Research on qanats in Spain

Abstract

Different types of drainage galleries exist in Span: *mina de agua*, qanat, *cimbra or tajea* and galleries associated with a groundwater dam (buried in the bed of the channel to stop sub-surface circulation). A qanat is a type of drainage gallery located in the foothills where groundwater is captured. Qanats, also called *galerías con lumbreras, minados con espejuelos, viajes de agua,* or *alcavons* in Spain, can be seen as models for sustainable use of water in arid and semi-arid environments. Furthermore, in their local contexts, these hydraulic systems create their own landscapes and hydraulic heritage. As such, the technique is the basis for new ways of thinking about how to generate water in dry environments like the Southeast of Spain. There are several groups of Spanish researchers studying qanats and other types of horizontal wells as systems being able to generate endogenous water resources. Because of their extensive and continuous research over a number of years, the teams from the Universities of Murcia and Valencia stand out.

Key words: qanat, well, groundwater dam, semi-arid, Spain.

Introduction. The horizontal well technique as a response to the conditions of the arid and semiarid environments

Water is a limited and scarce resource in arid or semi-arid environments. Due to the limited amount of surface water derived from rainfall, water resources are subjected to high evaporation. Therefore, near and deep groundwater is exploited by low electrical energy consumption catchment systems to harvest water. In contrast to these systems, drainage and filter galleries like qanats and other horizontal wells are models of sustainability, from both an environmental and exploitation point of view. They are smart solutions to obtain water using the force of gravity through a covered horizontal well, with or without vertical wells, and associated or not associated to a groundwater dam, without exhausting renewable resources (Manuel et al 2018).

From a geographical point of view, the main interest lies in the study of the location and identification of these systems. Due to the scarcity of water in the regions under consideration, these small water supply systems were important for the founding of settlements and for agricultural uses. The systems have also been studied concerning social management (by-laws, ordinances, etc.), generated landscapes, new functionalities of this technology, as well as the value of material and intangible heritage associated to the exploitation of these endogenous water resources. In the case of Spain, and especially in dry Mediterranean Spain, these water inputs are of a very low-volume compared to water transfers coming from other river basins. Although, locally they are very important due to their contribution to the basic water needs of people and cattle and, in general, for socioeconomic reasons.

The history of the qanats in Spain extends back to the Roman Empire; to this period belongs the qanats of Los Arejos and Torralba in the Southeast (Murcia), Los Caños de Carmona in Andalusia or La Fuente del Canal de Medinaceli in Castile. However, it is in the Almoravid and Almohad period when the technique is widely diffused throughout Al-Andalus (Gómez, 2004, p 95), as will be discussed below. This water extraction technique continued to develop in medieval and modern Christian times, with systems such as the Arca del Agua (Guadalupe, Cáceres) or the *viaje de agua*of the Fuente Grande of Ocaña (Toledo). Subsequently, in the eighteenth, nineteenth and early twentieth centuries, its number increased until the 1960s, when many of these water extraction systems fell into disuse due to the appearance of modern techniques. The beginning of the 21st century has been a period of discovery and valorization of abandoned qanats, and seen the appearance of new functionalities, and the rehabilitation and renewed applications of these techniques. With the aim to extend the scope of qanat studies in Water History, especially after the thematic issue in 2018, this paper provides an overview of qanats and qanat research in Spain.

Fig.1 Drinking trough and washing space at the end of the qanat's pithead in Fuente Grande (Los Vélez, Almería)

Research on qanats

As for the age of qanat technology, some authors such as Goblot (1979) suggest they developed between the 3rd – 1st centuries BC, in Armenia and Mesopotamia. However, other authors have argued for an even earlier development around the turn of the first millennium BC. Peter Magee (2005, p 228), for instance, claims that qanats already appeared in the Arabian Peninsula in the year 1000 BC, two hundred years earlier than has been argued for southwest Iran. These techniques of the horizontal draining well of the Middle East would have spread through routes such as the old Silk Road, both East

and West. The first documentary evidence for qanats may come from the Assyrian king Sargon II, who in the 7th century BC in a battle in Persia, describes the finding of underground water channels (Laureano 2005, p 135). Vitruvius, architect and roman treatise writer of the 1st century BC, describes among the methods to obtain water, one based on wells that were connected by underground conduits (From Architecture VIII, I, 6). Works like The Nabatean Agriculture of Qûtâma, translated into Arabic in the tenth century AD and whose data go back to the III-V centuries BC (El Faiz 2005, p 30) also influenced the spread of these techniques.

Regarding the origin of the horizontal well or covered conduit (gallery) technique, some authors, such as Goblot (1979), refer to a mining origin.These theories are in part based on accounts like that of Sennacherib, Sargon II's son, who seems to have learned the technique of underground pipes in Urartur, an old mining center, that were used later to supply the city of Nineveh (Laureano 2005, p 136). Other authors, such as Barcelo and Carbonero (1986) have argued that there might be multiple origins; they argue that there is not a single constructive technique, nor a uniform architecture, but that each system is a different world.

At the international level, there are more than fifty countries with horizontal covered wells (qanats). In regions like Yazd (Iran) and Turpan (Xingiang-China) numerous qanats can be found. There is a wide literature that has influenced the studies on this topic in Spain. Since the mid-1960s, several publications on underground galleries were published, analyzing qanats in Iran (English 1968; Wulff 1968; Beaumont 1968) or the filter galleries of Puebla in Mexico (Seele 1969). In the 1970s, the work of the Japanese geographer Kobori (1973, 1976, 1979) can be highlighted. These publications study qanats in arid areas like Iran, Syria or the Sahara. In the 1970s two texts appeared that had an important impact of further investigations: Wilkinson's study (1977) on Oman's *aflâj* and Goblot's handbook on qanats (1979). Subsequently, Bethemont's work (1980) on the use of inland waters and other works on qanats in Iran (Sajjdi 1982; Behnia 1988) can be highlighted. In the 1990s, the territorial scope of the studies was extended with Barnes and Fleming's work (1991, 1995) on Peru, Beekman and Weigand's (1996, 1999) on Mexico, and Lightfoot's (1996, 1997, 2000) on North Africa. In the last decade, various studies on these topics have been published; those that stand out are the studies of Palerm Viqueira (2001, 2004) on Mexican qanats or the most recent ones carried out on Iran and nearby areas like Kazakhstan and Afghanistan (Semsar 2003; Deom and Sala 2006; Goes *et al*. 2016; Semsar and Labbaf 2017). In Spain, there are many interesting contributions that will be discussed below.

