The Watermills of the Sierra de Cádiz (Spain)

A Traditional *Open* Water Re-circulation System

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Abstract

Traditional hydraulic milling was the main productive activity in the Sierra de Cádiz (Andalusia, Spain), as evidenced by the existence of 85 mills spread throughout the region. Although the date of their construction is unknown, the first documentary evidence of their existence appeared in the 16th century. In the 18th century, a more comprehensive account of the set of mills in the Sierra was drawn up thanks to the Ensenada Cadastre. The majority were operational until the mid-20th century, albeit with some difficulties. The disappearance of this handmade trade has led to the obsolescence and abandonment of its architecture and infrastructure. However, the infrastructure remains there, as traces of a recent past in which it is still possible to see the *Circular Water Story* that made them work. This article explains the hydraulic system that was used by the mills in the Sierra de Cádiz. Located next to rivers and streams, they formed part of an *open* water re-circulation system, which captured the water at a specific point in the riverbed of origin, artificially diverted it to the mill and then ended up returning it to the same riverbed of origin, at a different point from the initial one. The methodology used is based on the preparation of graphic documents and photographic recognition to select the riverbanks that show the adaptations and variations of the water re-circulation system according to the hydrographic, topographic, and productive characteristics of each territory. As some of these old artificial riverbeds are still operational, today they are used as a natural resource to supply water to other productive activities, thus proving the usefulness of the system, the suitability of the construction techniques applied, and their consequent integration into the landscape. The research carried out justifies the need to protect and catalogue these architectural hydraulic systems before they disappear completely, in order to benefit from the learning that can be derived from the reading, interpretation, and transformation of the territory and its landscape.

Keywords

watermill; pre-industrial architecture; rural infrastructure; rural landscape; hydraulic circuit; traditional water system; circular water stories; landscape architecture.

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Introduction

Pre-industrial rural communities have been characterised by their symbiotic relationships with natural resources, which were used to farm the land and obtain raw materials from their surroundings, transforming them into basic commodities that enabled the communities to survive. According to M. Hough (1990), "a valid design philosophy, … tied to ecological values and principles; …; to the essential bond of people to nature, and to the biological sustainability of life itself" (p. 179). This applies to the conversion of grains into flour and bread. This process inspired several inventions, in each case generating specific architectural systems and infrastructures that create a dialogical physical-territorial connection and which, at the same time, have shaped and developed the landscape.

The study of these currently abandoned systems is extremely interesting due to the set of values they represent—they reflect architectural, ethnological, and landscape values, but also functional, constructive or strategic ones, all expressing the appropriate relationship of the architectures with their environment and the essential use of local resources available for the development of their activities. Therefore, as stated by M. Vellinga (2013), these structures are "increasingly identified as a repository of traditional knowledge that may be of value in contemporary attempts to develop more sustainable built environments" (p. 570).

FIGURE 1 Location and agricultural regions of the province of Cádiz. Elaboration according to the Ministry of Agriculture, Fishing and Food.

This article originates from a more extensive study focused on the hydraulic flour mills of the Sierra de Cádiz[1], in Andalusia, Spain (Fig. 1). Milling was their main productive activity in the mountainous region, a markedly rural, artisan environment, historically isolated and dominated by small, white villages, scattered buildings, and small properties, with 85 watermills dispersed throughout the Sierra de Cádiz, many of which are still standing but are now abandoned and in a poor state of preservation. This fact is explained by the orographic and cultural features and heavy winter rainfall, which gives rise to a significant hydrographic network, with a capillary network of numerous fast, low-flow streams that run through the region forming a resource that irrigates the entire province. The Guadalete and Guadalporcún rivers are the main rivers that structure the territory of this region and, together with the rest of the streams and tributaries, they determine the different riverbanks where the hydraulic flour mills are located (Fig. 2).

1 Sierra de Cádiz is one of the five agricultural districts established by the Ministry of Agriculture, Fishing and Food for the province of Cádiz; the district has an area of 105,435 ha and has 14 municipalities: Alcalá del Valle, Algodonales, Benaocaz, El Bosque, El Gastor, Grazalema, Olvera, Prado del Rey, Puerto Serrano, Setenil de las Bodegas, Torre Alháquime, Ubrique, Villaluenga del Rosario, and Zahara de la Sierra.

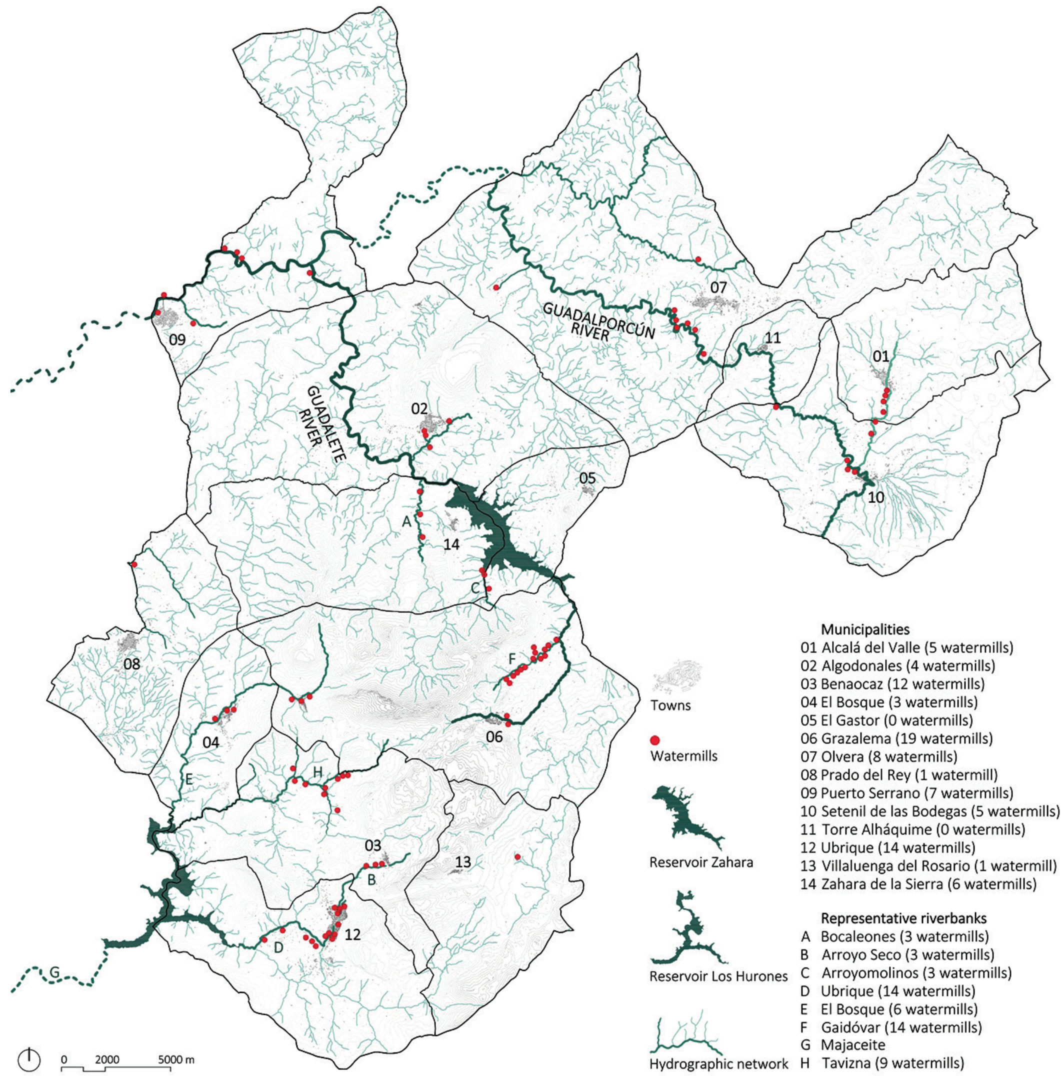

FIGURE 2 Map of the physical and territorial environment of the Sierra de Cádiz: topography, hydrography, and municipal districts. Location of the hydraulic mills according to the riverbanks and mountain municipalities that make up the Sierra de Cádiz.

