up with them. Nevertheless, for this to work, sailors or engineers had to know precisely how much water each ship could carry. Thus, the theory of floating bodies was needed, as had been presented in the first chapter.

5 Conclusion

Following the Uwens classes, and for the rest of the seventeenth-century, there would seem to have been no further teaching of hydrostatics in the Class of the Sphere. Up until the end of the century, nine different Jesuits held this chair of mathematics in Lisbon. However, the archives in Portugal only contain class notes from two—the Englishman John Rishton (c. 1615–1656), who taught from 1651 to 1652, and the Bohemian Valentin Stansel (1621–1705), who held the chair from 1658 to 1663. Their classes dealt more broadly with astronomy, and neither addressed mechanics or hydraulics. The absence of the teaching of hydraulics in the sources might derive from the Class of the Sphere's primary goal of serving the crown's interests, which, after 1640, were mostly focused on the Portuguese War of Restoration (1640–1668). In fact, these years witnessed the opening of another Jesuit mathematics class, in Elvas, the largest Portuguese town on the border with Spain, almost exclusively focused on military topics, especially fortifications (Leitão 2003: 237).

Matters then began to change at the turn of the eighteenth-century. In 1692, the Superior General of the Society of Jesus called for a reform of Jesuit mathematical teaching in Portugal (Baldini and Leitão 2004: 648–664, 704–723). Following this reform, which subsequently took place after 1700, all Class of the Sphere professors were Portuguese. The first one was Luíz Gonzaga (1666–1747), who taught there from 1700 to 1706. Although the manuscripts from his classes still do not address hydraulics-related topics, there is a 9-folio manuscript of an opinion that Gonzaga submitted to the king about the "plumbing of the Mondego" River in 1702 (Gonzaga 1702). The mathematics reform in Portugal also led to the appearance of printed mathematics books, which reveal a focus turned more towards theoretical mathematics, such as Euclidean geometry. The study of Gonzaga's opinion on the Mondego River falls beyond the scope of this article, but it should prompt further studies on works of hydraulics undertaken by Jesuit mathematicians in eighteenth-century Portugal. Indeed, even though topics of hydrostatics seem to be absent from eighteenth-century Class of the Sphere manuscripts, its professors might still have been working in the field, as Delgado was in the early 1600s (*Sphaera Mundi* 2008: 197–243). Evidence of this stems from the later work of the

Portuguese Jesuit Estêvão Dias Cabral (1734–1811), whose major contributions are addressed in another article in this volume. By 1700, the field of hydraulics had undergone deep changes, with contributions by Evangelista Torriceli (1608–1647), Blaise Pascal (1623–1662) and Robert Boyle (1627–1691), among others. Nevertheless, in the end, they all continued to deal with the same problems that had existed in hydraulics in the first half of the seventeenth-century—the vacuum, pressure and cohesion of matter.

Although arriving from different scientific traditions, both Lembo and Uwens addressed all of these problems in their classes. This diversity of traditions derives, in great part, from the international character of the Class of the Sphere. Lisbon was the point of departure for every ship that sailed for the Portuguese territories overseas in the early-modern period, and the Jesuits had many of their missions there. Thus, all Jesuit missionaries had to pass through Lisbon, where they might stay for weeks or years. During this stay, those with mathematical training taught in the Class of the Sphere. As they were coming from different countries, their mathematical influences and backgrounds also differed substantially. For instance, both Lembo and Uwens explained the hydrostatic paradox, even while taking different approaches. Lembo believed in a disseminated vacuum inside all matter, but Uwens did not, and both criticized what most Aristotelian philosophers said on the topic. And, nevertheless, as members of the Society of Jesus, they surely also saw themselves as Aristotelians.

This variety of ideas in a group that is often not at the center of the history of science—Jesuit mathematicians teaching in Iberia—should lead to a rethinking of the role of these characters in the development of both hydrostatics and early-modern science more generally. It was neither the fact that they were teaching in Iberia nor their membership in the Society of Jesus that prevented them from engaging with the most recent scientific results in hydrostatics of the time. On the contrary, sometimes these Jesuits went beyond the most advanced contributions of their time, even if not in the way that we would have expected them to go.

References

Manuscripts

Fallon, Simon. 1638. *Materias mathematicas nas quais se contem astronometria, astrologia e outronometria*, Biblioteca Nacional de Portugal (BNP), Cod. 2127.

Gall, Johann Chrysostomus. 1623. *Tractado breve da mechanica*, Arquivo Nacional da Torre do Tombo (ANTT), Ms. Liv. 2340, fols. 150r–165v.

Gall, Johann Chrysostomus. 1625. *Tratado sobre a esphera material, celeste, e natvral por o padre mestre Christovão Galo…*, BNP Cod. 1869.

Gonzaga, Luís. 1702. Opinion on the plumbing of the Mondego river. Biblioteca da Ajuda, 51-VI-16 [doc 17].

Lembo, Giovanni Paolo. 1615–17. *Tratado breve das machinas hydraulicas*, ANTT, Ms. Liv. 1770, fols. 95r–120v.
Uwens, Hendrick. 1645. *Tratado da estática pello p. m. Enrique Boseo…*, BNP, Cod. 4333; Biblioteca Pública de Évora, CXXVI/2–7.

Primary Sources

Aristotle, *Physics*, tr. Robin Waterfield (Oxford: Oxford Univ. Press, 1996).
Commentariorum collegii Conimbricensis… in octo libros physicorum… secunda pars (Lyon, 1594).
Ciermans, Joannes, *Disciplinæ mathematicæ traditæ anno* (1640); BNP, Res. 3140; BNP, S.A. 624 A.
Della Porta, Giovanni Battista, *Pneumaticorum libri tres* (Naples, 1601).
Favaro, Antonio, *Le Opere de Galileo Galilei* XI.
Galilei, Galileo, *Discourse on Bodies in Water*, tr. Thomas Salusbury (1663), with Introduction and Notes by Stillman Drake (Urbana, IL: Univ. of Illinois Press, 1960).
Galilei, Galileo. 1954. *Dialogues Concerning Two New Sciences* (1638), tr. by Henry Crew & Alfonso de Salvio (orig. 1914). New York: Dover Publications, Inc.
Guldin, Paul. 1635. *De centro gravitatis trium specierum quantitatis continuæ*. Vienna.
Stevin, Simon, *The Principal Works of Simon Stevin, Vol. 1*, ed. E. Dijksterhuis (Amsterdam: Swets and Zeitlinger, 1955).

Secondary Sources

Sphaera Mundi: A Ciência na « Aula da Esfera » . Manuscritos Científicos do Colégio de Santo Antão nas colecções da BNP, ed. Henrique Leitão (Lisboa: Biblioteca Nacional de Portugal, 2008).
Albuquerque Luís de, "A 'Aula de Esfera' do Colégio de Santo Antão no Século XVII," *Agrupamento de Estudos de Cartografia Antiga*, LXX Secção de Coimbra (Coimbra: Junta de Investigações do Ultramar, 1972).
Baldini, Ugo, "The Portuguese Assistancy of the Society of Jesus and Scientific Activities in its Asian Missions until 1640," in *History of Mathematical Sciences, Portugal and East Asia* (Lisbon: Fundação Oriente, 2000).
Baldini, Ugo, "The teaching of mathematics in the Jesuit colleges of Portugal from 1640 to Pombal," in: *The Practice of Mathematics in Portugal. Papers from the International Meeting organized by the Portuguese Mathematical Society, Óbidos, 16–18 November, 2000*, eds. Luís Saraiva and Henrique Leitão (Coimbra: Imprensa da Universidade de Coimbra, 2004).
Baldini, Ugo, "Giovanni Paolo Lembo's lessons in Lisbon: a partial content analysis," *Proceedings of the International Conference History of Astronomy in Portugal: Institutions, Theories, Practices*, ed. Luís Saraiva (Porto: Sociedade Portuguesa de Astronomia, 2014).
Baldini, Ugo, "The Academy of Mathematics of the Collegio Romano from 1553 to 1612," in *Jesuit Science and the Republic of Letters,* ed. Mordechai Feingold (Cambridge, Mass.: MIT Press, 2003).
Baldini, Ugo and Henrique Leitão, "Documents and Letters," Appendix C, in *The Practice of Mathematics in Portugal. Papers from the International Meeting organized by the Portuguese Mathematical Society*, eds. L. Saraiva and H. Leitão (Coimbra: Acta Universitatis Conimbrigensis, 2004).
Chalmers, Alan, *One Hundred Years of Pressure: Hydrostatics from Stevin to Newton* (Springer, 2017).
Dear, P., *Discipline and Experience: The Mathematical Way in the Scientific Revolution* (Chicago: Chicago University Press, 1995).