Qanats in Spain

Depending on how water is extracted and collected, it is possible to distinguish different types of galleries in Spain, as discussed below. There are simple systems of excavated galleries to collect the subsurface water (cimbra) or from an aquifer (mina de agua); as well as more complex ones, like horizontal wells, which are excavated to reach the water table with vertical aeration wells (galerias con lumbreras), or presas subalveas, built on the riverbed of the rambla to interrupt the subsurface circulation.

The techniques of water capturing by means of horizontal wells (qanat) – presumably with origin in the Persian Empire – were extended in the fifth century BC to Egypt, Syria and Palestine (Evenari et al 1961; English 1968). Later, the arrival of the Roman Empire to the Middle East enabled the Romans to acquire knowledge about these techniques. In Spain, there are horizontal wells and covered conduits with a Roman origin like the qanats of Los Arejos in Águilas (Murcia)(Gil y Gómez 1993, p 139), Torralba in the watercourse of the Madroño stream (López 2009, p 105), Fuentes de Béjar (Gómez 2005, p 106), Caños de Carmona in Alcalá de Guadaira (Sevilla) (Grupo GEOS 2005, p 70; Fernández 2005, p 63; Grupo GEOS 2008, p 208), Fuente de la Canal of Medinaceli (Soria) (Morales y Borobio (1991-92), and the water mine (table 1) of the Huerta de Martin Pérez in Carmona (Sevilla) (Millán 2013, p 53).

The arrival of Arabs and Berbers in 711 AD to the Iberian Peninsula brought the development of collecting and piping of groundwater by means of opening trenches and groundwater dams in the sediments of riverbeds of ramblas (riverbeds with temporary or occasional flow due to rainfall). Some examples are the Fuente del Oro, in the bed of River Guadalentín in Lorca (Gómez 2004, p 111; Gil et al. 2011) or the Caño Viejo in the Rambla de Nogalte in Puerto Lumbreras, near Lorca (Gómez 2004, p 97). Cimbras predominate but there are also drainage galleries such as the qanat of Fuente la Peña in Fuentelapeña (Zamora) (Polo 2008, p 174) or the Raudal de la Magdalena in Jaén (Díez 2008, p 198). The latter has a Roman origin but was developed in 10th and 11th centuries.

There are several hydraulic complexes from the Middle Ages built under Christian rule using the qanat technique, such as Arca del Agua in Guadalupe (Cáceres) or some Viajes de Agua in Madrid. The origin of the piped water supply from Las Villuercas to Monasterio and the village of Guadalupe dates from 1350, under the command of the prior Mr. Toribio Fernández de Mena (Amez, 2004, p 189). In 1507 the master builder of the masonry work of the Monasterio de Guadalupe, Alfonso de Plasencia, wrote a book about the maintenance, cleaning and reparation of the Arca del Agua (Royal Archives of the Monastery, catalog number C-113). The Viaje del Agua (Qanat) of the Fuente Grande de Ocaña (Toledo) was built even more recently. It was built between 1573 and 1578 using drawings attributed to Juan de Herrera (López-Camacho *et al*., 2005, p 44).

Fig. 2 Last shaft of the gallery of Béjar (between Lorca and Puerto Lumbreras)

In the 18th century there were several publications on qanats in Madrid, known as Viajes de Agua (Aznar 1727), or on the rebuilding of the groundwater dam of Fuente del Oro in Guadalentín (Lorca) (García 1739). In the Valle del Almanzora, the Cimbra del Cebollar and Mina de Toribio can be highlighted. These systems were extended from 1719 to 1878. Toribio Martínez de la Vega, Ildefonso Cerdá, Juan Fernando Feigenspan and Antonio Farces Yesares were successively in charge of the management (Gómez 2016, p 133).

In the 19th century, many dug and open galleries in the border between Andalucía and Murcia were built, like the qanat of the Fuente del Cabezo (1864) in Huercal-Overa(Gil y Gómez 2014). Contracaño was also built in 1890. It is a groundwater dam with a preceding filter gallery that captures the interstitial water between sands and gravels from the channel of the Rambla de Nogalte in Puerto Lumbreras (Gómez 2004, p 110). For the construction of the groundwater dam, a large trench was opened in the deposits of the Ramblade Nogalte as it passes through Puerto Lumbreras (Region of Murcia). The trench was 15 meters wide by 120 meters long and it formeda transverse arch (diagonal) reaching almost eight meters deep to the impermeable bedrock (a conglomerate that local tradition said was the base of the mountains that intruded under the bed of the rambla). The dam has a trapezoidal shape, with the base (about 4 meters) wider than the cusp (1 meter), made with stone and hydraulic lime. Preceding and attached to the dam, was a drainage gallery with seven shafts, which has on its front wall (in contact with the riverbed of the rambla) some holes called *troneras, piqueras* and *mechinales. These* holes are located 0.30 meters from the base of the gallery (they are plugged with clean and loose stone) to allow the subsurface circulation of that buried reservoir (with dimensions of 120x8x1200 cubic meters) to penetrate the interior.The gallery has a span of 1.80 x 0.80 meters and its bed is covered with hydraulic lime.Water is brought (due to gravity and slope) to the surface.Once above

ground level, the water supplies Los Caños and then accumulates in a pond (with a capacity of 1000 cubic meters) for later distribution for irrigation. Irrigation organization dates from July 25, 1926, when the Communidad de Propietarios de las Aguas del Caño and Balsa de Lumbreras was established (Gómez 2004, p 113; Gil y Gómez 2006, p 108).

