WATER PLANNING IN ALCOBAÇA CISTERCIAN LANDS

O ORDENAMENTO HIDRÁULICO NO TERRITÓRIO CISTERCIENSE DE ALCOBAÇA

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ABSTRACT

This paper concerns the main domain (*coutos*) of the Cistercian Abbey of Alcobaça (central Portugal), founded in 1153. It shows the involvement of the monks in shaping hydraulic landscapes along time. This monastic territory is limited westwards by the Atlantic ocean with a cliff coast indented by two large gulfs, the former Pederneira and Alfeizerão lagoons, sanded up presently. These landscapes have been consolidated along with the monks' intervention in the hydrographic plan, particularly through a network of canals, the types of which can be summarized as follows: canals for water conveyance and evacuation, to and from the abbey buildings; canals related with water-powered engines as grain-, oil-, saw- and fulling-mills, forges and other industrial devices; canals consequent to the diversion of rivers and streams with

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two main purposes: to drain the fields in order to improve the marshes for agricultural use, and to irrigate cultures.

KEYWORDS: Hydraulic landscapes, Canals, Cistercians, Alcobaça Abbey.

RESUMO
Este artigo respeita os coutos da Abadia Cisterciense de Alcobaça (Portugal Central), fundada em 1153. Nele se apresenta o envolvimento dos monges na modelação de paisagens hidráulicas ao longo do tempo. Este território monástico está limitado pelo Oceano Atlântico, a oeste, sendo a costa escarpada recortada por dois grandes golfos, as antigas lagoas de Pederneira e de Alfeizerão, actualmente assoreadas. A intervenção dos monges permitiu que estas paisagens se fossem consolidando, através, sobretudo, da instalação de uma rede de canais cuja tipologia pode ser resumida do seguinte modo: canais para adução aos edifícios comunitários e para evacuação de águas; canais para a produção da energia hídrica necessária a moinhos, lagares, serrações, pisões, forjas e outros equipamentos industriais; canais relacionados com o desvio de rios e ribeiros, com duas finalidades básicas: drenagem dos campos, com vista à sua recuperação para a agricultura, e irrigação agrícola.

PALAVRAS-CHAVE: Paisagens hidráulicas, Canais, Cistercienses, Abadia de Alcobaça.

A note on the history and art of the monastery

The Cistercian Abbey of Alcobaça, a superb set of buildings erected between the 12th and 18th centuries, was founded by King Afonso Henriques in April 1153. The monarch endowed it with a vast adjacent area, the *coutos*, that stretched as far as the Atlantic coast. Because of the area's potential for Muslim incursions, construction work only began in 1178. The monks moved to the new, incomplete abbey in August 1223, and Alcobaça became the head of the Cistercian Order in Portugal in 1567.

The current external aspect of the abbey, deeply altered since its initial arrangement, is the result of extension and improvement work carried out between the 16th and 18th centuries.

Fig. 1. *Alcobaça. View of the Cistercian abbey from the south-west (V. F. Jorge).*

The main events in the abbey's history include: creation of the *comenda* (commendam) in the latter half of the 15th century and middle of the 17th century, with abusive exploitation of the Order's assets; the ruin left behind by the 1755 earthquake and the great floods of 1772; and finally the devastation caused by French invaders in 1811, which plunged the abbey into a terrible and irreversible financial crisis. After the prohibition of religious orders in Portugal in 1834, the monastery was secularised and made into a prison, then barracks and other administrative services[4].

The church's admirable state of preservation is thanks to the fact that it has remained open as the town's main place of worship and its greatest icon.

Geophysical setting of the former monastic estate

The choice of a solitary, forested area to install the abbey at the confluence of the rivers Alcoa and Baça was linked to the three fundamental demands of medieval Cistercian landscapes, which blend the rural and the spiritual: isolation, water and stone.

The Alcobaça Monastery site's former physical geography can be described as follows: a rocky coast with cliffs; a narrow strip of dunes along the shore; extensive sand movement moderated only by the wooded areas found in the poorest and sandiest soils; coastline eaten into by two large gulfs, now totally silted up due to natural and human action. They were known as the lagoons of Pederneira, to the north, and Alfeizerão, of which the bay of São Martinho remains. These lands were constantly waterlogged due to the complicated drainage and dense network of torrential watercourses whose waters needed constant

[4] D.M. COCHERIL, *Alcobaça: Abadia Cisterciense de Portugal.* Imprensa Nacional-Casa da Moeda, Lisbon 1989.

regulation[5]. A second area parallel to the coast formed of generally gently sloping hills interspersed with narrow valleys where watercourses flow, most of which have seasonal regimes. A third area formed of a "typhonic", rocky valley ends in the foothills of the limestone massif of the Serra dos Candeeiros.