Dyck, Maarten, “Gravitating towards stability: Guidobaldo’s Aristotelian-Archimedean Synthesis,” in *History of Science*, 2006, xliv.

Feingold, Mordechai, “Jesuits: Savants,” in *Jesuit Science and the Republic of Letters*, ed. Mordechai Feingold (Cambridge, Mass.: The MIT Press, 2003).

Giurgevich, Luana, “Visiting Old Libraries: Scientific Books in the Religious Institutions of Early Modern Portugal,” *Early Science and Medicine*, 2016, 21:252–272.

Sousa Viterbo. 1899–1922. *Diccionario Historico e Documental dos Architectos, Engenheiros e Constructores Portugueses* (Vols. 1–3). Lisbon: Imprensa Nacional, 1899–1922.

Grant, Edward, *Much Ado About Nothing: Theories of space and vacuum from the Middle Ages to the Scientific Revolution* (Cambridge: Cambridge Univ. Press, 1981).

Guldin, Paul, *De centro gravitatis trium specierum quantitatis continuæ* (Vienna: 1635).

Maffioli, Cesare, *Out of Galileo: The Science of Waters 1628–1718* (Rotterdam: Erasmus publishing, 1994).

Laird, W. R. “Hero of Alexandria and Renaissance Mechanics,” in *Mathematical Practitioners and the Transformation of Natural Knowledge in Early Modern Europe*, eds. L. B. Cormack et al. (Springer 2017), pp. 149–165.

Langford, Jerome, *Galileo, Science and the Church* (Ann Arbor, MI: The Univ. of Michigan Press, 1992), 3rd ed.

Lattis, James, *Between Copernicus and Galileo: Christoph Clavius and the collapse of Ptolemaic cosmology* (Chicago: Chicago Univ. Press, 1994).

Leitão, Henrique, “The First Telescopes in Portugal,” in *Actas do 1º Congresso Luso-Brasileiro de História da Ciência e da Técnica* (Évora: Univ. de Évora, 2001), p. 107–118.

Leitão, Henrique, “Jesuit Mathematical Practice in Portugal, 1540–1759,” in: *The New Science and Jesuit Science: Seventeenth Century Perspectives*, ed. Mordechai Feingold (Dordrecht: Kluwer Academic Publishers, 2003), pp. 229–247.

Leitão, Henrique, “Entering Dangerous Ground: Jesuits Teaching Astrology and Chiromancy in Lisbon,” *The Jesuits II: Cultures, Sciences and Arts 1540–1773*, eds. John O’ Malley SJ, Gavin A. Bailey, Steven. J. Harris & T. F. Kennedy SJ (Toronto: University of Toronto Press, 2006), pp. 371–389.

Navarro, Víctor, “Tradition and Scientific Change in Early Modern Spain: The Role of the Jesuits,” in: *Jesuit Science and the Republic of Letters*, ed. Mordechai Feingold (Cambridge, Mass.: The MIT Press, 2003), pp. 331–387.

Portuondo, María M., “Iberian science: Reflections and studies,” *History of Science*, 2017, 55 (2):123–132.

Raphael, Renée, *Reading Galileo: Scribal Technologies and the Two New Sciences* (Baltimore, MD: Johns Hopkins University Press, 2017).

Shea, William and Mariano Artigas, *Galileo in Rome: The Rise and Fall of a Troublesome Genius* (Oxford: Oxford Univ. Press, 2003).

Tarrant, Neil, “Giambattista della Porta and the Roman Inquisition: censorship and the definition of Nature’s limits in sixteenth-century Italy,” *British Journal for the History of Science*, 2013, 46(4):601–625.

Valleriani, Matteo, “Ancient Pneumatics Transformed during the Early Modern Period,” *Nuncius*, 2014, 29: 127–173.

Valleriani, Matteo, *Galileo Engineer* (Springer, 2010).

Wallace, William, *Galileo and His Sources: The Heritage of the Collegio Romano in Galileo’s Science* (Princeton, NJ: Princeton Univ. Press, 1984).

The Making of a Hydraulics Expert: Estevão Dias Cabral (1734–1811)

Henrique Leitão

Abstract
The personal trajectory of Estevão Dias Cabral (1734–1811) highlights some of the more pressing problems of late eighteenth century hydraulics and their relation to civil engineering. It also puts into evidence some specific conditions for the practice of science at the period. Cabral was one of the many Jesuits who were expelled from Portugal following the Marquis of Pombal's decree in 1759. Like several of his fellow Jesuits, he managed to apply his sound, but not specialized, training in science in a very flexible manner, progressively directing his interests towards hydraulic problems: first as a teacher of mathematics, then as an author of books on erudite antiquarianism, and, finally, as a technical consultant on various problems related to water management, the control of river flows and the prevention of floods. Cabral was also an inventor of technical improvements, the most notable being an innovative paddle wheel that allowed for the measurement of flow velocity at different depths. Upon returning to Portugal in 1788, he became the Kingdom's leading expert in the study and control of river flows, doing important work on some of the country's major rivers.

1 Introduction

By the late eighteenth century, civil engineering and, more specifically, hydraulic engineering had not yet emerged as truly autonomous professional fields. Hydraulics experts existed, but not as an identifiable professional group. A centuries-old tradition of studies on hydraulic questions had already led to the creation

H. Leitão (✉)
Centro Interuniversitário de História das Ciências e Tecnologia, Faculdade de Ciências, Universidade de Lisboa, 1749-016 Lisboa, Portugal
e-mail: leitao.henrique@gmail.com

A. Duarte Rodrigues and C. Toribio Marín (eds.), *The History of Water Management in the Iberian Peninsula*, Trends in the History of Science,
https://doi.org/10.1007/978-3-030-34061-2_17

of a specific and rich body of knowledge, but a distinct group of experts was only then beginning to take shape as an independent professional group. The specialists in the field—and there were quite a number of them—came from a variety of different origins and by way of very distinct professional paths. But how exactly did a person end up becoming such an expert? Instead of attempting a broad and thorough investigation of this question, this essay proposes a much more modest, but, it is hoped, still valuable approach. In this chapter, I follow the career of one such specialist, the Portuguese Estevão Dias Cabral (1734–1811), who made relevant contributions to hydraulic engineering in both Italy and Portugal. Starting as a simple teacher of mathematics, Cabral ended his career as a recognized expert in the field, the first person in Portugal to whom the title of "professor hidráulico" was given. By looking, in some detail, at the personal trajectory of this poorly known figure, we may gain a number of insights into the mix of challenges and opportunities, of specific knowledge and occasional circumstances that might congregate to create such a specialist. In the case of Cabral, one important aspect to note is the way in which he acquired his specialist status of undisputed authority in a country where the field still remained very much in its infancy.