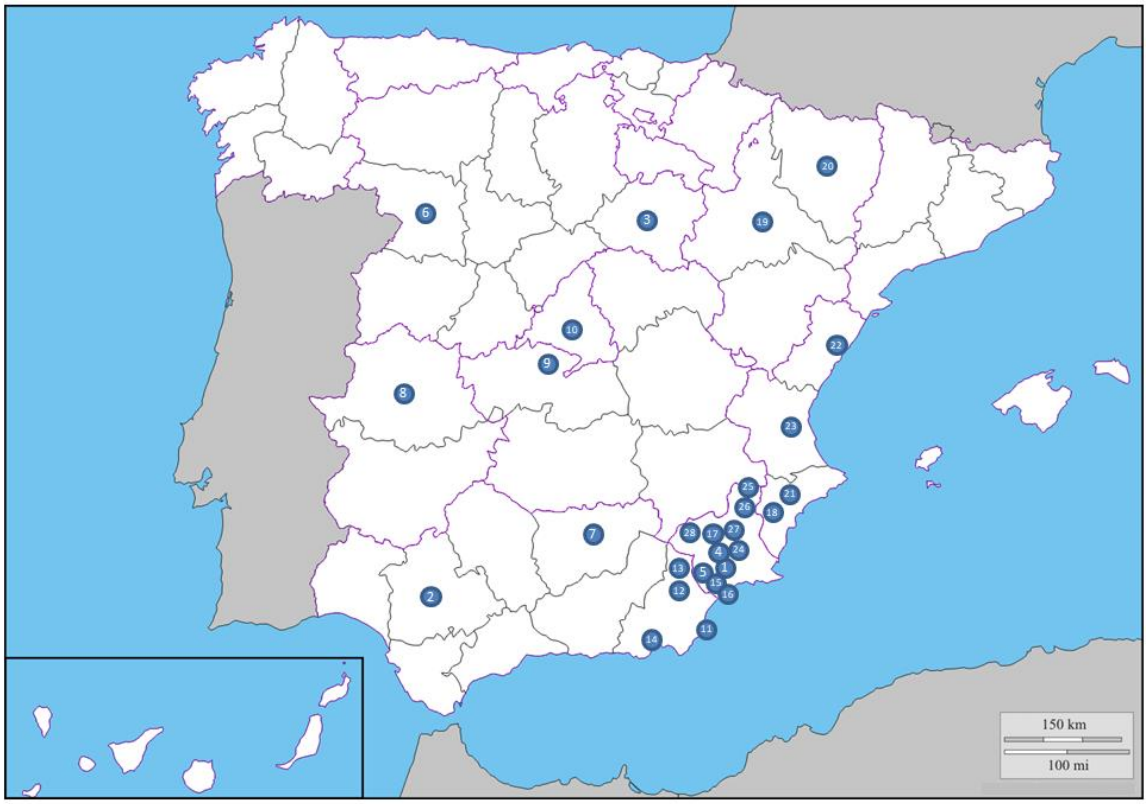

Fig.3 Location map of the main qanats in Spain

1.Dam and gallery in Rambla de Béjar (Lorca-Murcia), 2. Los Caños de Carmona (Sevilla), 3. Fuente de la Canal of Medinaceli (Soria), 4. Fuente del Oro in Guadalentín River (Lorca-Murcia), 5. Caño Viejo in Rambla de Nogalte (Puerto Lumbreras-Murcia), 6. Fuente de La Peña qanat (Zamora), 7. Raudal de la Magdalena (Jaén), 8. Arca del Agua of Guadalupe (Cáceres), 9. Fuente Grande of Ocaña (Toledo), 10. Viajes de agua (Madrid), 11. Cimbra del Cebollar (Cuevas del Almanzora-Almería), 12. Fuente del Cabezo qanat (Huércal-Overa in Almería), 13. Qanats in Los Vélez (Almería), 14. Cimbras de Ragol (Almería), 15. Contracaño in Rambla de Nogalte (Puerto Lumbreras-Murcia), 16. Gallery and shafts in Los Arejos (Águilas-Murcia), 17. Minado of Torralba (Lorca-Murcia), 18. Fuente Antigua of Crevillente (Alicante), 19. Fonnueva gallery (Zaragoza), 20. Cimbra of Fuente Madre de Castejón de Monegros (Huesca), 21. Font de la Tosca qanat (Relleu-Alicante), 22. Fuente de la Bocamina in Suero (Castellón), 23. Mina de la Cartuja de Porta Coeli (Serra-Valencia), 24. Veto qanat (Mula-Murcia), 25. Minado con espejuelos de Las Tobarrillas (Yecla-Murcia), 26. Minado con espejuelos del Pulpillo (Yecla-Murcia), 27. Fuente del Rey qanat (Cieza-Murcia), 28. Minas de aguas in Benizar and Otos (Moratalla-Murcia).