Historical Context and Brief State of Affairs

Although previous evidence had been found of the existence of the watermills (Derry & Williams, 1977), it was not until the last two centuries of the Roman Empire that they became more widely used by the ruling countries (Holt, 1990). However, in Spain, the first document to refer to a watermill dates from the 10th century (Escalera Reyes, 1983, p. 28), though it was only after the 13th century that they achieved major expansion, most probably due to their dissemination carried out by the Arabs (García de Cortázar, 1974, pp. 180-181).

Regarding the Sierra de Cádiz, the foundation and settlement of this region has two major phases: the stage when the mountain range was under Muslim rule (8th to 13th centuries), and the stage following the conquest and recovery by the Crown of Castile (13th to 15th centuries).

The mills in the Sierra de Cádiz are not chronologically dated. Although there are Phoenician ruins in the region and some of these built-up areas have been linked to Roman settlements (Suárez Japón, 1982, p.

319)[2], the origin of the majority of their communities lies under Muslim rule.[3] Therefore, it is very likely that they were the first settlements of Muslims who, as of the 8th century, imported their horizontal-wheeled watermills, which are less technically complex than those with vertical wheels that had gradually replaced the horizontal-wheeled mills throughout the Middle Ages, except in those mountainous and isolated areas whose orographic conditions meant that the horizontal-wheeled mills had to be maintained, such as in the Sierra de Cádiz. The first documentary evidence of the existence of mills in the area can be found in a clause dated 26th February 1584, contained in the *Municipal by-laws archive of la Villa de Zahara* (Escalera Reyes, 1983, p. 42), which reveals that their existence was common at that time, which must be why, in the 16th century, the mills were fully integrated into the way of life of the Sierra. At that time, many of the watermills in Europe drove the complex structure of monopolies, privileges, and banal rights that characterised the feudal regime, as they were a major economic and vital source for the community. Nonetheless, in areas where the feudal power was not so strong, such as in the Sierra de Cádiz[4], there were small mills "whose occupancy and use would be of a communal, neighbourly or family nature" (Escalera Reyes, 1983, p. 36). In the 18th century, we can find a more comprehensive account of the watermills thanks to the *General Answers* of the Ensenada Cadastre (1750Ð1754), through which we now know that there were 61 flour mills in the region due to textual and sometimes graphic descriptions (Fig. 3). Second to these, the Planimetric Surveys of 1873-1874 are the most accurate historical cartography that has allowed us to count the watermills in the region, since they coincide in time with their period of maximum operation. These documents, contrasted with the fieldwork, have been fundamental in locating the 85 watermills that are still in existence[5].

In the Sierra de Cádiz, the watermills were kept in full operation until the beginning of the 20th century, with the exception of 4 watermills (in the municipalities of Algodonales, Grazalema and Zahara de la Sierra) to which 6 bakeries were associated (Escalera Reyes, 1983, pp. 152-154). This was unusual, considering the general closure of flour mills in Spain during the first half of the 20th century, when the ultimate transition towards economic modernisation took place (demographic growth, technological innovations in the second half of the 19th century, improvements in agricultural activity, etc.). After the introduction of the Austro-Hungarian milling system (from the 1878 Universal Exhibition in Paris), traditional mills gradually disappeared and were replaced by flour mills: in the period from 1856 to 1900 alone, the number of mills recorded in Spain fell by 22%, while the number of flour mills rose from 82 to 712 (Nadal Oller, 1992, p.161). After the Civil War they experienced an upturn in their production, paradoxically due to the grain control and rationing policy of the Franco regime, systematically infringed by the mills in the Sierra in light of the post-war shortages, when bread was a staple and essential food for the rural and farmer community. The mills of the Sierra continued to mill in secret, evading the policies that ordained their closure and dodging the inspections of the Tax Prosecution Office and the National Wheat Service, with the help of the complex topography of the Sierra, well known by the millers. In this way, the millers overcame the obstacles of the interventionist policies, but there were other factors that caused their ultimate downfall, such as the competition of flour mills, the abandonment of farmhouses and ranches, and the depopulation of rural areas whose people were their main consumers or "clients", the overcoming of the subsistence economy that characterised the Sierra, or the progressive decline of the crops in favour of livestock specialisation (Escalera Reyes, 1983, p. 49).

2 Hippa in Olvera, Laccipo with Setenil de las Bodegas, Ocurri with Ubrique and Benaocaz and Lastigi with Zahara de la Sierra.

3 Benaocaz, Grazalema, Olvera, Setenil de las Bodegas, Torre Alháquime, Ubrique, Villaluenga del Rosario and Zahara de la Sierra.

4 Due to their Muslim past and because, after their conquest and integration in the Crown of Castile, the lordships in which these lands were integrated were always based in other towns and cities, and they only built a recreational estate, which is the origin of the current municipality of El Bosque (Pérez Ordoñez, 2009, pp. 124-125).

5 For more information on the use of the Planimetric Surveys to locate water mills in the Sierra de Cádiz, see: Rivero-Lamela & Ramos-Carranza (2019).

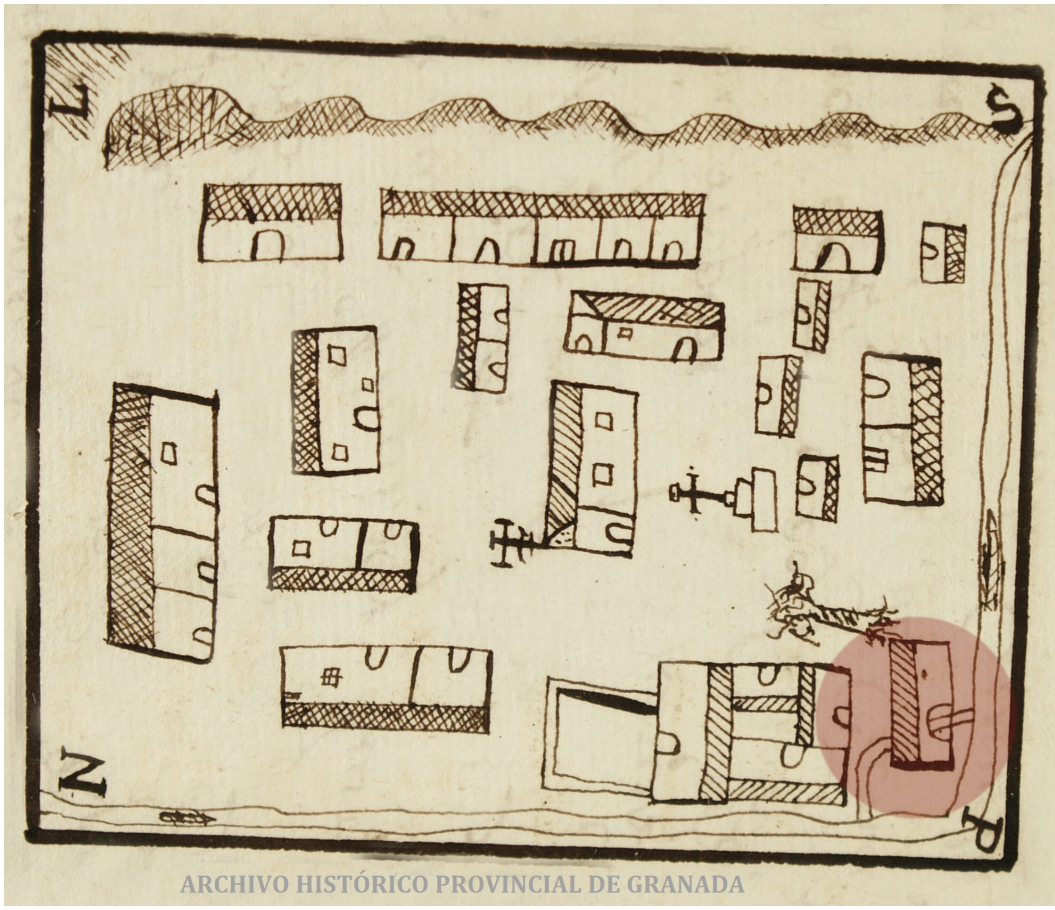

FIGURE 3 El Bosque (Marchenilla), as seen in *Autos, respuestas generales y estados de El Bosque*. Ensenada Cadastre. 1753-1754. Symbol: D-L/1513. Image by Archivo Histórico Provincial de Granada (Historical Archive of the Granada Province) Reprinted with permission.