* * *

Estevão Dias Cabral was born in the small town of Tinalhas, near Castelo Branco, on February 23, 1734.[1] As with many youth at that time, especially those showing intellectual promise, he went on to study at a Jesuit college, in his case, at the college in Coimbra. The school established by the Jesuits in Coimbra was renowned as one of the country's leading educational institution, with its fame having spread beyond the national borders. Cabral's acquaintance with the Jesuits soon evolved into a deeper commitment, and he formally entered the Society of Jesus on February 14, 1750.[2] His joining the Society seems to have displeased his father—who obviously had other plans for his son—but Estevão's determination was solid, and he remained at the Coimbra college, where he pursued his studies. Although the core of the college's curriculum spanned the humanities, philosophy and theology, we know that he also studied some mathematics. He had the opportunity to acquire some advanced training in mathematics, as the teacher at the Coimbra college, for some years after 1753, was Inácio Monteiro (1724–1812), one of the order's most celebrated mathematicians in Portugal. There is no certainty that Cabral attended Monteiro's classes, but, in such a relatively small institution as the Coimbra college, he would definitely have benefitted from the prevailing scientific ambience. In fact, in 1754, thus while Cabral was still in Coimbra, the first volume of Inácio Monteiro's ambitious textbook *Compendio dos Elementos de Mathematica* was published (Monteiro 1754–1756).[3] This represented an important stage

[1]Cabral is not a wholly unknown figure. A biographical sketch can be found in Gusmão (1855). See also Gomes (1968), Quintela (1986b). Other biographical sources of information are detailed below.

[2]Lisbon, BNP, *Catalogo dos Sogeitos, Patres ac Fratres*, 40.

[3]On this influential textbook, see Rosendo (1998); on the general context of Monteiro's life, see Monteiro (2004).

in efforts to reform the teaching of mathematics in Jesuit schools in Portugal that already dated back to the beginning of the eighteenth century. Cabral's future career confirms his thorough education in mathematics and, perhaps more relevantly, his natural inclination towards this type of intellectual pursuit.

Estevão Cabral entered the Society of Jesus in the closing years of the Society's life in Portugal. A complex series of events developed over the subsequent years that eventually led to the expulsion of the Jesuits from Portugal. On September 3, 1759, Pombal's decree ordering the immediate expulsion of all Jesuits closed the Coimbra college and sent the Jesuits to Italy, mostly to the Papal States.

There is still very little knowledge about the first years in the life of Estevão Cabral in Italy.[4] He was sent to Rome and spent time at the Roman college, where he engaged in mathematical studies, initially as a student, but seemingly also teaching after some years. Aloysius and Augustini De Baecker, in their *Bibliothèque de la Compagnie de Jesus*, provide an interesting piece of information while noting that Cabral worked in the re-organization of the Kircherian museum (Baecker 1890, I: 487–488). This suggests an interest in natural history and antiquarianism that, as we shall return to below, also shaped Cabral's intellectual profile. Contrary to many of the exiled Portuguese Jesuits, Cabral seems to have found a stable and intellectually stimulating new life right from his earliest times in Italy. After some years at the Roman College, he moved to the Collegio Tiburtino in Tivoli, near Rome. It was there that he became a fully-fledged professed priest in 1767, and was teaching mathematics by 1770 (Russo and Trigueiros 2013: 176–179).

In 1771, Estevão Cabral published his first work, a mathematics textbook related to his teaching duties: *Elementa praecipua Euclidis geometriae planae ac solidae ex conicis etiam, ac sphaericis sectionibus collecta, faciliorique methodo demonstrata. Accedunt Arithemicae et Algebrae* (Cabral 1771). As the title reveals, the book is a pedagogically-oriented summary of mathematical topics covering selections from the first books of Euclid's *Elements*, a selection of propositions on conical sections, properties of the sphere and applications to astronomy and cosmography, and some practical geometry and arithmetic, as well as quite a substantial explanation of algebra and algebraic operations. Despite its somewhat elementary, pedagogically-adapted approach, the work covers a wide span of topics, thereby revealing the competence of its author in the most important branches of mathematics. The book acquired some popularity, despite the fact that, in 1773, following the suppression of the Society of Jesus by the Pope, its educational system fell into disarray. The book's appeal is furthermore confirmed by the fact that it received a second revised edition in 1785 (Cabral 1785).

Cabral's initial mathematical training in Coimbra, and its subsequent deepening while in Italy, as well as his first publication, seemed to indicate the burgeoning of an expert in mathematics. Towards the end of the decade, however, perhaps as a consequence of the Jesuits' suppression in 1773, his interests began diverging

[4] Some documents are listed in Russo and Trigueiros (2013, pp. 176–179). For the general context of expelled Iberian Jesuits in Italy, but without any information on Cabral, see Baldini and Brizzi (2010).

somewhat. In 1779, together with Fausto Del Re (1725–1793), he published a book on the most famous monuments of the city of Tivoli: *Delle ville e de' piú notabili monumenti antichi della cita', e del territorio di Tivoli* (Cabral 1779). According to its Preface, the book was intended to satisfy the interest and curiosity of the many foreigners that visited Tivoli and inquired about its beautiful monuments. The authors offer an extended and learned description of the main buildings and villas, analyse the inscriptions on monuments, describe the environs and provide some historical background to the places of greatest renown. The book is both a sort of tourist guide without images and a lengthy exercise in erudite antiquarianism. The *Efemeridi Litterarie di Roma*, the periodical that informed elite Roman society about the latest literary publications, noted the book's publication with a flattering comment.[5] For the scholarly and aristocratic milieu in Italy, this was perhaps their first acquaintance with the "abbate Stefano Cabral," who, for the first time, appeared outside of Jesuit (and former Jesuit) educational circles. Indeed, the book was dedicated to the powerful cardinal Giovanni Battista Rezzonico (1740–1785), whom Cabral had perhaps met during his stay at the Roman college. *Delle ville e de' piú notabili monumenti antichi* reveals that, by the late 1770s, the exiled Portuguese former Jesuit had already established a solid network of social connections, having further mastered the fine art of tailoring scholarly knowledge to the tastes of aristocratic readers. He had thus been able to safely come through both the Order's expulsion from Portugal in 1759 and its suppression in 1773. Clearly, Cabral had more talents than mere scientific gifts and his ambitions were not restricted to being a simple mathematics teacher or a scientific tutor to wealthy patrons.

Interestingly, one of the chapters, "Degli antichi Acquidotti Romani, che passavano per l'Agro Tiburtino" (Cabral 1779: 173–209), covers Roman aqueducts, thereby revealing a turn of interests that would characterize Estevão Cabral's subsequent activities. It was, perhaps, either because of that chapter or because the chapter was itself a consequence of a deeper interest in aqueducts and water management that, in late 1783, Cardinal Guillelmo Pallota (1727–1795), the prefect of the Congregation on Waters, the "Congregazione delle acque" (*Congregatio pro viis, pontibus et aquis curandis*), appointed Cabral as a consultant (assessor) to Monsignor Benedetto Passionei (1719–1787). Passionei had become the Congregation secretary in May 1783 and headed the Commission that had been set up to study longstanding and worrying problems with the Velino and Nera Rivers.[6] The Congregation was the body responsible for construction and maintenance work in the Papal States, and Cabral's involvement was to be a turning point in his professional life.[7]

[5]*Efemeridi Letterarie di Roma*, t. 8, num. XXVI (1779) 201–202. The book is descibed as "scritto con tale nitidezza di stile, con tale sobrietà, sceltezza di erudizione, che speriamo, che non dovrà lasciar nulla a desiderare" (p. 201), and, "questo libricciuolo diverrà classico presso degli eruditi viaggiatori" (p. 202).

[6]Cabral himself informs us about this (Cabral 1786: iii).

[7]Founded on January 22, 1588, the bull *Immensa aeterni Dei* established fifteen permanent congregations. The *Congregatio decimatertia pro viis, pontibus et aquis curandis* [Congregation for the care of roads, bridges and waters] acted as a sort of ministry for public works and public engineering for the papal states. On its creation and early years, see Long (2018).

The Velino River traverses the countryside near the city of Rieti, in the region of Lazio, in central Italy. In pre-historical times, fed by water from the Velino, the Rieti plain (*Piana Reatina*), a plateau located at about 370 meters in altitude, regularly flooded, forming a large wetland. The Romans called it *Lacus Velinus*, but this large swath of stagnant waters had become associated with illnesses and all sorts of health problems. Responding to the persistent complaints of the inhabitants of Rieti, in 271 BC, the Roman Consul Manius Curius Dentatus decided to drain the Rieti plain: a canal was constructed, the Curiano Trench (*Cava Curiana*), which led the waters over a natural cliff, where they fell into the Nera River below. This fall created a spectacular sight, known as the "cadute della Marmore," named after the nearby town of Marmore. The fall of the Velino River into the Nera is a three level (jump) fall of water, crossing a total height of 165 meters; it is a truly sensational natural event that has been very well-known, visited and described by travellers since Roman times.