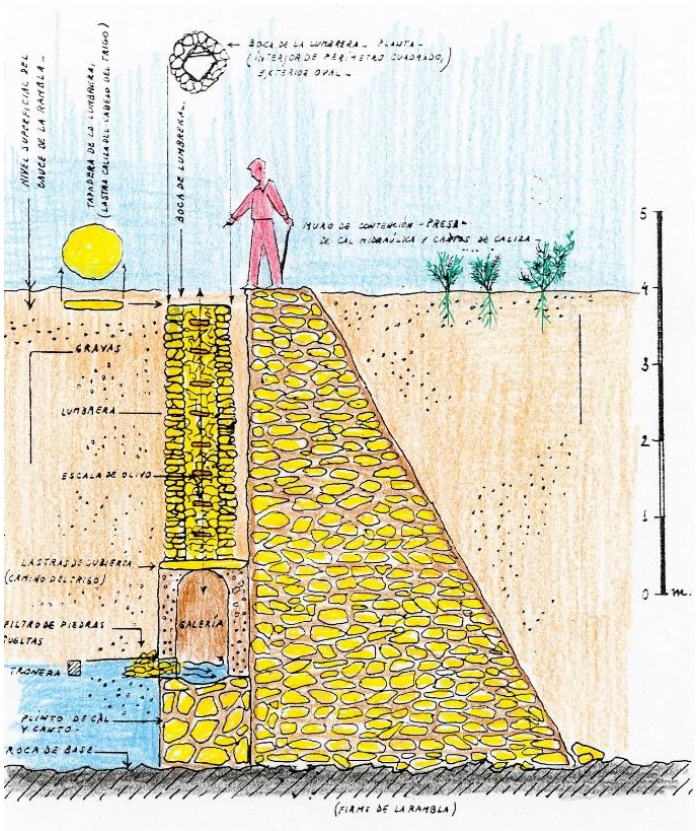

Fig.4Sketch of the Contracaño groundwater dam in the riverbed of the Rambla de Nogalte (Puerto Lumbreras)

In the 20th century a good number of studies on the techniques of the horizontal well (galleries) can be found: in 1918, the Junta Consultiva Agronómica (Agronomic Advisory Board, at national level) edited an inventory of horizontal well (galleries) which included information about the volumes of water they collected, and the amount of water generated by these hydraulic systems. Publications on *viajes de agua* in Madrid (the name that qanats are given in this city) increased, such as those by Gil Clemente (1916), Bonet (1935), and Oliver Asín (1958). Publications from this period which stand out include that of Troll and Braun, which was published in 1972 in Germany and translated into Spanish in 1974, and those of Llamas Madurga (1976) and Vidal Domínguez (1989).

Regarding the municipalities of Almería like Huercal-Overa, the studies of García Asensio (1910) and Llobet Reverter (1958) can be mentioned, along with the thesis of Sáenz Lorite (1977) and Ferre Bueno (1979) about the valleys of Andarax and Almanzora, the studies of Bertrand and Cressier on Ragol's form works (1995), and more recently, the studies of Dietmar Roth about Vélez (2001, 2016).

In relation to the Balearic Islands, the studies of Barceló (1986) stand out, as well as Carbonero's, Rosselló-Bordoy's and many others, who have extended their research beyond Mallorca to areas from Al-Andalus such as the Fuente Antigua of Crevillente.In

the Canary Islands there are many galleries, most of them *mina de agua* type. Some of the most outstanding works on water drainage are those of Wladimiro Rodríguez (1988), Luis Miguel Pérez (2003), and Alejandro González (2006).

In the central area of Spain, the team of the University of Alcalá led by Irene Bustamante and López-Camacho (2001, 2005) made remarkable works focused on Madrid and Alcalá de Henares (water trips) and nearby places like the Fuente Grande of Ocaña (Toledo).

In Aragon, the qanat of Bureta is notable. According to recent research, including the use of OSL (Optically Stimulated Luminescence) dating, this qanat dates from the 12th century AD(Gerrard 2011; Bailiff et al. 2015; Bailiff et al. 2018)). Also, the gallery of La Fonnueva de Bulbuente (Zaragoza) excavated in the quaternary materials of the bed of the Huecha River, and the *cimbra*of the Fuente Madre de Castejón in Monegros (Huesca) (Hermosilla, 2008) are relevant.

In regards to Valencia, there are several studies which should be mentioned. These include Monleón Guillén's (1988) on "alcavons" of the Foia de Castalla and Bernabé Maestre's (1989) on Petrer and the Domenech Rodríguez (1989) on Bocairent. The ESTEPA team (University of Valencia), led by Hermosilla Plá, published extensively on Eastern Spain (2005, 2006, 2008), though they also conducted numerous studies in Mediterranean countries like Tunisia, with studies of the galleries in the towns of Kebili, Tozeur, Gafsa and Gabes (2011), the central-eastern region (2012) and the north-western region of this country (2013).They have made progress in developing a methodology for recording and a typology for classifying galleries and how they relate totraditional and historical irrigation systems. This research has led to a doctoral thesis at the University of Valencia by the team member Miguel Antequera under the title *Las galerías drenantes en el sector oriental y suroriental de la Península Ibérica. Identificación, análisis y gestión patrimonial* (2015) (Draining galleries in Eastern and Southeastern area of Iberian Peninsula. Identification, analysis and asset management).

In southeastern Spain the research, undertaken by the team led by Gil and Gómez from the University of Murcia (E0A5-03 Cambios ambientales, transformaciones paisajísticas y ordenación del territorio (SURESTE); Environmental changes, landscape transformations and spatial planning) stands out. In 1993 they coined the term "galerías con lumbreras" (galleries with skylights) following the terminology of JacintaPalerm Viqueira (2001, 2004); as well as the term "minado con espejuelos" (mined tunnel with shafts) (Gómez *et al.* 2007a). Above all, they studied groundwater dams with attached or preceding filter galleries (Gil *et al*. 2011). In covered conduits so-called mixed sections may occur when they cross the sediments of a rambla, as happens in the Tobarrilas-Yecla (Gil and Gómez 2006), or in the Canal del Sifón in Fuente Álamo (Gómez *et al*. 2007b; Gil *et al*. 2012).Through the sands, the covered conduit becomes a filter gallery in which the wall receiving the subsurface circulation depends on smallholes (*mechinales, piqueras o troneras*) and the following wall becomes a groundwater dam.