Taking their current inactivity into account and the fact that many mills are in a complete state of ruin, this study aims to understand how these hydraulic mills worked in relation to their activating channels—rivers and streams—, in order to draw conclusions that may be useful in current water management practices and landscape projects in the region or in other similar geographical areas. Their lack of cataloguing and cultural interest is due to the fact that they have been considered as constructions whose purpose justified their existence, being forgotten when they were no longer indispensable. It is interesting to note that the current state and local maps do not show any of these old mills.

There is growing literature on the study of these types of mills, but it is still fragmented. In the international context, Adam Lucas' monograph (2006) serves as a reference point, providing a general outlook of milling in ancient and medieval societies, and showing the continuity in the use of the horizontal wheel. The works by Colin Rynne (2013) for Western Ireland can also be mentioned. The fact is that the horizontal-wheeled mills are technically the oldest hydraulic devices. The different types in existence vary depending on how they obtain the amount and force of water required to make the wheel turn. When it was not possible for the wheel to directly enter the river because of its insufficient flow or speed, the construction of artificial waterfalls or dams became necessary. In these cases, the water had to be captured and carried to the point capable of creating a strong jet of water, which was achieved in different ways through irrigation channels, channels at a higher point, or vertical or inclined shafts or buckets, as shown by the works of E. Veiga de Oliveira (1967) or A. Jespersen (1953).

In the Iberian Peninsula, there have also been numerous studies on water mills with horizontal waterwheels or vertical wheels. However, few works approach the issue from an architectural and infrastructural perspective that connects the mills to their riverbanks, or that conceives them as a territorial system of water circulation, and that uses planimetric drawing as a methodological tool. Some examples along this line have been developed in the north-west of Portugal (Matos, 2011; Matos & Barata, 2016; Silva Costa, Lopes Cordeiro, Batista Vieira, & Vaz, 2016), in the Basque Country (Izaga Reiner & Herreras Moratinos, 2016), in Segovia (Sanz Elorza, 2012), in Seville (Sánchez-Jiménez & González, 2018) or in Granada (Reyes Mesa, 2000), but none has focused on the Sierra de Cádiz region.

An *open* hydraulic re-circulation system

All the flour mills in the Sierra de Cádiz shared the same formal, spatial, and constructive characteristics, and basic infrastructures for their operation. Each had a horizontal waterwheel and a channel to divert water from the stream, bypassing the topography and carrying it to the buckets (penstock tower) –one or two–, a channel that enabled the water to fall with enough power to drive the waterwheel. Additionally, some had ponds, which gathered the water in case of a lack of river flow. Once the mill mechanism was activated, the water returned to its natural course due to the strategic location of the mill, which was always close to the stream. This generated a *circular water story*, a pseudo-natural circuit that derived from the logical interpretation of the natural conditions of the environment. According to British historian A. Keller (1984), the “molino de cubo” (bucket mill), as it is referred to in Spanish, comes from the Arabic *arubah*. Ancient ruins of this kind have been found in Israel, as is highlighted by S. Avitsur (1960), and their structure (Fig. 4) is very similar to that of the mills in the Sierra de Cádiz that we have described.

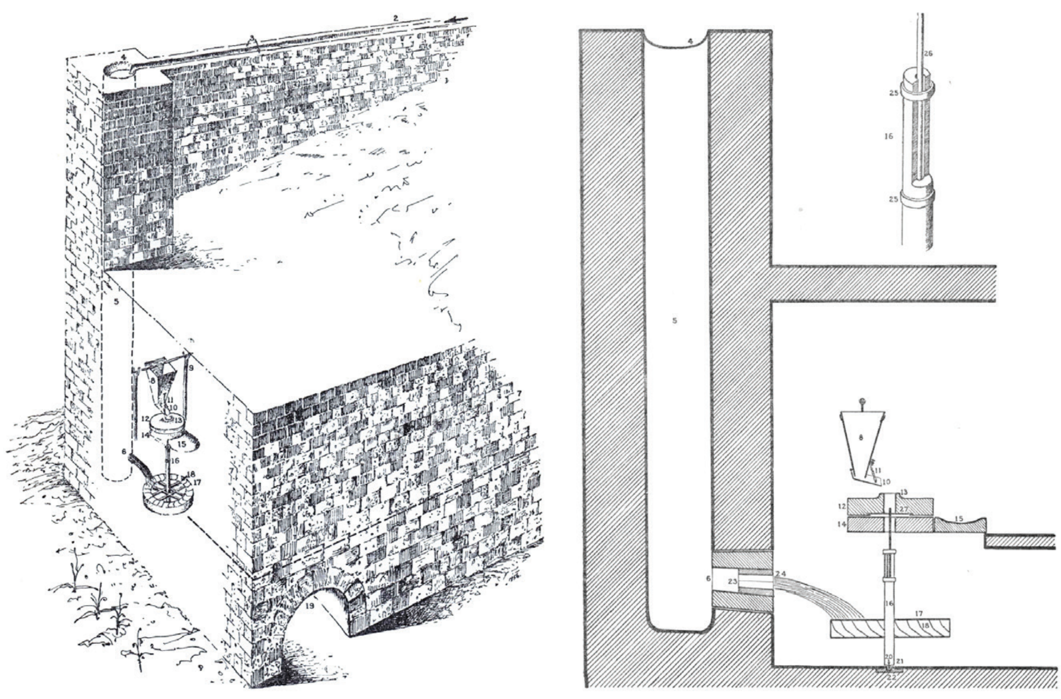

FIGURE 4 Structure of an ordinary *arubah* penstock mill (Avitsur, 1960, pp. 42-43).

There is an invaluable Spanish manuscript from the 16th century by Pedro Juan de Lastanosa known as “The Twenty-One Books of Devices and Machines”, in which the bucket mills are described and drawn, which may or may not already have a pond (Fig. 5).