Even though the Curiano trench and the spectacular fall at Marmore did succeed in drying the Rieti valley, as planned, this unfortunately led to another serious problem. On some occasions, when the Velino river flow was at its heights, the inflow of waters from the Nera led to a dramatic increase in the water level of the former, and to consequent flooding in the surrounding terrains and properties. Even some towns in the region became at risk. This situation especially threatened the town of Terni, whose population, quite understandably, complained bitterly. The solution that had been so beneficial to Rieti threatened Terni with destruction. Not surprisingly, protests, heated polemics and legal action ensued. In 54 BC, the question arrived at the Roman Senate, and debates took place, with Aulus Pompeius representing the *Ternani* and Cicero representing the *Reatini*. The senate might have chosen to take no action then, but nature was to aid the population of Terni. Without adequate maintenance, the Curiano Trench became progressively and increasingly obstructed, and its flows correspondingly diminished. Large wetland in the Rieti Valley reappeared. While the inhabitants of Rieti might once again have protested, the population of Terni must surely have felt relieved.

The need to drain the Rieti plain while simultaneously controlling flows into the Nera River became a constant problem down through the centuries, with the protests and mutual accusations between the Reatini and the Ternani similarly persisting. In 1422, Pope Gregory XII ordered the construction of a new canal—the Gregorian Trench (*Cava Gregoriana*)—and, in 1545, Pope Paul III had to intervene in ordering the construction of the so-called Pauline Trench (*Cava Paolina*). This turned out to be a complex engineering project that included a regulating valve to control the flow. Work was only completed in 1598, when it was inaugurated by Pope Clement VIII, and was hence called the Clementine Trench (*Cava Clementina*). Nevertheless, the problems still continued. The Nera caused frequent floods, with the effects believed to have reached Rome, as the Nera then flowed into the Tevere. In Rome, the population was convinced that some of the disastrous Tevere flooding in Rome stemmed from changes in the flows of the Nera.

By the 1780s, controlling the flows of the Velino and the Nera still remained a thorny issue. Estevão Cabral was charged by the "Congregazione delle acque" to visit the site and inspect the Velino, the "cadute della Marmore" and the flow of the Nera. The result of this field mission and his careful observations led to the publication of his report *Ragioni per ispiegare, e riparare i danni del fiume Nera* (Cabral 1784), his first text on hydraulic matters. Cabral is presented as "perito matematico eletto dalla S. Congregazione," the former Jesuit teacher of mathematics now having been invested with a new and quite definite professional identity and, furthermore, attached to what was one of the most pressing engineering issues in the Papal States. Cabral's report did not pass unnoticed among the learned and wealthy and, once again, the *Efemeridi Litterarie di Roma* reacted to the report's appearance. Despite introducing the topic with some caution—"although a local and forensic examination might seem not worthy to be presented in a literary journal"—the editors nevertheless decided to summarize the contents.[8]

Estevão Cabral's first foray into the important and controversial question of the Rivers Velino and Nera was mostly descriptive, with his interest in the topic having not been fully satisfied. Indeed, his interests had been piqued by a more scientific motive. In 1779, one Francesco Carrara (b. 1716) had written a short 20-page booklet on the fall of the Velino into the Nera: *La Caduta del Velino nella Nera* (Carrara 1779). The book, offered to Pope Pius VI, was mostly an exercise in history and scholarship. However, while Carrara's scientific interests were not totally absent, as we shall see below, his purpose was clearly of a more erudite nature. Carrara deftly managed a plethora of ancient authors and classical sources to trace the rich history of the Rivers Velino and Nera, and especially of the "Cadute del Marmore," from antiquity through to present times. In fact, Carrara's historical excursus constitutes a fine history of the problems surrounding the Velino and its famous fall.

One of the most interesting sections of this work is the author's learned discussion of other waterfalls all around the world to establish the point that, "from the most exact observations of geographers and travellers, among the falls of rivers this one is the largest one" (Carrara 1779: xii). Carrara compares the "cadute delle Marmore" with other famous falls and cataracts, such as those of the Nile and others in Europe (Sweden, Switzerland).[9] Having established that these falls were not as high as that in Marmore, he proceeded to discuss the falls in India and the Americas, "the ones that can compare" with the Velino fall. He discusses river falls in Kashmir, the Niagara, and, quite interestingly, waterfalls in Spanish America, Quito and Peru

8"Benchè una perizia locale e forense, quale si è quella che ora annunciamo, possa parere a qualcuno non degna di essere inserita in un foglio literario" (p. 65), in *Efemeridi Letterarie di Roma*, t. 13, num. IX (1784) 65–66.

9"Crediamo di poter avanzare dopo le più esatte osservazioni dei Geografi, e dei Viaggiatori, che questa fra le Cadute dei fiumi sia la maggiore. Gli antichi ci hanno molto parlato della Cataratte del Nilo. […] Sono mentovate le cadute dei fiumi della Svezia, ma quella del Motala presso Norpingh non è che circa 40. palmi Romani, e l'altra dell'Elva non cade che da uno scoglio di doppia altezza. La caduta del Reno presso Schaffosa negli Svizzeri, e l'altra di Turneao rammentata dal Maupertuis nulla ha di più rimarchevole" (Carrara 1779: xii).

as well.[10] In the end, he reassuringly concludes: "We are therefore right in the belief that the fall in Terni is the highest one of all that have been observed until today."[11]

While Carrara's erudite historical hydrology was quite impressive, the same cannot be said about his brief detours and descriptions that are of a more objective and scientific nature. These were, unfortunately, somewhat imprecise, and opened a flank that detractors did not hesitate to exploit. Specifically, Carrara made a remark on the flow velocity of rivers, linking their flow velocity to the height of their falls: "The observations of the experts in hydrostatics have revealed a law of nature, according to which waters accelerate their course more or less according to the approximate height they are about to fall. An excessive height must produce a proportionate velocity. In fact, this velocity can be discerned in the Velino about a mile away from the fall."[12]

Perhaps unbeknownst to Carrara, with these words, he was addressing a very difficult topic. The exact velocity of the water in a flowing stream or river was an issue that had attracted major attention in the previous decades, but that still remained very much open to debate. Research on this topic had experienced an important development early in the seventeenth century, following the publication of Benedetto Castelli's *Della misura dell'acqua correnti* (Castelli 1628), and again at the end of the century, following Domenico Guglielmini's *Aquarum fluentium mensura nova methodo inquisita* (Guglielmini 1690). In between, a rich tradition of hydrological studies had developed in Italy. Indeed, while discussions and research around this topic had accumulated by the first half of the eighteenth century, many questions still remained to be answered (Vischer 2010).

Furthermore, Cabral's *Ragioni per ispiegare, e riparare i danni del fiume Nera* had not exhausted everything that he had to say about the problems of the Velino and Nera Rivers. Perhaps still more importantly, he was a much deeper thinker—

[10]"Le sole Cadute dell'India, e dell'America possono adunque venire al paragone. Nel Regno di Kachemir sottoposto all'Imperatore del Mogol, e non molto lungi dalla Città di Bamber si dice esservi una caduta, la quale forma uno spettacolo cotanto nobile, che l'Imperatore Gehan-Guir fece ridurre una rocca, che le sta di faccia, alla forma di teatro, per potere più comodamente goderne da quel punto la bellezza: si dice ancora che questa caduta è di un'altezza prodigiosa […] ma non si sa a quanti palmi possa dessa ascendere. La caduta o il salto di Niagara nel Canadà è per verità sorprendente per la forza, per lo strepito, e per la bianchezza delle acque, per la sua forma, che si assomiglia ad un ferro di cavallo; e per alcuni scogli, che formando una isoletta vengono a dividerne le acque; ma la sua altezza non è che di circa 200 palmi romani. Tra le provincie di Guayaquil, e del Quito si osserva una caduta chiamata dagli Spagnoli Chorrera. L' Ulloa dice di non aver veduta cosa simile: ma misurata dai Matematici non è stata ritrovata che di circa 450 palmi romani […] si parla della caduta di Zumaco nel Perù di là dalle Cordelliere, e si vorrebbe far credere, che questa fosse di 1300 palmi, […] ma essa non è stata misurata da alcun perito […]" (Carrara 1779: xii–xiii).