Water supply for the medieval abbey

Collecting and using water

The abbey's water supply came from an underground water flow extracted from an aquifer located in Chiqueda de Cima, 3.500km south-west of Alcobaça in a broad and very fertile valley. A small, semi-buried stone structure, in a precarious state, protects the opening from impurities and possible landslides. It has a rectangular design (3.2 x 2.6m). The walls are 0.6m thick and it has a low indoor height (1.2m). The inside of the water container can be accessed through an opening (1.2 x 0.9m) torn into the building's frontispiece. The dual-pitched roof is formed of dressed rectangular limestone slabs. We believe that the first supply of water for use by the established religious community was obtained from a well or spring located within the abbey's grounds.

A ditch was opened leading from the River Alcoa, with an inlet 1.500km upstream of the abbey, to provide water of less drinkable quality but in greater quantities for the community's other needs: irrigating the fields and vegetable gardens, waterwheels, mills and forges, washing out latrines, etc. The monks built a weir made of stone to dam the flowing water and allow it to build up in volume and height so it to be redirected at

[5] In the 18th century, there were still many marshes and ponds in the area previously occupied by the Pederneira and Alfeizerão lagoons.

a constant flow, using a sluice for regulating or interrupting the flow. The weir is still in good working condition today.

Fig. 2. *Weir on the Alcoa river allowing the Abbey non-drinking water supply (V. F. Jorge).*

The water ran in the open air in a channel that had an earth bed and banks, with a flood relief ditch flowing into the River Alcoa, and it extended along the left bank of the Alcoa, bordering the monastery site to the east.

Drinking water supply

The drinking water supply system for the abbey has a total length of 3.280km. The water was carried in a duct of uniform profile and was propelled by gravity. At some points along the way, the gradient forced it to make some turns in order to achieve the average slope desired to maintain a stable flow and strength of current, something which required qualified practical knowledge about water engineering.

An examination of the piping, which is still intact at several points along the way but has been neglected and is highly vulnerable to imminent structural loss, allowed some preliminary conclusions to be drawn. The best-preserved sections are located at points 1 and 4 on the map of the area.

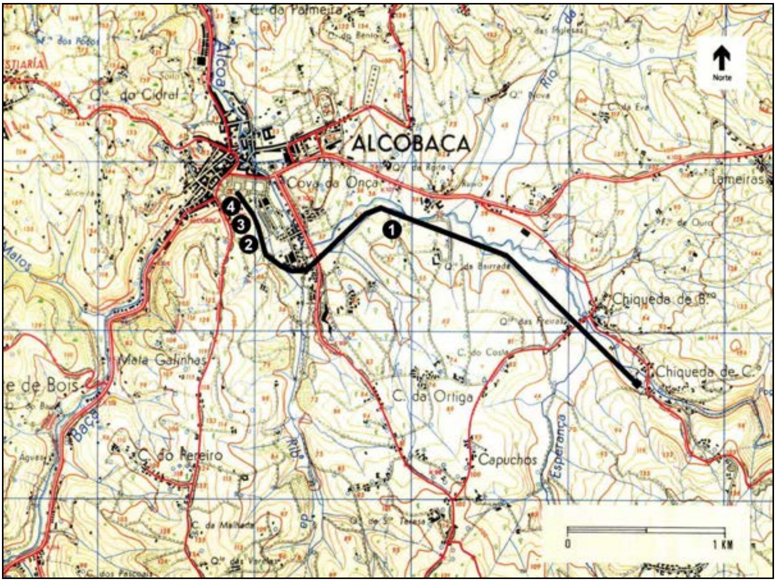

Fig. 3. *Alcobaça. Cistercian abbey. Drinking water supply course (V. F. Jorge)*

It was not difficult to map the sections destroyed by buildings, landslips or land clearing because there are still many identifiable remnants. In the direction of movement, the aqueduct's topography has the following main characteristics:

- from where it starts to point 1, water was transported at the surface and underground, with the duct laid at different depths. The duct lies directly on the soil and is stabilised by the weight of the stone blocks themselves. The missing section was destroyed at the beginning of the 1970s;
- between points 1 and 2, the water was carried at the surface. The duct lies on a stone wall that varies in height. The arches that were located at point 1 and formed the highest and most visible part of the aqueduct were demolished at the end of the 2000s due to urbanism infrastructure works. Further ahead, in the Lameirão neighbourhood, a section of the duct lying on a wall has been ruined, although many fragments still remain;
- on the final stretch, between point 2 and the southern wall of the church, the duct is installed in a gallery because of the elevation of the site and the need to ensure an adequate slope for the flow. At point 2, the underground corridor is 1.32m high and 0.72m wide, the walls are made of stone and the roof is flat and formed of limestone slabs. Between points 3 and 4, the gallery was opened in ground formed of rock strata and has an average height of 1.8m and an average width of 0.84m. As the overburdening of the land and the risk of shear cracking are more significant here than in the upstream section, the trench is covered using an oval barrel vault made of bricks laid in a running bond. In this section, there is a water outlet from the duct (an offshoot) which supplied water to a fountain. The gallery-aqueduct, which was big enough to allow people to make periodic inspections and to perform maintenance cleans and conservation repairs, could accessed directly through three manholes (which also provided ventilation and natural light) that were placed at equal distances along it. Work carried out in the last century to clear the southern area of the church and open drainage and surface water runoff

ditches (to stop or reduce rising damp in the walls) uncovered the remains of the final part of the gallery section of the aqueduct in the corner of the royal pantheon, but it had been mutilated at an unknown date.