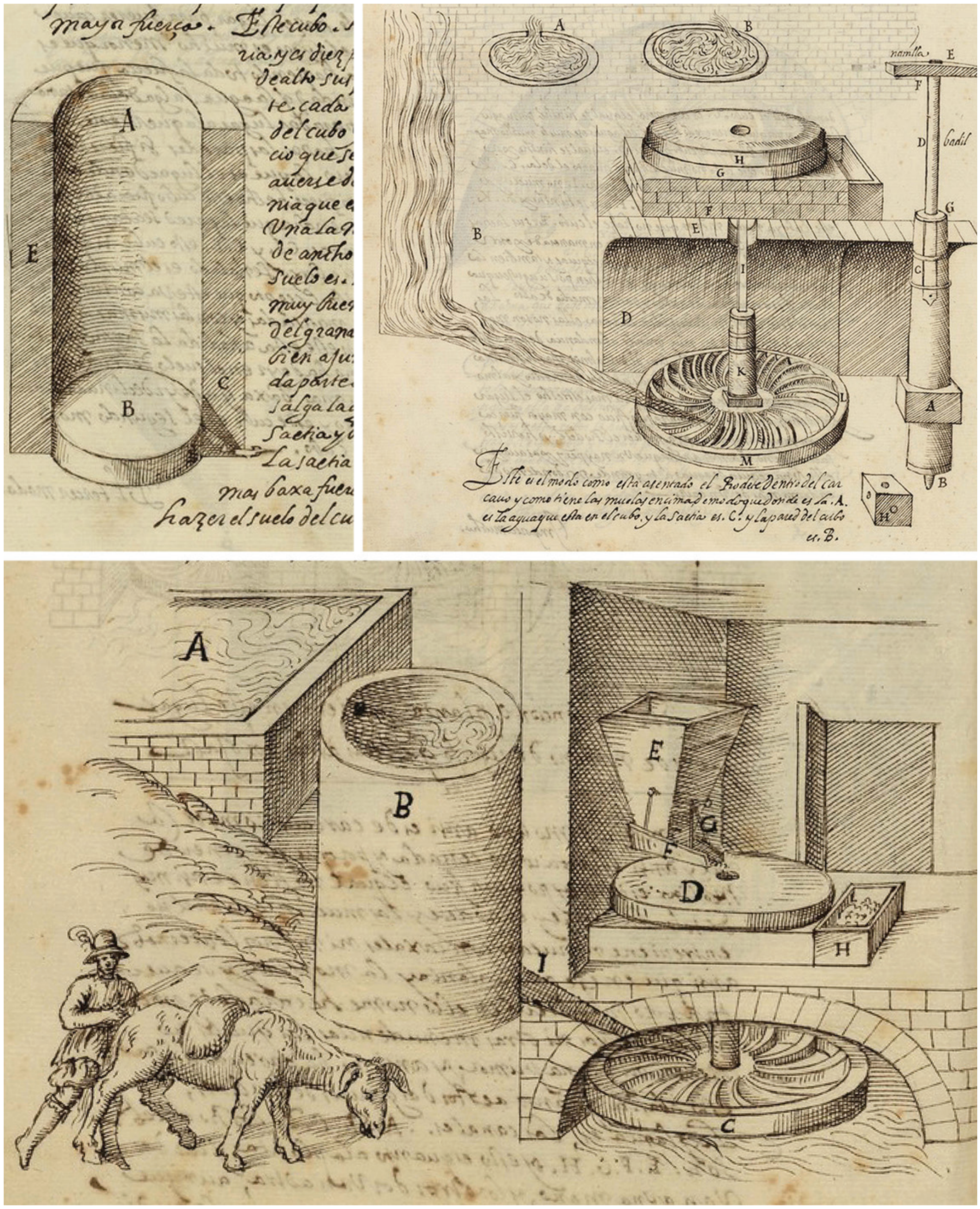

FIGURE 5 Bucket mill in the 16th-century manuscript "The Twenty-One Books of Devices and Machines" by Pedro Juan de Lastanosa. Images property of the Biblioteca Nacional de España [Spanish National Library].

The work already carried out to locate all the mills in the region and their study at riverbank level allows us to understand their operation as open re-circulation systems of water resources. In other words, the mill or group of mills are not a cyclical—and therefore closed—system that starts and ends at a geometric point; these mills are connected at the exact point to create an artificial but innocuous circuit, which captures the water and directs it towards the mill, in a route that ends in the same riverbed of origin, downstream, at another point different from the initial one. It is, therefore, a system of re-circulation of surface water that depends on the natural course of the stream itself to complete the technical process of using, exploiting, and returning the water (Fig. 6).

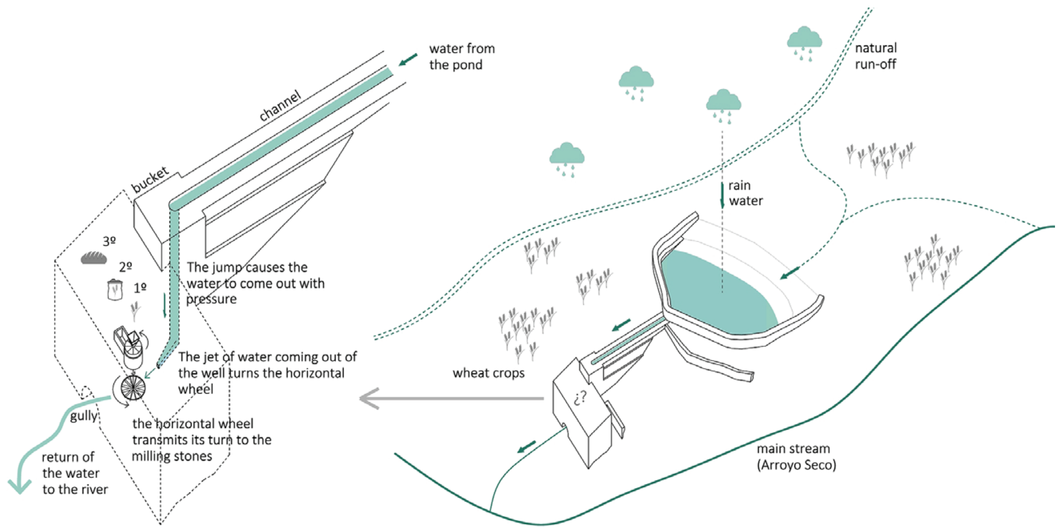

FIGURE 6 Functional diagram of the mill, drawn according to the ruins found. Second mill (B-02), riverbank of Arroyo Seco, Benaocaz.

This circular use of water allows for the introduction of different variations that made this generic scheme a more complex system due to the physiographic and climatic singularity of the Sierra de Cádiz. This created an extensive hydrographic network which, together with numerous roads and communication routes, also adapted to the topography, connected mills, cropland, and pasture land, communities and other scattered buildings. This idea of connectivity through the communication and water infrastructures was transferred to the water re-circulation system, as in various riverbanks just one riverbed would activate various mills and would also irrigate the nearest crops.

We consider that the analysis of the mills' architecture and its connection to the land is an appropriate way to explain the interrelationship with the river and other natural elements. We perceive the different water re-circulation circuits as parts of a larger system: the mill structure created around a specific riverbank, which strategically distributes the mills and their hydraulic infrastructures along the riverbed and, from a larger perspective, the mill configuration of the whole region.

Methodology

The research method is straightforward to explain and complex to implement. It is based on understanding the different scales that coexist around the mill building and its water circulation system to try to extract all possible knowledge. In this sense, this methodology allows for a scope of research that includes the relationship between different scales of work and addresses the implied link between technologies, cultural contexts, and efficiency that historian P. Oliver (2006) deems necessary for the full understanding of the fact or reality to be analysed: "To understand the full implications of the technologies used, it is necessary to consider them in relation to their cultural contexts, as well as in terms of their efficiency or performance" (p. 122).

Thus, after locating 85 mills by analysing the historical cartography and completing it with exhaustive fieldwork, it was possible to verify the different contexts, territories, and states of conservation of the mills. These factors justified the selection of the representative riverbanks of the region in which the hydraulic milling system, the circularity of the water, and the productive operation would be studied in detail.

The analysis of the mill banks of the Sierra de Cádiz revealed different water re-circulation systems: systems that need ponds in order to prevent the consequences of the lack of flow from the stream or river due to the insufficient rain in summer periods (the riverbank of the Arroyo Seco, located in Benaocaz); systems in which the channelled water is also used for the irrigation of nearby agricultural land (the riverbank of Bocaleones, located in Zahara de la Sierra); and finally, water circulation systems used by several mills (the riverbank of Gaidóvar, in Grazalema).

Arroyo Seco Riverbank

On this mill bank (Fig. 7), the only constructions that have been in existence since the 19th century are three mills that are dependent on the Arroyo Seco, whose name ("dry stream"), reveals the scarce quantity of flowing water, not enough to guarantee the mill's operation throughout the year. The scarcity of water explains the current absence of farmland. The wheat, barley, and rye plantations (dry crops) that existed there, according to the 1873 Planimetric Surveys, have become unproductive lands used for pastures. The irregular flow of the Arroyo Seco forced the mills to provide their own infrastructure to guarantee the continuous supply of water: these are the ponds that precede the channel that ultimately carried the water to the mill. The position of these ponds, as can be seen on the map (Fig. 7), was built in line with the topography to take advantage of natural runoff from the rain, whose water is added to that which could be obtained by artificially diverting the bed of the Arroyo Seco in times of enough flow. There is no physical evidence of a connection between ponds and the river, but it is likely that there are unbuilt surface channels (diversions), these being mere ditches dug into the ground.

It was, therefore, a double water collection system that made the most of the natural efficiency provided by the topography and the rainwater runoffs, thus increasing the natural functioning of Arroyo Seco as these ponds were converted into small natural waters accumulators which, once used for milling, were returned to the stream and improve the mill's operation.

FIGURE 7 Arroyo Seco Riverbank, in Benaocaz. Presence of 3 hydraulic mills (from left to right): B-03: El Pontón Mill, B-02: Second Mill and B-01: First Mill.

To the north of the stream, a path that runs parallel (called "Cañada de Piedras") gives rise to a strip of land divided into rectangular and elongated plots: this optimises the rights of way and the benefits derived from the river. These plots are transversally divided by two water lines located very close to the surface which, it seems, helped to store water in the mill ponds (drawn on the map of Fig. 7 with dotted blue lines. On one of these it says "natural run-off"; currently this constitutes ditches created by erosion after rain).