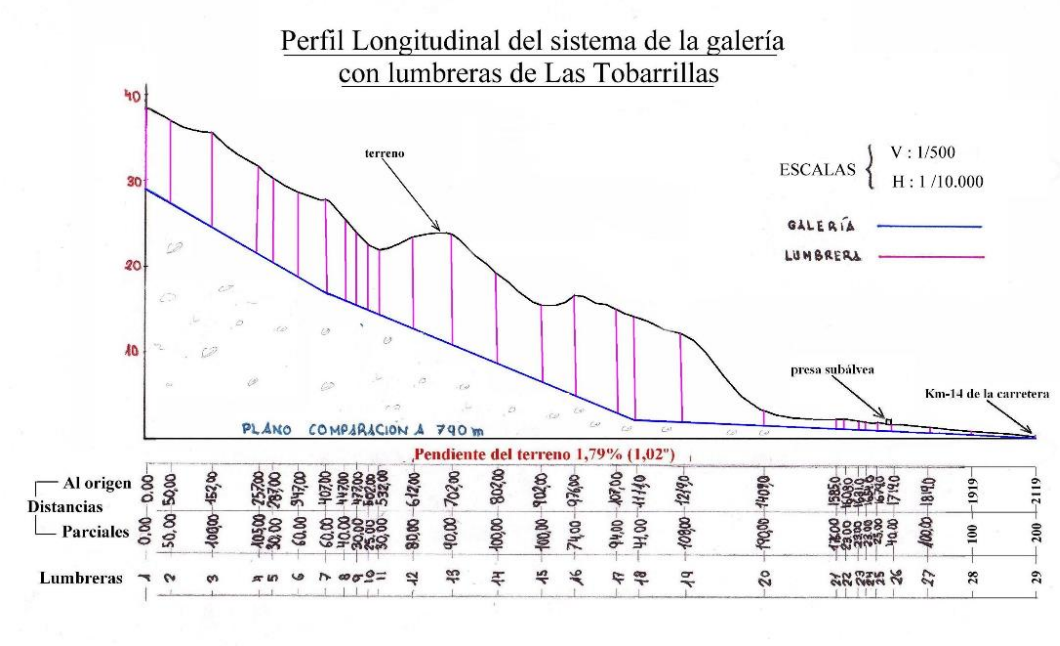

Fig. 5Features of Las Tobarrillas qanat (Yecla, Murcia)

State of the art in Spain

In Spain, there are two research groups whose work on qanats is notable: ESTEPA from the University of Valencia and E0A5-03 SURESTE from the University of Murcia. The following section will describe their current work in Spain.

The ESTEPA team of the University of Valencia has developed a worksheet for drafting inventories of qanats and groundwater dams to classify them according to the geomorphological and topological features of their location (Antequera 2015, p. 334). The categories they have developed are:

- Mountains: includes slope environments, slope base and platforms, whether they are detrital, tabular or calcareous (*minas* and qanat, also *alcavons* for surface and underground captures),
- Foothills: in category are grouped the piedmont (ravine, colluvial, etc.), the glacis (of accumulation, of erosion, with cover, ravine, etc.), and the alluvial fans (qanat with vertical and side shafts).
- River courses and river terraces: river beds and terraces, talwegs and ravines (*alcavons*, *cimbras*, *tajeas*) groundwater dams for surface and underground waters harvesting.

To precisely determine the correct location in one or the other environment, in addition to considering their geomorphological characteristics, they rely on the existing slope, following the classification proposed by Young (1974). In the environments of plains, courses and river terraces, the slope is lower than 2% or 3%. In transitional environmental contexts, such as piedmont, glacis or alluvial fans the slope oscillates between 2% or 3% and 10% or 12%. In mountain environments, the slope is higher than 10% or 12% (Hermosilla 2008, p 75-86; Antequera 2015, p. 335).

Some of key contributions of the team's work include the mapping of these systems' location and general features, hydrogeological contexts, sketches and features, irrigation systems and supply systems associated and heritage assessment in which the importance of these systems from a cultural heritage standpoint are evaluated on a scale from "very high" to "of no interest". The evaluation method attempts to represent the complexity of the heritage concept (hydraulic) in a simple and practical way. This evaluation is based on the use of ten assessment criteria, which in turn are linked to compliance with three specific variables per indicator. The ten variables are: water culture, representativeness, authenticity, integrity, documentary references, technology, artistic heritage, landscaping, hydraulics, participation & awareness of social agents (Antequera 2015, p. 344).

The team of the University of Murcia E0A5-03 SURESTE has also contributed new methodologies to study of qanats in Spain. They have developed worksheets for horizontal wells (galleries) associated or not associated to a groundwater dam. They analyse these systems in geographical and historical contexts and the features of the system (how the water is captured, conducted stored, distributed and used) are noted and described. They have also developed a methodological outline for recording and studying qanats that involves the following stages:

- fieldwork (to collect information and develop initial hypotheses, etc.).
- analysis of sources and archives (search throughoriginal documentation, preparation of a diachronic study of systems in other places which can be used as comparison).
- interviews with water managers and users (qualitative and quantitative approach, perception of interviewees about the state and future of the hydraulic system and about its associated heritage and landscape).

It has been the Murcian team that classified the sixty-eight systems located in the territory of the Region of Murcia according to the way in which water is collected. This classification resulted in the four categories already mentioned earlier in the paper:

- drainage galleries (*galerías con lumberas, minados con espejuelos*) those that are excavated in foothills, and act as qanats in the strictest sense. That is, horizontal wells with a slight slope that connects the mother well (aquifer) with the surface and wich can have vertical shafts along its course. Examples include the qanat of Veto in Yechar-Mula, or the Fuente del Pinar in Yecla, the Fountain of the King in Cieza, the *galería con lumbreras* of the Garrobillo in Águilas, and the *minado con espejuelos* of the Alquerías in Jumilla.