Some notes on the technique and construction of the water transport system outside the monastery: the duct is formed of rectangular limestone blocks of standard sizes (l x w x h = 1.12 x 0.36 x 0.24m) and a U-shaped pit excavated lengthways measuring 0.16m in diameter. The ends were joined using male and female joints that were cut very accurately, and the duct joints were sealed using water-repellent mortar (a mixture of lime and fine sand). The roof is made of dressed slabs made of the same type of material. Along the water supply network, at more or less equal intervals, there are square settling basins measuring 0.54m in width and 0.27m in depth, where run-off sediment from erosion would accumulate. They also helped dissipate energy from the current.

Upon reaching the church, the water from Chiqueda fell into a small surge tank placed within the south wall of the nave, where it stopped being transported by duct and moved to pressurized distribution through pipes. Immediately before draining into the receptacle, the duct has two mini-sluices that made it possible to interrupt the flow of water and divert it to a supplementary plumbing network that ensured supply would not be interrupted in the case of emergencies. Along the edge of the tank there is a surface overflow designed to drive the water that goes over the edge to the outside if a blockage were to occur.

In the surge tank, the water was guided to the cloister's fountain through piping that went underneath the church's nave. On the inner face of the northern wall, engraved in ashlar, there is the Latin inscription *AQUE DUCTVS* illustrated with two sculpted hands facing each other that point to the underground duct for the purposes of any possible maintenance or restoration work. In the fountain, fresh water was distributed among the main everyday usage points in the residential area[6].

Drinking water distribution

The clean water supply and distribution plumbing circuits inside the medieval monastery are not clear to us, since there is not enough archaeological evidence to fully dispel doubts. It is known that as well as the changes made to the initial plumbing and equipment when the religious complex was reformed and extended – specifically in the former kitchen and lay brothers' wing – the Dionysian cloister was also highly changed with the 19th century adaptation of the abbey into barracks and the restoration works performed throughout the last century. With these limitations and uncertainties, our suggested reconstitution of the drinking water routes within the medieval residential area is solely based on the little evidence that can still be seen at the site and experience and knowledge about other efficient means of household water planning and management, following the usual plan used by Cistercian monasteries in the Middle Ages and Early Modern Period. So, from the remarkable fountain in the cloister – which was protected by a polygonal structure but has since been altered and no longer has its original appearance – fresh water was driven rationally using a forced system to the areas inside the abbey that most needed it, particularly the kitchen, the lay brothers' area and the infirmary. The gravity-driven water

[6] The change in heigh over the water supply system from upstream to downstream is 5.3m over a distance of 3.280km, so its average gradient is 1.6‰ ($\angle h$ = 1.6m/km). Under good water conditions, the estimated water flow would be roughly 10 litres/minute, which meant a maximum daily supply of around 14m³ or 14,000 litres, following Manning's equation.

distribution provided the necessary technical conditions between the fountain and the different branches for freshwater.