The use of natural conditions and resources minimised the transformation of the landscape by reducing the construction of channels for water collection, which is why these mills were located in front of or at the side of the riverbed. Each had a wheel, which resulted in moderate production, typical of an environment with a few scattered buildings and covering mainly the needs of the town of Benaocaz, 500 m from the First Mill (B-01).

At present, the three mills are in ruins, which influences the level of conservation of the roads mentioned. However, the remains of their infrastructures still allow the hydraulic system that made them work to be determined. At their lowest point, the ponds were connected with the channels, whose length varied according to the distance at which the mill was located and the topographical unevenness. This explains the function of the bucket and the position of the mill: the bucket had to be placed in the area of greatest unevenness so that the natural fall of the water generated sufficient force to move the horizontal wheel; the mill had to be placed as close as possible to the riverbed to ultimately return the water to the natural course of the river (Fig. 8).

In the case of El Pontón Mill (B-03), its location allowed it to fill the pond directly due to the free fall of the water, although this meant that there was a greater distance between the mill and the pond. In this case, the length of the channel turned the mill infrastructure into a sort of dock that linked both arms of the stream, benefiting from the difference in height between the pond and the mill, which then allowed the waterfall to turn the horizontal wheel.

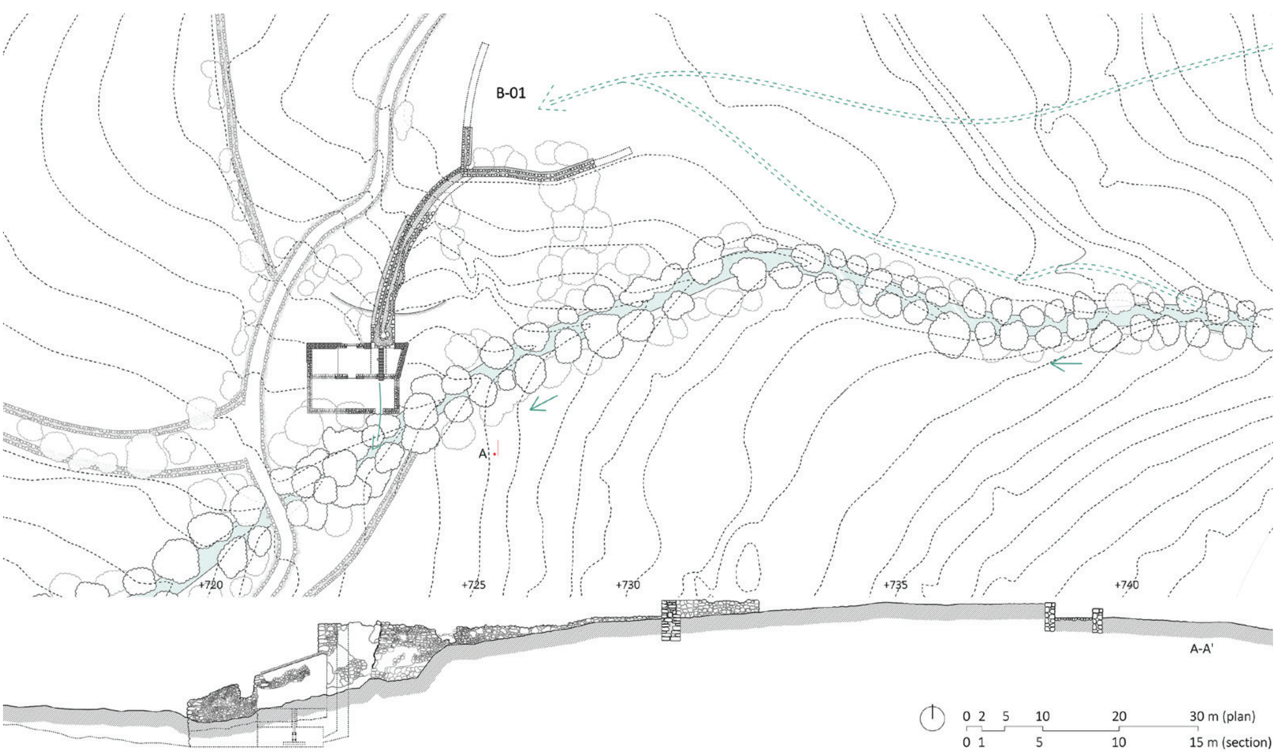

FIGURE 8 First Mill (B-01). Arroyo Seco riverbank, in Benaocaz.

Regarding the months of operation of the mills and whether they were seasonal or operated throughout the year, it is not possible to find this information. The mills of this riverbank have been abandoned for decades and we do not have any first-hand testimonies. The only document that makes reference to this aspect is the Ensenada Cadastre (1750-1754). In its response to question number 17, it accounts for six flour mills in the locality (through our fieldwork we have located twelve mills), and says that two of them "mill in winter when there is a lot of rainfall", with another three "using the river water, occasionally stopping" and the remaining one "using the river water". We do not know whether it is referring to the mills of the Arroyo Seco, although it is unlikely that they only milled in winter, because those are the mills that are within the closest proximity to the municipality of Benaocaz. We shall aim for the hypothesis that they also milled in summer thanks to the ponds, though on a more occasional basis.

In terms of the production of these mills, this is an aspect that is difficult to measure as it depended on the number of wheels that the mill had and on the period in which it was active each year. The Ensenada Cadastre, again in response to question number 17, mentions the annual income that the six aforementioned mills generated: the one that mills throughout the whole year produces "44 fanegas[6] (bushels) of wheat", the two that only mill in winter produce "6 fanegas of wheat" and those mills whose production is sometimes stopped produce "between 20 and 24 fanegas".

One thing we can say for certain is that they were essential for the rural community to survive. The mills of the Sierra de Cádiz were "maquileros", which means that they could not officially buy or sell wheat or flour, and they were limited to milling the wheat that was brought to them by farmers or individual locals in exchange for the "maquila", which is the payment in kind –generally flour– or money to remunerate the work of the miller.

Bocaleones Riverbank

Despite its distance from the town (3 km), this has always been an inhabited and cultivated riverbank, a fact that can be confirmed by the historical cartography and the presence of three mills, one of which has now completely disappeared—which is why only two appear on the map in Fig. 9.

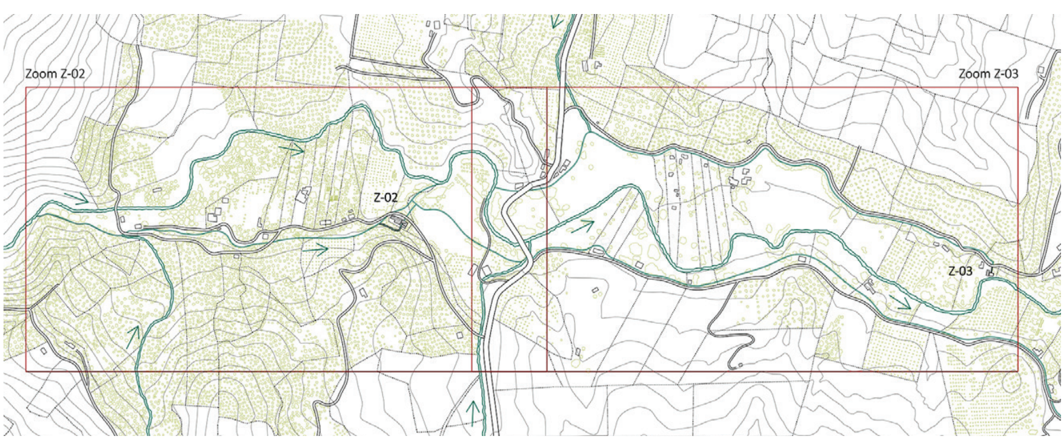

FIGURE 9 Bocaleones riverbank, in Zahara de la Sierra. Presence of 2 hydraulic mills (from left to right): Z-02: Bocaleones Mill and Z-03: Flour Mill.

6 A fanega (bushel) is a unit of measurement from traditional Spanish metrology, which in Castile equates to 55.5 litres, although this varies depending on the region.