[11]"Siamo adunque in diritto di credere, che la Caduta di Terni sia la maggiore di quante sono state finora osservate" (Carrara 1779: xiii).

[12]"Le osservazioni degl'Idrostatici ci hanno fatto conoscere una legge della natura, a tenore della quale le acque accelerano il loro corsò più, o meno, secondo che è maggiore, o minore l'altezza, dalla quale debbono prossimamente cadere. Un'altezza sì smisurata dèe produrre uma proporzionata velocità. Di fatto questa velocità si comincia a conoscere nel Velino circa un miglio lontano dalla Caduta" (Carrara 1779: ix–x).

and experimenter—in hydrostatics than his previous work had suggested. Two years after his first report on the River Nera, Estevão Cabral returned to the topic by publishing a much more ambitious work, whose full title reveals that he held higher aims than simply the Velino fall: *Ricerche istoriche, fisiche ed idrostatiche sopra la caduta del Velino nella Nera, colla dichiarazione di um nuovo metodo per determinare la velocità e la quantità delle Acque Correnti ed altro nuovo metodo de elevare l'Acqua ne' Sifoni a grande alteza* (Cabral 1786) (Fig. 1).

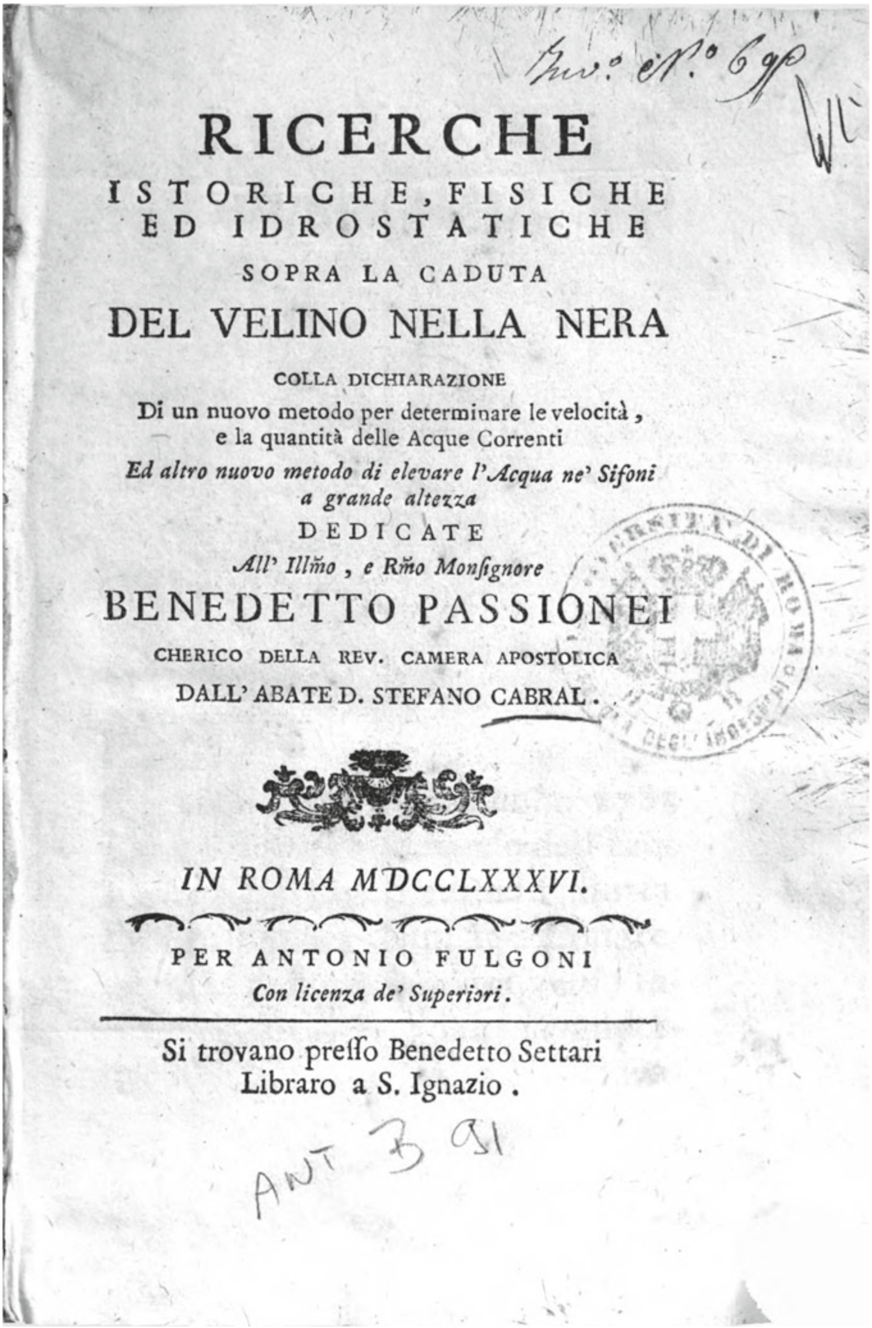
Cabral's 1786 book actually contains three interrelated, but independent texts, as duly announced on the title page. The main body of the work, under the heading "Ricerche istoriche, fisiche ed idrostatiche sopra la caduta del Velino nella Nera," discusses the history and problems of the Velino river fall into the Nera (Cabral 1786, pp. 1–39). There then follows an extended "Appendice I. Nuovo metodo per determinare le velocità, e la quantità delle acque correnti" (Cabral 1786, pp. 40–73). Subsequently, there comes a shorter text under the title "Appendice II. Maniera di elevar l'acqua ne'sifoni sino all'alteza dovuta al peso dell'atmosfera" (Cabral 1786, pp. 74–80). The book opens with a text addressed to Monsignor Passionei that explains the origins of the work. Cabral recalls how he had been in the service of Cardinal Pallota since the end of 1783 and that he had received instructions to examine the much disputed question of the Velino and Nera Rivers.[13] This duty had subsequently led him to write about this famous and very controversial problem; he then remarked:

> It is true that other authors have already treated the subject of the Velino and its fall; the most recent one was a learned writer [*dissertatore*], in the year of 1779, in an elegant and well prepared booklet; but the opportunity to make an attentive visit to that place and the questions that were there discussed between the litigant sides suggested to me that I present some reflections since many of that things that have been written do not correspond to the local facts.[14]

Cabral is obviously referring here to Francesco Carrara and the *La Caduta del Velino nella Nera* (1779), but, despite the unavoidable polite circumlocutions, his polemical intention becomes apparent from the very beginning. However, he also immediately adds that his objective is not mere controversy; more importantly, he announces his intention to present new findings:

[13]"Mi fu fin dall'anno 1783 per commando dell'Emmo. Sig. Cardinal Pallotta, Prefetto allora della Sac. Congregazione delle Acque, imposto l'incarico di servirla quanto comportavono le mie deboli forze" (Cabral 1786: iii–iv).

[14]"É vero que già altre penne si sono con plauso occupate attorno al Velino, e sua cadutta; ed ultimamente un dotto Dissertatore nell'anno 1779 in un operetta corredata da bella pianta, e da bel profilo; ma l'occasione dell'atenta Visita di quei luoghi alpestri, e le quistioni ivi eccitate tra le Parti litiganti mi hanno dato motivo di farvi parecchie riflessioni, onde molti fatti locali non mi sembrano corrispondenti a quello scritto." (Cabral 1786: v–vi).