Fig. 6 Shafts of the Pulpillo qanat (Yecla, Murcia)

- *Minas de agua*, excavated in mountainous areas to increase flow. Generally, they have a short gallery, and are without vertical shafts or only have a small number of them. Examples include the Fuente de Benito, in the Sierra del Oro, in Abarán; the Fuente de la Perdiz, in Sierra Espuña, in Alhama de Murcia; the mines of Benizar and Otos in Moratalla, etc.
- *Cimbras or tajeas* are open and built in the beds of ramblas and river terraces. The covered gallery is immersed in the water table and water is filtered by the roof and walls to be collected in the inner base. From here the water is driven along the slope to the outside, such as in the Caño Viejo de Nogalte in Puerto Lumbreras, in Los Estanquicos in Jumilla, in the galleryof El Cocón in Águilas, and in the Vilerda Rambla in Puerto Lumbreras.
- Attached galleries or underground dams with holes (*mechinales, piqueras o troneras*) that allow water to penetrate the gallery such as in the Contracaño of the Nogalte Rambla in Puerto Lumbreras, in the Fuente del Oro in the Guadalentín River as it passes through Lorca, and the Béjar Rambla between Puerto Lumbreras and Lorca. Also included in this category are mixed galleries. While draining galleries at their origin, in the sections where the conduit crosses sediments in the bed of the rambla or river-rambla, the gallery includes a groundwater dam with holes in the wall to favor the drainage of the subsuperficial reservoir. This is the case of the *minado con espejuelos* of Las Tobarrillas, in Yecla; the gallery of Los Pozos de La Fuente, when it crosses the Avilés Rambla; or the Canal del Sifón as it passes through the Álamo and Las Murtas Ramblas (Gil 2007, p 160; Gil *et al.* 2011, p 5; Gómez *et al.* 2012, p 240).

Fig. 7 Hole in the wall (*mechinal, piquera o tronera*) of the preceding filter gallery to the groundwater dam of the Contracaño (Puerto Lumbreras, Murcia)

An example of a system that is environmentally, socially and economically sustainable is the "Caño y Contracaño System", which is exploited in the Nogalte Rambla (in the dry Southeast of Spain) by the irrigation association of Caño and Balsa de Lumbreras (Gil *et al.* 2012, p 193). At the beginning of December 2016, the Caño-Contracaño System captured about 2 liters per second from the subsurface flow (it took 130 hours to fill the pond where water accumulates before irrigation). On 15, 16 and 17 December, in Puerto Lumbreras, a storm dumped a total of 227 liters per square meter, which generated in the gallery a flow of 25 liters per second until March 20. In Tonosa (Los Vélez), at the headwaters of the Nogalte rambla, the storm had brought precipitation of 280 litres per square metre. After infiltrating the ground, some of the water flowed downstream between the rambla sediments. Three months later (from 20 March 2017) the groundwater level of the system was full, until saturating and surfacing in Peñas Blancas (on the opposite side to the groundwater dam). The system had drained more than 50 liters per second (the pond was filled in less than 6 hours), and this flow rate was maintained until the end of November 2017.

Faced with a drought (like the one that Spain experienced, especially in the Southeast, in 2017) with rainfall amounts of one third of the annual average rainfall in regions with a structural water deficit and where external contributions, such as the Tajo-Segura transfer (in May 2017) and the Negratín-Almanzora transfer (in September 2017), have been closed, endogenous resources like those generated by the Caño and Contracaño system have a great importance at the local level. They are the main water resource (including because of its quality than volume, just 0.5 grams of salt per liter) used for irrigation by companies such as Barberet & Blanc, who produce cut flowers that are exported to more than fifty countries and employs more than four hundred people.

Another example of a qanat is the one rehabilitated at Casa Herrera in El Jimenado (Jumilla, Region of Murcia) on the 320-hectare estate dedicated to olive groves. Its previous owner, José María Guardiola, rehabilitated part of the gallery in 1903. The current owner, Atanasio Molina Martínez and his family, reconstructed 200 meters of gallery, as well as the pithead and the pond in which the water accumulates, in 2008. To increase the amount of water supplied, the upper layer of the land has been adapted into large terraces that allow receiving the waters of the runoff concentrated in a ravine. Large separation dikes between terraces with spillways deal with the flood water, allowing the water to pass from one terrace to the next. With this technique of derivation in an intermittent flow bed, the system manages to increase infiltration and favor the water capture by the qanat. Despite the high cost, the owners (the largest landowners of Jumilla) are extending the rehabilitation of qanats, for example at the Partido de Los Alamos farm, in the foothills of Santa Ana Mountains and in the galleries owned by the Water Society of El Prado and La Pinosa (Gil et al, 2013 p 150).

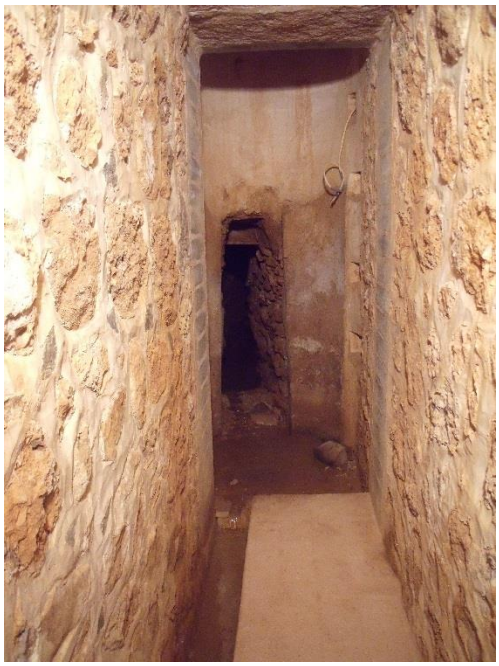

Fig. 8 Interior view of the ganat of Casa Herrera (Jumilla), in the foreground rehabilitated part; in the background, the original part of the gallery

The Murcia group has also studied new applications of the draining gallery technique, like in the Campo de Cartagena basin. Located in the Southeast of the Region of Murcia, this 1200 square kilometer plain has its lower part covered by the Mar Menor saltwater lagoon. The coastal plain topography, with a gradual decline from 200 to 0 meters above sea level, leads water (from rain and irrigation) to infiltrate and end up in the Mar Menor lagoon, increasing local salinity and eutrophication. On the inner bank, in its southeastern boundary, the Arco Sur-Mar Menor Irrigation Community has recreated the technique of qanats to drain waters that infiltrate coastal plains before reaching the Mar Menor lagoon (Gil *et al* 2013, p 152).