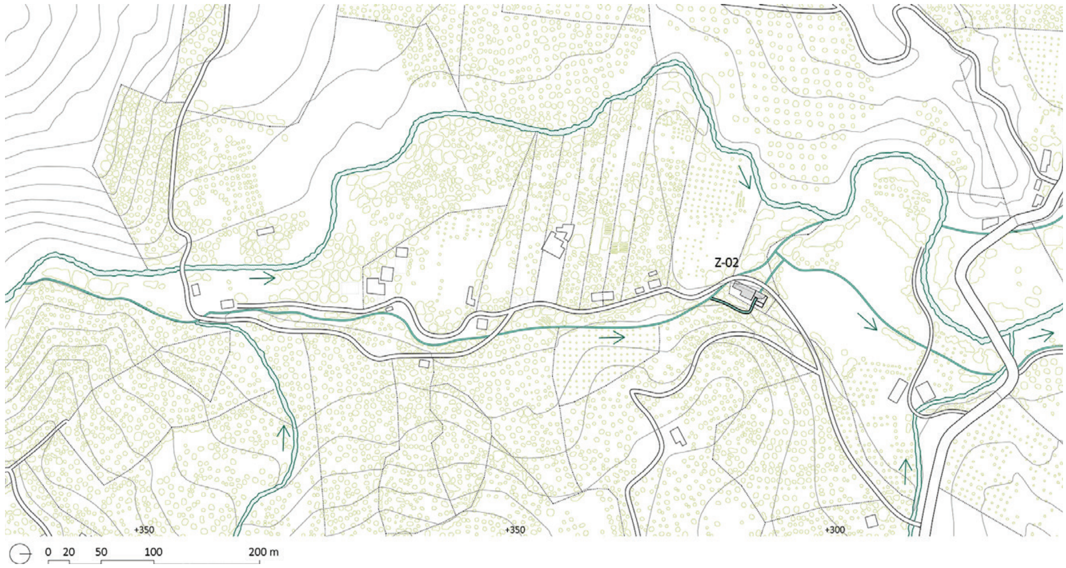

FIGURE 10 Surroundings of the Bocaleones Mill (Z-02).

None of the mills on this riverbank has a pond, which indicates that Bocaleones was a river with sufficient and regular flow throughout the year. The hydraulic system of the mills—the irrigation channels, together with the roads and the stream, structured the whole valley and determined land distribution, communications and irrigation systems, giving rise to productive land.

The first irrigation channel (the one furthest to the south) emerged from the riverbed at +300 m and ran for about 820 m until it rejoined the river, downstream at +285 m. Its function was—and still is—to irrigate all the agricultural plots on both sides. A second circuit (or second irrigation channel) emerged from this main channel and was responsible for feeding the Bocaleones Mill (Z-02), whose water discharged from the gully was channelled again through a channel that ran along the right bank of the stream, parallel to one of the paths that runs along this bank, and whose only function was to irrigate the crops. It was, therefore, a diverse system of water circulation; in this case, the mill took advantage of the water management needs of an agricultural environment. The synergy between milling, cultivation, and irrigation created benefits that were greater than their individual action. (Fig. 10).

The channel that fed the Flour Mill (Z-03) measures 1113 m, from the point where it connected with the Bocaleones stream at +280 m until it ended at a height of +275 m. In this way, a surface circuit was created on the left bank of the stream. This circuit acted as a cut or dock and fulfilled the functions of watering the land as it passed and bringing the water to the mill at the right level. The channel ran again parallel to the path, and both, as on the other bank, adapted to a certain height for greater ease of construction (Fig. 11).

This system meant that the plots of land delimited by rivers and channels were shaped with little width and greater depth, in order to achieve the least possible easement. The repercussions of the hydraulic infrastructures in which the mills operated can be seen in many of the anthropic layers that make up the current landscape of this riverbank.

Infrastructure and architecture become an essential and necessary link to enable the life and operation of the riverbank. As stated by Professor J. M. Palerm Salazar (2019), these types of actions on the land are a “product of people’s experience … they build an evocative landscape in a way of linking to the land between walls, houses and roads” (p.17) with the intention of inhabiting a place.

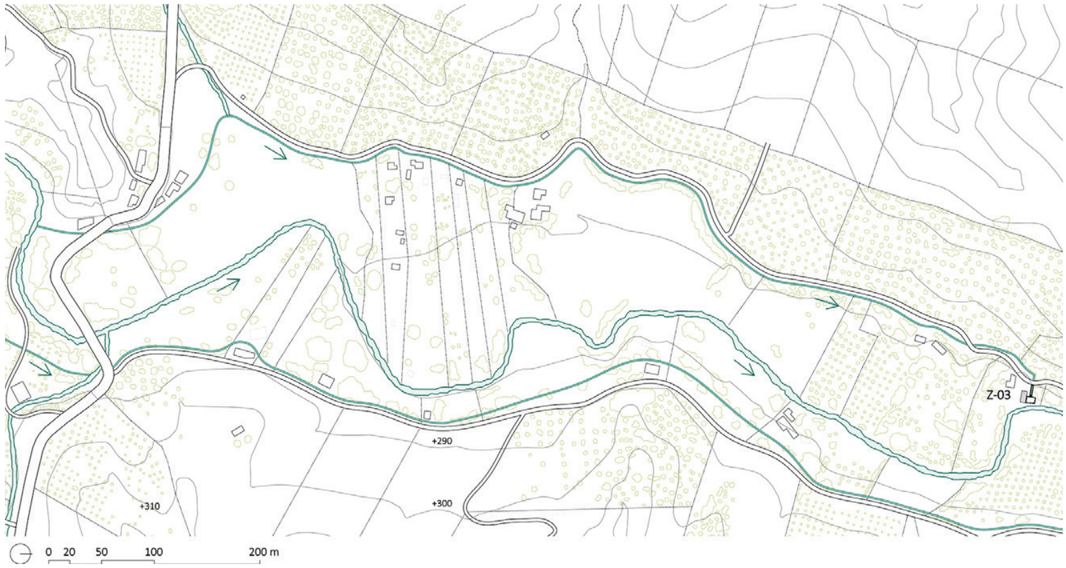

FIGURE 11 Surroundings of the Flour Mill (Z-03).

Gaidóvar Riverbank

On this riverbank (Fig. 12), the water circulation system connected pairs of consecutive mills, in addition to being used for the irrigation of adjacent lands. Of the fourteen existing mills, none had a pond, and all had one wheel (less production but more mills), which shows sufficient river flow and controlled production to meet the needs of their surroundings. Pairs of mills could be found where the topography is a little smoother, just at the beginning of the riverbed. The first four, located at a higher altitude, were grouped and connected by their irrigation channels (G-01, G-02, G-03, and G-04, Fig. 13). The hydraulic system was the same in both mill pairs, except for the length of the surface channels. In both cases, they irrigated the crops on the surrounding land. These crops were flushed out, following the traditional technique for cultivating sloping soils. Once the mechanisms of these first mills was activated, the water discharged was led to the next ones. The system was repeated: once the horizontal wheel was activated, the water exited through the gullies of the G-02 and G-04 mills and gravity returned it to the Gaidóvar stream (Figs. 14 & 15).

The fact that the land adjacent to the mills was suitable for cultivation explains the layout and extension of the irrigation channel linking mills G-01 and G-02. The collaboration that enabled the construction of the channel and the optimisation of a natural resource such as water, speaks volumes about the local character of the region and the soundness of a channelling system built decades ago which is partially still maintained, despite the mills no longer being operational.