RICERCHE
ISTORICHE, FISICHE
ED IDROSTATICHE
SOPRA LA CADUTA
DEL VELINO NELLA NERA
COLLA DICHIARAZIONE
Di un nuovo metodo per determinare le velocità,
e la quantità delle Acque Correnti
*Ed altro nuovo metodo di elevare l'Acqua ne' Sifoni
a grande altezza*
DEDICATE
All' Illmo, e Rmo Monsignore
BENEDETTO PASSIONEI
CHERICO DELLA REV. CAMERA APOSTOLICA
DALL' ABATE D. STEFANO CABRAL.

IN ROMA MDCCLXXXVI.

PER ANTONIO FULGONI
Con licenza de' Superiori.

Si trovano presso Benedetto Settari
Libraro a S. Ignazio.

Fig. 1 Title page of *Ricerche istoriche, fisiche ed idrostatiche sopra la caduta del Velino nella Nera*, by Stefano Cabral, that is, Estevão Dias Cabral

> In addition to the controversies that were held about some questions, in part of physics and in part of hydraulics, I am spurred to add more, with the hope of presenting publicly some new things not irrelevant to those who know [these topics].[15]

The main section of the book then sets out a clear description of the history of the problem of the Velino and Nera Rivers. Cabral's prose is clear and precise; his historical knowledge is broad and detailed. Furthermore, there are hardly any rhetorical flourishes or other literary embellishments. His arguments are grounded solidly in in situ observations and precise measurements.

His first task involves criticizing Carrara's geographical descriptions and the measurements proposed in *La Caduta del Velino nella Nera* (1779). The fact that Carrara (whom he never cites by name) provided a defective geographical description of the area renders, according to Cabral, all of his subsequent explanations wrong. Cabral sets about correcting these mistakes, but rapidly chooses to move onto more scientific matters, by challenging Carrara's description of the flow velocity:

> In the same description in page 10 are shown the rules of hydrostatics together with those of the acceleration of falling bodies: from this it is concluded that because of the fall the Velino starts to accelerate one mile before […] I, however, am persuaded that the natural reason for the acceleration of the Velino in the final mile is not the fall itself but the excessive slope of the river bed that was open in the stone in a straight line.[16]

In the remainder of the analysis, Cabral presents his interpretation of the Velino problems, but the "new findings" that he had promised are reserved for the Appendices. In the first Appendix, "Nuovo metodo per determinare le velocità, e la quantità delle acque correnti," Cabral changes his approach. Warning readers that he is abandoning the discussion about rivers, he engages in a detailed analysis of the question of flow velocity and its measurement:

> I plan to do something pleasing to the learned by adding some reflections of mine on the measurement of the flow of rivers; indeed, these reflections are related to hydrostatics in general and not specifically to rivers.[17]

Speaking strictly from the point of view of hydrodynamics, this Appendix is the most original of Cabral's works. He puts forward a brilliant and original study in regard to determining flow velocity as a function of depth. The question was not only critical from a theoretical point of view; it was also of direct relevance to

[15]"Oltre a ciò le controversie sul luogo medesimo dibattute, riguardanti alcuni punti parte Fisici, e parte Idraulici, mi stimolano ancora a farne menzione, colla speranza di produrre in publico qualque cosa nuova, ed agli intendenti non ingrata" (Cabral 1786: vii).

[16]"Nella medesima descrizione pag 10 si pongono in vista le regole dell'Idrostatica e dell'accelerazione de gravi cadenti; per quindi conchiudere, che per cagion de la caduta, il Velino incommincia ad accelerarsi un miglio prima […] Noi piuttosto siamo persuasi, che la cagion naturale dell'accelerazione del Velino nel miglio precedente sia, non la caduta, ma l'artifiziale troppa pendeza dell'alveo, aperto sul sasso in linea retta." (Cabral 1786, p. 9).

[17]"M'avviso di far cosa gradita agli Intendenti, se in questo luogo aggiungerò varie riflessione sulla misura della Portata de´fiumi: quantumque relative in generale alla scienza Idrostatica, e non ristrette soltanto ai fiumi" (Cabral 1786, p. 9).

practical applications, since any acceptable estimates of river flows require knowledge about water velocity at different depths. Of course, the main difficulty came with the measurement of subsurface water velocities, a topic that many had attempted to deal with over its long history.[18] Already by the end of the seventeenth century, Domenico Guglielmini (1655–1710) had addressed the question and proposed an instrument to measure flow velocity in his *Aquarum fluentium mensura nova methodo inquisita* (Guglielmini 1690), an influential book that was reissued in several editions.[19] Henri Pitot (1695–1771), in a study published in *Mémoires de l'Académie* [of Paris], had proposed, in 1732, the so-called "Pitot tube," which he used for measuring the flow velocity under the Seine bridges in Paris. He concluded that flow velocity usually decreases with depth.[20] In Italy, in the second half of the eighteenth century, a number of researchers devised new instruments and conducted important experiments: Francesco Domenico Michelotti (1710–1777) in 1767, Antonio Maria Lorgna (1735–1796) in 1777, and Leonardo Ximenes (1716–1786) in 1780, among others, developed hydrometric dynamometers to determine the velocity of water at different depths. Estevão Cabral entered this active research field by devising a new instrument, a paddle wheel, to accomplish these measurements. Using this new instrument, he then engaged in a series of careful experiments.[21] He observed that water velocity increased with depth from the surface up until a point at which it reached a maximum, before then decreasing downwards to the bed of the river. This profile of subsurface velocity differed quite sharply from that which hydraulics had hitherto assumed: it was generally believed that, in open-channel flows, the maximum velocity was reached at the surface. Historians have indeed already noted the originality and importance of these achievements (Quintela 1991), but the aspect that nevertheless needs underlining here is simply to note that this Appendix reveals a new facet of Cabral's intellectual profile. What emerges from these pages is the work of a competent and original thinker in hydraulics, fully cognizant of the theory and the experimental techniques, deeply engaged in the design and use of instruments and in the performing of experiments. By the mid-1780s, Estevão Cabral was no longer a mere technical advisor, visiting sites and producing reports on the management of rivers.

Appendix II confirms these personality traits and his direct involvement with instruments and hydraulic machines. It is also a piece of hydrodynamics that is quite unrelated to the problem of river management, a fact that Cabral recognizes in his opening lines:

[18]For the general scientific context, see Kolupaila (1961), Rouse and Ince (1963), Blay (2007), Calero (2008).

[19]Afterwards in: Domenico Guglielmini, *Opera omnia mathematica, hydrodinamica, medica et physica* (Geneva, 1719) and Italian version, «Misura dell'acque correnti ricercata com nuovo metodo dal Dottor Domenico Guiglielmini», in *Raccolta d'autori che trattano del moto dell'acque* (1723), vol. II, pp. 1–103. On Domenico Guglielmini, see Calero (2008, pp. 275–278).

[20]The "Pitot tube" was first presented in Pitot (1732); see also Calero (2008, pp. 490–92).

[21]A detailed technical explanation of this Appendix can be found in Quintela (1986a, 1991), and Loureiro (1986).