To use these waters (mostly from irrigation returns), the Arco Sur-Mar Menor Irrigation Community has made some drainage ditches a few meters from the inner bank of the lagoon. The ditches are about 150 meters in length and 3 meters in depth, and have a drain on them with a grooved tube of 100 mm in diameter. It pours into a lateral collector pitcher, where the ditches are directed. The pitcher (vertical watertight well) is 4 meters in diameter and 6 meters deep, houses the pumping equipment and elevates to a regulating tank with a capacity of 2500 cubic meters. The system that captures the drainage water is 16250 meters in length and has 14 brackish water reception pitchers, which are pumped to the 20893 m^3 reservoir next to the desalination plant (with a treatment capacity of 28000 m3 / day) that the Irrigation Community owns, located between Cabo de Palos and Cala Reona. Through this renewed drainage gallery system, a collection of brackish water is obtained, which ranges from 445,000 m3 to 810,000 m3 per year (Gil *et al* 2013, p 152).

Concluding remarks

Building and exploitation of qanats can be one environmentally sustainable model, especially when built with locally-available materials. Qanats only drain the rainfall and collect water during the hydrological year (renewable resources) without "looting" the aquifers reserves. All qanats discussed above offer clear benefits in dry environments, because they do not need energy consumption to capture, drive and evacuate the flow of water. In addition, there is little risk of evaporation with covered horizontal wells, excavated or built underground.

Socially and economically there remain several challenges. Qanats need skilled labor for their maintenance. As such, the rural exodus has been one of the causes of their abandonment, with other job offers that were less risky or comfortable and better paid. In addition, the flow of water, with traditional irrigation techniques, did not allow an expansion of the irrigated area and/or an increase in the productivity that would have made the system profitable in that economic moment. Additionally, qanats are vulnerable to aquifers' overexploitation in its surroundings. Where legal action could not adequately demonstrate the relationship between aquifer exhaustion and this new kinds of exploitation or where other factors of higher productivity and social possibilities were put forward that could generate more jobs, qanat systems ended up being abandoned because their maintenance was not economically sustainable.

Actually, in the areas where qanats did survive, it was due to the will of some users who did not surrender to difficulties and the general indifference of society. Today, water has become a scarce and a very valuable resource, due to the increase in consumption generated by several factors including population growth, and increased agricultural production, especially in semi-arid environments with favorable temperatures where the application of irrigation, can allow for year-round cultivation. Furthermore, as for livestock, the increase in livestock heads is mainly linked to stabling, which follows hygiene standards and sanitary maintenance that also increases the need for water. Even industry and leisure activities increase the demand for water. At the moment, and even more so in times of drought, water is the most valuable resource.

In such conditions, qanat systems should be considered anew. The quality of the water is even good enough for human supply. The use of qanats is economically and environmentally sustainable for the type of agriculture that does not require large amounts of water, which can be achieved when new irrigation techniques are used. This sustainability allows the maintenance and improvement of the system. Another issue to consider is the heritage value, both material and immaterial, of these systems. They are quickly becoming an object of cultural and leisure interest for the municipalities where they are located. This is the case of the Calle del Agua (Water Street) in Pliego, or the Caño-Contracaño in Puerto Lumbreras, both in the Region of Murcia.

In summary, the Spanish qanats that are still in use are very interesting endogenous resources generating systems at the local level. The quality of the water makes them an important source of water for people, cattle and irrigation. It is an integral system from collection to distribution, with a succession of uses such as supply, cattle drinking, domestic uses in laundries, industrial uses in mills and fulling mills, environmental uses in wetlands and finally for support of irrigated spaces. The galleries have generated and kept an associated hydraulic heritage and a water landscape in arid or semi-arid environments within a rich water culture in the southeast of the Iberian Peninsula.