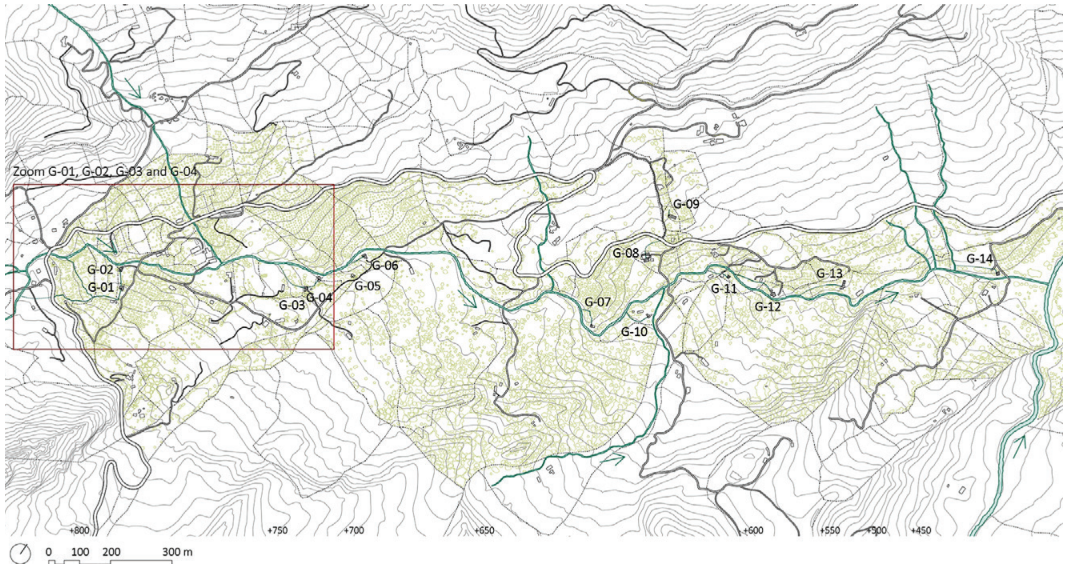

FIGURE 12 Gaidóvar riverbank, in Grazalema. Presence of 14 hydraulic mills (from left to right): G-01: La Cruz Mill, G-02: El Rincón Mill, G-03: El Pero Mill, G-04: El Portal Mill, G-05: El Algarrobo Mill, G-06: La Pasá Mill, G-07: El Caballo Mill, G-08: J. M. Chacón Mill, G-09: La Batana Mill, G-10: El Juncal Mill, G-11: El Zurdo Mill, G-12: El Pastor Mill, G-13: Caracol and G-14: Pataita Mill.

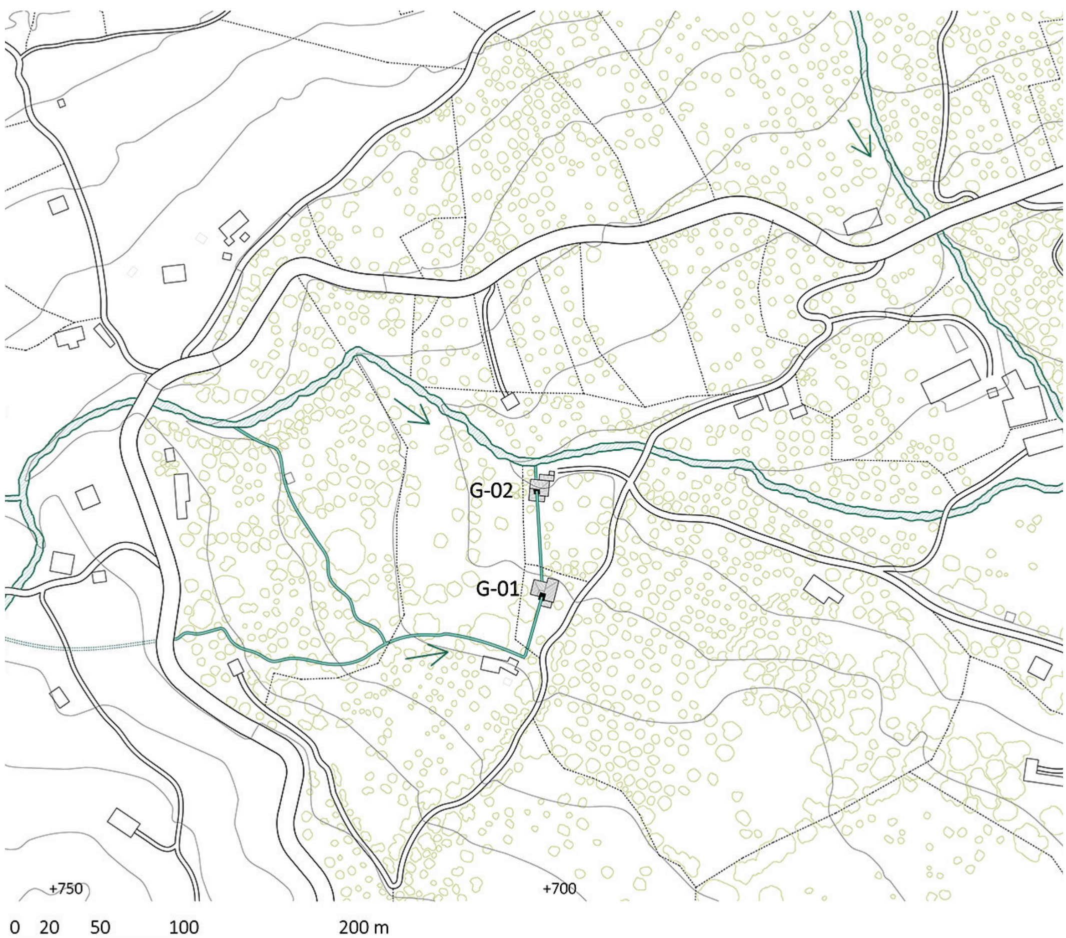

FIGURE 13 Surroundings of La Cruz (G-01), El Rincón (G-02), El Pero (G-03), and El Portal (G-04) Mills.

FIGURE 14 Section of the riverbank of Gaidóvar, in Grazalema. La Cruz (G-01) and El Rincón (G-02) Mills. Photograph taken by the authors via drone (2017).

FIGURE 15 Section of the riverbank of Gaidóvar, in Grazalema. El Pero (G-03) and El Portal (G-04) Mills. Photograph taken by the authors via drone (2017).

Water, Milling, and the Miller

The two factors that made this activity possible, beyond the milling mechanism itself, and that affected the social conditions and the stories of people involved with the mills, were the raw materials – grains, and the source of energy –rivers. These factors influenced their location and meant that the mills and the families that inhabited them were relatively isolated from the population centres.

Water is a vital element within rural communities. The artificial pipelines that the mills required covered, in numerous cases, many metres and crossed the lands of gardeners and farmers who benefited from this circumstance, using the channelled water to irrigate their crops. Each local resident was in charge of cleaning the stretch of irrigation channel that ran through their land, in the collective management of water carried out by the community, dependent on the intensive use of the hydraulic system that, in many cases, was regulated by the customary laws imposed on each riverbank (Escalera Reyes, 1983, p. 131), and which determined the time taken to distribute the water between farmers and millers.

The other factor, grains, was also an essential part of their location, as the wheat milled by each mill generally came from the surrounding lands, which made up their main area of activity.

In the Sierra de Cádiz, the mills were a family trade, and the miller, as a skilled tradesman, was indispensable and key to the life and economy of the rural communities. This was a "middle class" profession in rural areas, and for many years they were able to take advantage of the fact that they were the only sources of flour production available to make bread.

The milling process started with the transportation of the wheat to the mill carried out by a nearby local resident. First the wheat was weighed and then cleaned, washed, and put out to dry in the sun on mats, a task that was carried out by housewives, who also coordinated it with washing clothes by using the water that came out of the gullies. 16).

Once dried, the wheat was entered into the chute, and then it would fall onto the stones where it would begin to be milled until it became flour.

Generally, all of these tasks were carried out by the family itself, who passed on the knowledge of the trade from generation to generation. It was common for a family of millers to move from one mill to another within the same area, with the aim of finding a mill with a greater production capacity to thus improve their financial circumstances (Escalera Reyes, 1983, p. 168).

The productivity of each mill depended on the force of the water and the number of stones that it had. However, Escalera Reyes (1983, p. 137) establishes that production was greater in the harvesting seasons for wheat (June-August) and olives (November-December), as this was when the farmhouses and ranches were more inhabited by dry labourers, and estimates that the production capacity of the mills in the area was between one or one and a half fanegas per hour.

The investment and maintenance costs were minimal, and it was normal for there to be no employees and for the family of the miller to carry out all tasks, which meant that this trade was cost-effective and secure (Ordóñez Vergara, 1993), taking into account the ups and downs that the political future and industrial development caused in the 20th century, which led to many mills working in secret and sneaking in new tasks to increase their income.