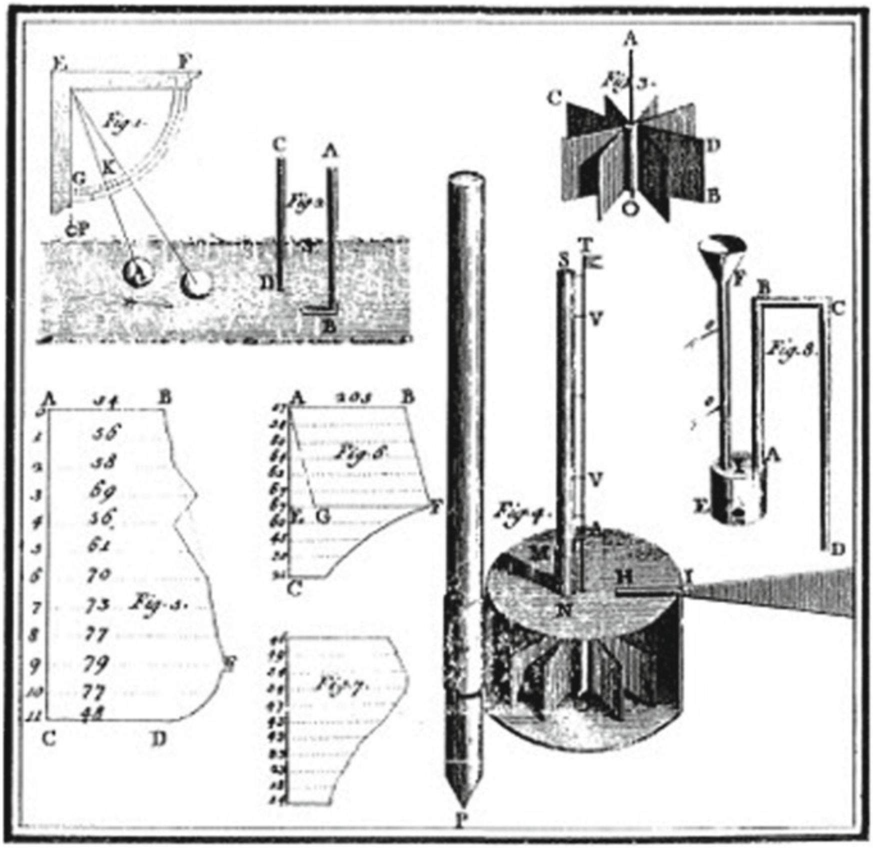


Fig. 2 Estevão Dias Cabral's researches on the velocity of water flow, in *Ricerche istoriche, fisiche ed idrostatiche*

> Although the present Appendix bears no relation with the history of the Velino and Nera, and can therefore be considered inopportune in this place, we have nevertheless decided to present it here.[22]

Of course, these were mere rhetorical hesitations. Cabral was far too interested in presenting his new ideas and new inventions for the raising of water to be deterred by the fact that this had nothing to do with the book's main subject. Furthermore, despite the main topic of *Ricerche istoriche* being the Marmore fall, only around half of the book's pages actually address that question (Fig. 2).

[22]"Comecchè non abbia la presente appendice alcuna relazione coll'istoria Velino-Nare, e possa però stimarci in questo luogo affatto inopportuna, abbiamo nondimmeno creduto di qui soggiugerla" (Cabral 1786, p. 74).

Ricerche istoriche was well received. Once again, *Efemeridi Letterari di Roma* reviewed the book, this time granting it a more extended, four-page summary.[23]

In addition to its technical contents, *Ricerche istoriche, fisiche ed idrostatiche sopra la caduta del Velino nella Nera* is also an interesting book in another sense. Its distribution of materials reflects the complex path that hydraulics experts sometimes had to take and the career decisions that they were faced with. On the one hand, given the great significance of public hydraulics works, the option to act as technical consultants was always open. On the other hand, given the intrinsic complexity of hydraulics, engaging in more scientific work was attractive to many, especially to those more creative individuals. In this sense, *Ricerche istoriche, fisiche ed idrostatiche* reflects these two facets of the identity of many late eighteenth century hydraulics experts, while also displaying the hesitation between these two career path options.

Cabral's book generated some discussion before his suggestions were finally approved by the Passionei Commission. In the following year, 1787, Pope Pius VI put the architect Andrea Vici (1743–1817) in charge of renovation work on the "caduta delle Marmore," which greatly improved the situation. As for Cabral's hydraulics results and experiments, they mostly seem to have been forgotten.

In May 1788, Estevão Dias Cabral returned to Portugal.

* * *

Estevão Cabral's actions in the service of the water congregation radically altered the life of this ex-Jesuit. The history of the Portuguese Jesuits who were expelled from the country and sent to the Papal States constitutes a bleak episode in the history of Portugal. While some got lucky and found suitable living conditions, and were thus able to re-start their lives, many others languished in minor occupations, as priests in remote parishes, tutors or other minor positions (Baldini and Brizzi 2010). Furthermore, few ever attained any prominence and still fewer ever returned to their home country. In this context, the path of Estevão Dias Cabral was quite uncommon. By profiting from the exceptional conditions that the Jesuit order provided in Italy (until 1773), he was able not only to improve his technical skills, but also to establish personal connections that opened up access to the highest ecclesiastical levels in Rome. Whereas many eighteenth century experts in hydraulics were military or university-affiliated, Cabral relied on his network of contacts in the ecclesiastic milieu. His connection to the Vatican Congregation of the Waters resulted from his technical prowess, combined with obvious social skills. Ascending to the position of a trusted expert on hydrological matters required a complex mix of talents: the deep knowledge of the science and techniques involved had to be combined with the ability to persuade the learned and the literati and the stamina to complete extensive field work. On a more personal level, a career as a public consultant on hydraulic matters required that other decisions and choices be made between engaging in the more applied tasks, acting as a technical consultant, or, alternatively, dedicating oneself to more scientific pursuits.

[23] *Efemeridi Letterarie di Roma*, t. 15, num. XLV (1786) 353–356.

Estevão Cabral was able to establish a distinguished career and to return to his native country. He did so under exceptionally favourable circumstances: as a trusted technical advisor working for the Royal Court. Although Cabral seems to have returned to Portugal of his own initiative (Gusmão 1855), within just a few months of his arrival, he was already working for the Crown on complex problems of river control and flow regulation, especially related to the Mondego and Tagus Rivers.[24] Due to his return to his own country, the Crown now had access to the most experienced and renowned Portuguese expert on hydraulics. The man who returned in 1788 was not the former Jesuit who had been expelled in 1759; he was now the former distinguished technical consultant of the "Congregazione delle Acqua" and of the Papal States, the author of a solid work on river control, and the proponent of new ideas and new instruments in hydraulics.

In the following years, Cabral immersed himself in the various tasks required by the Crown. In Portugal, his milieu was no longer ecclesiastical, but rather associated with the group of lay experts working for the King. He was the undisputed authority on hydrological matters whose advice was constantly sought; national recognition did not take long and was soon fulsome. Not long after, he entered the select Royal Academy of Sciences, the first hydrology expert to gain such a distinction, and became a regular contributor to the Academy's journals.[25]

His involvement in pressing hydrological projects was not without some personal cost. After his return to Portugal, there is no indication that he ever again engaged either in original studies in hydrodynamics or in the performing of experiments such as those that he had discussed with such pride in *Ricerche istoriche*. Only indirectly are we able to discern some influence from his more theoretical contributions.[26] His only printed book in Portugal was a very elementary treatise on surveying, *Tractado de Agrimensura* (Cabral 1795), a manual to help in the training of land surveyors. As for his other publications, they were all reports on

[24]Control of these two rivers had always involved difficult problems. Works on the margins and flow of the Tagus, for example, have been recorded since the thirteenth century, with major engineering operations having been carried out every century.

[25]"Memoria sobre o paul da Otta, suas causas, e seus remedio". Memórias Económicas da Academia das Ciências de Lisboa, 1790, tomb II, pp. 144–154; "Memoria sobre os damnos causados pelo Tejo nas suas ribanceiras". Memórias Económicas da Academia das Ciências de Lisboa, 1790, tomb II, pp. 155–197; "Memoria sobre os damnos do Mondego no Campo de Coimbra e seu remedio". Memórias Económicas da Academia das Ciências de Lisboa, 1791, Tomo III, pp. 205–242. "Memoria sobre o tangue e torre, no sítio chamado com Lisboa Amoreiras, pertencente às Águas-Livres". Memórias Económicas da Academia das Ciências de Lisboa, 1791, tomb III, pp. 291–297. "Memoria sobre o modo de obter e conservar agua da chuva de optima qualidade". Memórias Económicas da Academia das Ciências de Lisboa, 1812, tomb IV, pp. 67–76.