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Figure 2

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Figure 3

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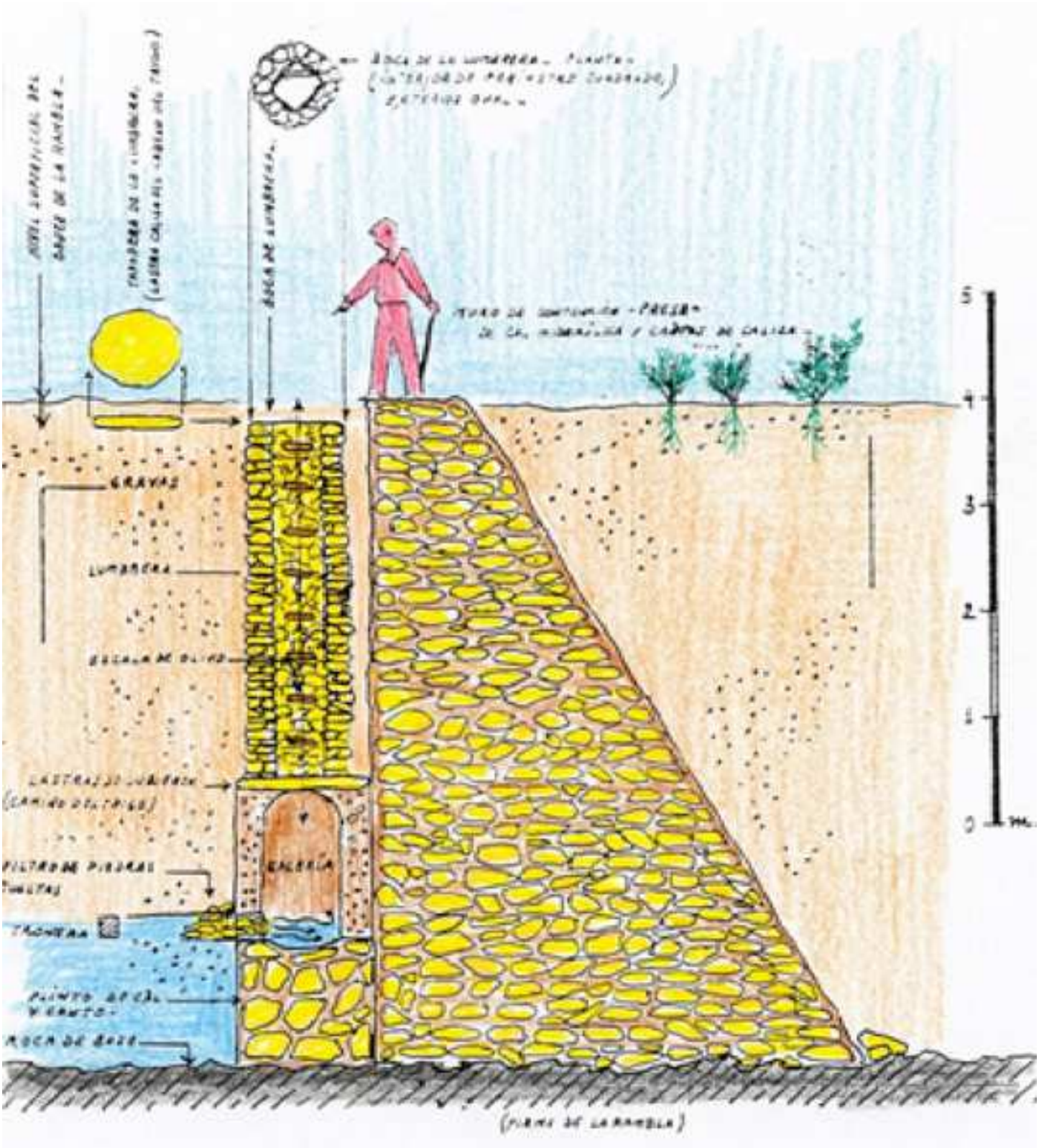

Figure 5

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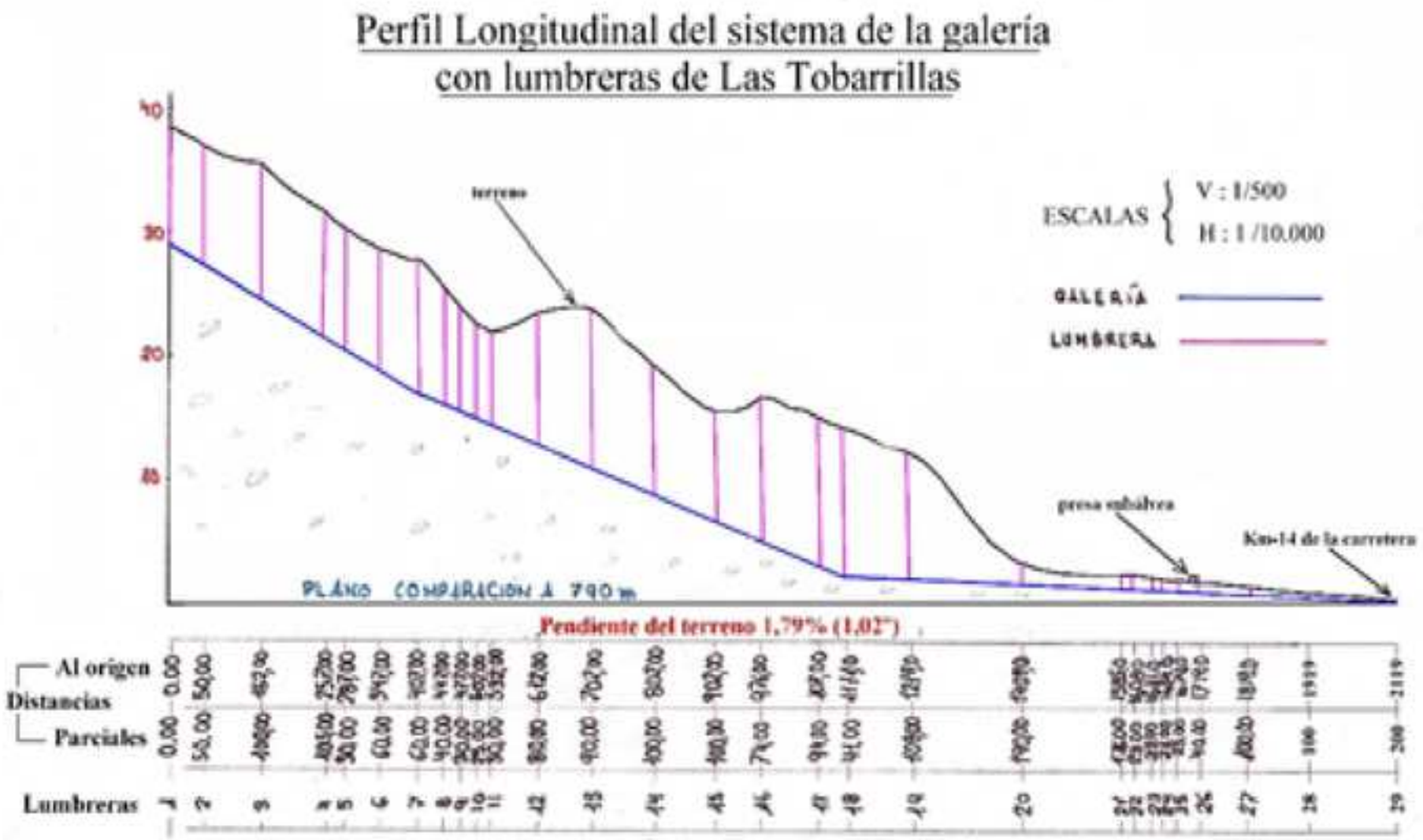

Figure 6

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