FIGURE 16 Women and children around the El Rodezno Mill, in Ubrique (Sierra de Cádiz). Image by Romero de Torres, E. (1934, p. 45).

Conclusions

This study reveals the existence of a traditional hydraulic system generated by an economic activity and supported by the constructions and infrastructures that were needed for the operation of the flour mills in the Sierra de Cádiz. In this case, the functionality of any productive activity leads to very limited interventions that still tended to optimise the natural resources required by said productive activity. Understanding this criterion has been essential to understanding the location of the mills and explaining the layout of their various hydraulic infrastructures, as well as to understanding other parts that are necessary for their operation—such as ponds—on the riverbanks with rivers or streams of irregular water flow.

The use of water through what we have called an *open* water re-circulation system, is also developed from this logical way of using the resources available in a region that, for decades, was isolated or had difficulty connecting to other regions or nearby places. The cases in which various productive activities coexisted (cultivation and milling), or even those in which the physiographic conditions have forced a shared use of the irrigation channels and riverbeds, demonstrate the validity of this form of water circulation.

It is clear that technological advances and changes in production systems are normally the reason why certain activities end, especially when it comes to manual activities. The same necessity and functionality that made these mills necessary condemned them to be abandoned and forgotten, thus ending up in ruins and disappearing. The mills and the infrastructures that still remain, even those that are in ruins, should be protected and conserved because, in addition to representing to a cultural and historical time in the region, they represent an identity. These structures also allow an understanding of the use that we can give to land, the way in which it is possible to use local materials, the use of passive technologies, the incorporation of constructive rationality or the adaptation to natural factors (rivers, topographies, crops...). All these factors show a balance between resources and demands, and the integration between natural and anthropic aspects—guidelines that should be a priority in all territorial and landscape management and intervention. We should consider the strong potential offered by these mills, since they could be reincorporated into rural development through innovative approaches. Therefore, this would be a first step in viewing mills as a heritage network in need of protection and reactivation.

References

Avitsur, S. (1960). On the History of the Exploitation of Water Power in Eretz-Israel. *Israel Exploration Journal*, 10(1), 37-45, http://www.jstor.com/stable/27924809

Derry, T.K., & Williams, T.I. (1977). *Historia de la tecnología* [History of technology]. Madrid, Spain: Siglo XXI.

Escalera Reyes, J. (1983). Molinos tradicionales [Traditional mills]. In J. Escalera Reyes & A. Villegas Santaella. *Molinos y panaderías tradicionales* [Traditional mills and bakeries] (pp. 13-173). Madrid, Spain: Editora Nacional.

García de Cortázar, J.A. (1974). *La época medieval* [The medieval era]. Madrid, Spain: Alianza.

Holt, R. (1990). Milling Technology in the Middle Ages: The Direction of Recent Research. *Industrial Archaeology Review*, 13(1), 50-58, doi: 10.1179/iar.1990.13.1.50.

Hough, M. (1990). *Out of place: restoring identity to the regional landscape*. New Haven and London: Yale University Press.

Izaga Reiner, J.M. & Herreras Moratinos, B. (2016). Protección del patrimonio de las cuencas fluviales del País Vasco [Protection of the heritage of the river basins of the Basque Country]. In ACEM, *X International Molinology Conference*, Segovia, Spain, 333-345.

Jespersen, A. (1953). *A Preliminary Analysis of the Development of the Gearing in Watermills in Western Europe*. Virum, Denmark: Danske Boghandleres Kommissionsanst.

Keller, A.G. (1984). "Northern" and "Southern" Horizontal Watermills. In *Energy in History: 11th Symposium of the International Cooperation in History of Technology Committee* (ICOHTEC), Lerbach (near Köln), September 2 - 7, 1984.

Lucas, A. (2006). *Wind, Water, Work. Ancient and Medieval Milling Technology.* Leiden, Netherlands: Brill.

Matos, B. R. (2011). *Património à prova de agua. Apontamento para a salvaguarda das azenhas & açudes nas margens do rio Ave, Vila Nova de Famalicão/Trofa* [Waterproof heritage. Notes to safeguard water mills and dams on the banks of the Ave River, Vila Nova de Famalicão/Trofa]. Vila Nova de Famalicão, Portugal: Câmara Municipal de Vila Nova de Famalicão.

Matos, B.R. & Barata, F. (2016). Ave's watermills: Territory, Architecture and Construction Systems. *International Molinology*, (92), 22-29.

Nadal Oller, J. (1992). *Moler, tejer y fundir: estudios de historia industrial* [Grinding, weaving and casting: industrial history studies]. Barcelona, Spain: Ariel.

Oliver, P. (2006). *Built to Meet Needs. Cultural Issues in Vernacular Architecture*. Oxford, England: Elsevier.

Ordóñez Vergara, P. (1993). Los molineros de La Alpujarra [The millers of La Alpujarra]. *Gazeta de antropología*, (10), 13, http://hdl.handle.net/10481/13642

Palerm Salazar, J.M. (2019). Monotonous repetition in architecture. Terraced landscapes. *Proyecto, progreso, arquitectura*. Paisaje de Bancales, (21), 12-19, doi: 10.12795/ppa.2019.i21.12.

Pérez Ordoñez, A. (2009). *Sierra de Cádiz andalusí: Arquitectura y urbanismo islámicos en la frontera occidental del Reino de Granada* [Sierra de Cádiz Andalusi: Islamic architecture and urbanism on the western border of the Kingdom of Granada]. Spain: Lulu.

Reyes Mesa, J.M. (2000). Technology and popular architecture: Waterwheels in the province of Granada. *Gazeta de Antropolgía*, (16), 1-13, http://hdl.handle.net/10481/7516

Rivero-Lamela, G. & Ramos-Carranza, A. (2019). Drawing and interpreting Planimetric surveys: rural landscape and old productive architectures in Sierra de Cádiz. *Disegnarecon*, 12(22), 18.1-18.23, http://disegnarecon.univaq.it/ojs/index.php/disegnarecon/article/view/501/376.

Romero de Torres, E. (1934). *Catálogo de los Monumentos Históricos y Artísticos de la provincia de Cádiz*. Tomo 6 [Catalog of the Historic and Artistic Monuments of the province of Cádiz. Volume 6]. Madrid, Spain: Ministerio de Instrucción Pública y Bellas Artes.

Rynne, C. (2013). Technological Continuity, Technological 'Survival': the Use of Horizontal Mills in Western Ireland, c. 1632–1940. *Industrial Archaeology Review*, 33(2), 96-105, doi: 10.1179/174581911X13188747258748.

Sánchez-Jiménez, F.J. & González, J.A. (2018). Watermills: The Origin of the Use of Renewable Hydraulic Energy in Spain. *Industrial Archaeology Review*, 40(1), 2-10, doi: 10.1080/03090728.2018.1449383.

Sanz Elorza, M. (2012). *Ingenios con memoria. Recorrido por los molinos harineros de la provincia de Segovia y por la gestión tradicional de los recursos hidráulicos* [Devices with memory. Tour of the flour mills of the province of Segovia and the traditional management of hydraulic resources]. Segovia, Spain: Caja Segovia.

Silva Costa, F., Lopes Cordeiro, J.M., Batista Vieira, A.A. & Vaz, S. (2016). O estudo dos moinhos e aproveitamentos hidráulicos no Concelho de Lousada (Noroeste de Portugal)-Proposta de um guião metdológico [Study of windmills and hydroelectric power plants in the municipality of Lousada (Northwest of Portugal) - Proposal for a methodological guide]. In ACEM, *X International Molinology Conference*, Segovia, Spain, 407-418.

Suárez Japón, J.M. (1982). *El hábitat rural en la Sierra de Cádiz: un ensayo de geografía del poblamiento* [The rural habitat in the Sierra de Cádiz: an essay on the geography of settlement]. Cádiz, Spain: Diputación de Cádiz.

Veiga de Oliveira, E. (1967). Moinhos de água em Portugal [Water mills in Portugal]. *Geographica*, 3(9), 49-70.

Vellinga, M. (2013). The noble vernacular. *The Journal of Architecture*, 18(4), 570-590, doi: 10.1080/13602365.2013.819813.