[26]For example, on the comments that the Portuguese translator, citing Cabral, makes on unit systems and other theoretical issues, see Michelotti's *Ensayo Hidrographico do Piemonte* (Michelotti 1803).

the conditions and problems of specific river situations.[27] Nevertheless, his impact would be clear and long-lasting. He became the first person to achieve renown and great social distinction solely for his expertise in hydraulics, the first elected to the Academy of Sciences on account of that expertise, and the first attributed the title of "professor hidráulico." Estevão Cabral was thus pivotal in the shaping of this field in Portugal.

References

Baecker, Augustini De and Aloys De Baecker. 1890. *Bibliothèque de la Compagnie de Jésus – Bibliographie.* Paris: Alphonse Picard.

Baldini, Ugo and Gian Paolo Brizzi (eds.). 2010. *La presenza in Italia dei gesuiti iberici espulsi. Aspetti religiosi, politici, culturali*. Bologna: Clueb.

Blay, Michel. 2007. *La science du mouvement des eaux. De Torricelli à Lagrange*. Paris: Belin.

Cabral, Estevão Dias. 1771. *Elementa praecipua Euclidis geometriae planae ac solidae ex conicis etiam, ac sphaericis sectionibus collecta, faciliorique methodo demonstrata. Accedunt Arithemicae et Algebrae*. *Principia Philosophica studiosis maxime necessaria.* Romae: per Archangelum Casalletti.

Cabral, Estevão Dias. 1779. *Delle ville e de' piú notabili monumenti antichi della cita', e del territorio di Tivoli, Nuova richerche di Stefano Cabral e Fausto del Re*. Rome: Stamperia del Puccionelli.

Cabral, Estevão Dias. 1784. *Ragioni per ispiegare, e riparare i danni del fiume Nera, combinate da Stefano Cabral perito matematico eletto dalla S. Congregazione dalle acque nell' accesso dell' Illustrissimo e Reverendisimo Monsig. Benedetto Passionei segretario di detta S. Congregazione ne' mesi di maggio e giugno 1783, per ordine della santità di N. S. Papa Pio VI*. Romae: nella stamperia della R. C. A.

Cabral, Estevão Dias. 1785. *Elementa praecipua Euclidis geometriae planae ac solidae ex conicis etiam, ac sphaericis sectionibus collecta, faciliorique methodo demonstrata. Accedunt Arithemicae et Algebrae*. *Principia Philosophica studiosis maxime necessaria. Editio secunda ab eodem recognita, et emendata.* Romae: sumptibus Benedicti Settari.

Cabral, Estevão Dias. 1786. *Ricerche istoriche, fisiche ed idrostatiche sopra la caduta del Velino nella Nera, colla dichiarazione Di um nuovo metodo per determinare la velocità e la quantità delle Acque Correnti Ed altro nuovo metodo de elevare l'Acqua ne' Sifoni a grande alteza*. Romae: per Antonio Fulgoni.

Cabral, Estevão Dias. 1795. *Tractado de agrimensura, no qual se propõe o preciso para hum medidor de campos. Lido na Academia Real das Sciencias por Estevão Cabral*. Lisbon: na Offic. da mesma Academia.

Calero, Julián Simón. 2008. *The Genesis of Fluid Mechanics, 1640–1780*. Dordrecht: Springer. Originally: *La génesis de la Mecânica de los Fluidos (1640–1780)*. Madrid: UNED, 1996.

Carrara, Francesco. 1779. *La Caduta del Velino nella Nera presentata a N. S. Pio Sesto da Francesco Carrara Segretario del Concilio*. Rome: Casaletti.

Castelli, Benedetto. 1628. *Della misura dell'acque correnti*. Rome: Nella Stamperia Camerale.

Gomes, João Pereira. 1968. «Cabral, Estevão», *Enciclopédia Verbo*, vol. 4, pp. 332–333.

[27] His publications are but a fraction of his extant works. A number of manuscript works are known to be stored in Portuguese archives, works that, to the best of my knowledge, have never been studied in detail. For example: Lisbon, BNP, mss 259, no. 14: Estudo sobre os alagamentos dos terrenos adjacentes ao rio das Enguias, pouco acima de Alcochete. P. Estevão Cabral, hydraulico, director da abertura do novo alveo do rio Mondego, Lisboa, nov. 1796.

Guglielmini, Domenico. 1690. *Aquarum fluentium mensura nova methodo inquisita*. Bologna: 1690. Afterwards in: Domenico Guglielmini, *Opera omnia mathematica, hydrodinamica, medica et physica* (Geneva, 1719). There is an Italian version: «Misura dell'acque correnti ricercata com nuovo metodo dal Dottor Domenico Guiglielmini», in *Raccolta d'autori che trattano del moto dell'acque*, 3 vols. (1723), vol. II, pp. 1–103.

Gusmão, F. A. Rodrigues de. 1855. *Memória da vida e escriptos de Estevam Dias Cabral.* Coimbra: Imprensa da Universidade.

Kolupaila, S. 1961. *Bibliography of Hidrometry*. Notre Dame: Ind. University of Notre Dame Press.

Long, Pamela O. 2018. *Engineering the Eternal City. Infrastructure, Topography, and the Culture of Knowledge in Late Sixteenth-Century Rome*. Chicago: The University of Chicago Press.

Loureiro, João Mimoso. 1986. «Calibração da "maquineta" de medição de caudais de Estêvão Cabral», in: *Estêvão Cabral – Segundo centenário da publicação «Richerche istoriche, fisiche ed idrostatiche sopra la caduta del Velino nella Nera»*. Lisbon: Direcção-Geral dos Recursos e Aproveitamentos Hidráulicos, pp. 55–58.

Michelotti, Francesco Domenico. 1767. *Sperimenti Idraulici principalmente diretti a confermare la teorica e a facilitare la pratica del misurare le acque corrent*i. Turin: nella Stamperia Reale.

Michelotti, Jose Therezio. 1803. *Ensayo Hidrographico do Piemonte*. Translated by Francisco Furtado de Mendonça. Rome: Antonio Fulgoni.

Monteiro, Inácio. 1754–1756. *Compendio dos Elementos de Mathematica*. Coimbra, 2 vols.

Monteiro, Miguel Maria Santos Corrêa. 2004. *Inácio Monteiro (1724–1812): um jesuíta português na dispersão*. Lisbon: Centro de História da Universidade.

Pitot, Henri. 1732. «Description d'une machine pour mésurer la vitesse des eaux courantes, et le sillage des vaisseaux», *Mémoires de l'Académie* [of Paris]. *Histoire de l'Académie Royale des Sciences*, année 1732, pp. 103–106.

Quintela, António de Carvalho. 1986a. «Breve notícia sobre Estêvão Cabral como pioneiro na hidrometria de rios», in: *Estêvão Cabral – Segundo centenário da publicação «Richerche istoriche, fisiche ed idrostatiche sopra la caduta del Velino nella Nera»*. Lisbon: Direcção-Geral dos Recursos e Aproveitamentos Hidráulicos, pp. 45–52.

Quintela, António de Carvalho. 1986b. «Nota bio-bibliográfica sobre Estêvão Cabral», in: *Estêvão Cabral – Segundo centenário da publicação «Richerche istoriche, fisiche ed idrostatiche sopra la caduta del Velino nella Nera»*. Lisbon: Direcção-Geral dos Recursos e Aproveitamentos Hidráulicos, pp. 61–67.

Quintela, António de Carvalho. 1991. «Estêvão Cabral's pioneering contribution to open channel hydrometry», *Hydrological Sciences*, 36 (3) 241–246.

Rosendo, Ana Isabel. 1998. «O *Compendio dos Elementos de Mathematica* do P. Inácio Monteiro», *Revista Portuguesa de Filosofia*, 54, 319–353.

Rouse, H. and S. Ince. 1963. *History of Hydraulics*. New York, Dover.

Russo, Mariagrazia e António Júlio Limpo Trigueiros. 2013. *I Gesuiti dell'Assistenza Lusitana esiliati in Italia (1759–1831)*. Padova: CLEUP.

Vischer, D. L. 2010. «Die Entwicklung der Abflussmesser vom treibenden Blatt zum Messflügel und wieder zurück», Hydrologie und Wasserbewwirtschaftung, 54(2) 129–137.