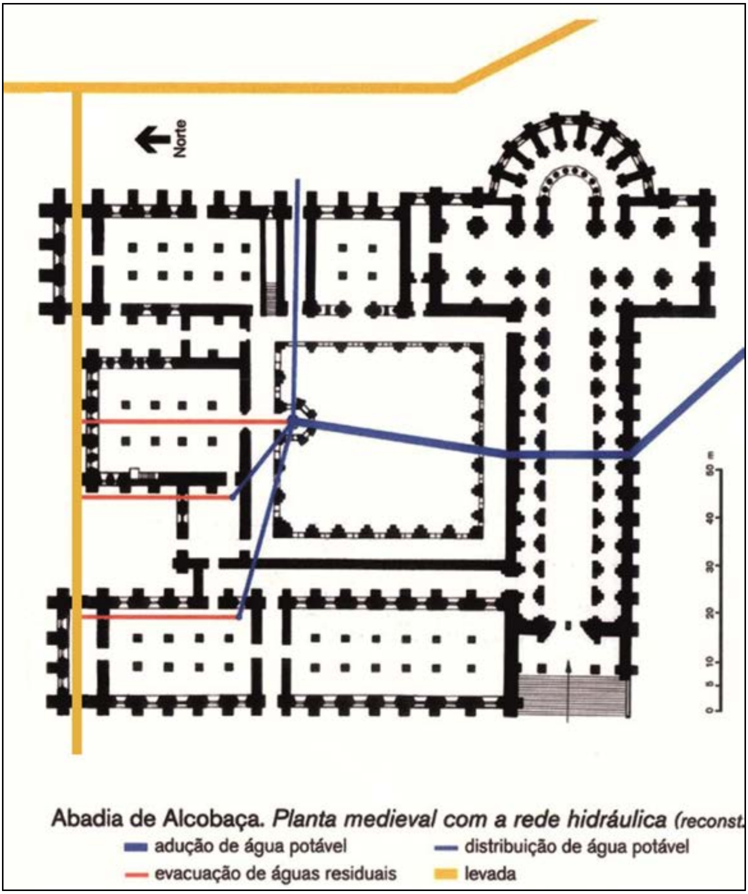

Fig. 4. *Alcobaça. Cistercian abbey. Layout of the medieval water network. Blue thick: drinking water supply; Blue thin: drinking water distribution; Red: removal of wastewater; Yellow: canal (V. F. Jorge)*

The amount of drinking water supplied to the monastery each day was more than the community needed, which is why there are no wells, tanks or reservoirs for storing water for contingency requirements.

Wastewater and rainwater disposal

It is difficult to analyse and retrospectively interpret the medieval system for removing waste and water because of gaps in knowledge about the internal course followed by water on the Alcobaça Monastery site. Despite the lack of archaeological evidence and examination, we believe that the sewage network for domestic wastewater (from the basin surrounding the cloister fountain, the kitchens, the lay brothers' wing, etc.) and rainwater flowed into an external sewer which went around the monastery to the north and passed below the two blocks of latrines, which increased its volume and discharge. This drain or channel diverted from the drain and regulated by a sluice, 'washed' the monastery and flowed downstream into the River Baça, which may have run closer to the front of the monastery site than it does today. The existence of this sewage channel is indisputable, considering the traditional location of the odourless latrines for monks and lay brothers at the far end of their dormitories, which were located in the wings east (for the monks) and west (for the lay brothers) of the cloister. It can be confirmed by the outline of the entrance to the monks' former toilet facilities, which can be seen on the inner face of the north wall of the *scriptorium* (now known as the winery) and the medieval dormitory.

The monastery's former watermills

The River Alcoa, renamed the Abadia when its waters are met by the River Baça, was very useful in a part where most of the monastery's mills stood. Its waters served the Chiqueda Estate, with its four-stone mill and six-lever olive oil press, the Freiras de Cós, or Nuns of Cós, Estate (Chiqueda), with its three-stone mill, and the Mosteiro and Praça mills, which had 11 stones between them, and the Fervença site, which had two mills and one vertical waterwheel (9 stones). These mills processed more than 50% of the grain stored in the granaries of the Order's barns. As well as mills moved by vertical or horizontal waterwheels, the watercourse was also used by larger olive oil presses (the Fervença olive oil press had two water-driven mills that assisted ten lever presses), the sawing mill housed within the monastery grounds (the only one using a hydraulic engine on a monastic estate), forges and fulling mills, among other manufacturing centres connected to the Cistercian monastery.

Name/location	*Number of millstones*	*Millstones for wheat (alveiras)*	*Millstones for corn etc. (segundeiras)*
Mosteiro Mill (Rua 16 de Outubro, formerly Rua da Levada – Alcobaça)	3	---	---
Praça Mill (Rua Alexandre Herculano, former Rua da Praça and Rua de Santo António)	4 8 (enlargement)	2	2
Chiqueda de Cima Mill (Prazeres de Aljubarrota)	4	---	---
Freiras de Cós Mill (Chiqueda de Baixo – Prazeres de Aljubarrota)	3	---	---
Baixo Mill (Fervença – Maiorga)	3	---	---
Meio Mill (Fervença – Maiorga)	3 4 (enlargement)	2	2
Cima Mill (Fervença – Maiorga)	2	1	1
Águas Mill – Belas de Baixo (Valado dos Frades)	3	---	---
Águas Mill – Belas de Cima	3	---	---
Engenho Mill (Águas – Belas)	3	---	---
Mill/Watermill in Cela Velha	3	---	---
Carreira Mill (Póvoa de Cós)	4	---	---
Mata Mill	5		

(Casal da Areia)		---	---
Castanheira Mill	?	?	?
Mata da Torre Mill	?	?	?

Tab.1. *Alcobaça Abbey' s horizontal and vertical wheel mills*

Water energy was joined by wind energy to help mill grain. But wind engines were unpredictable, difficult to harness, not to mention the lulls that caused the sails to slow down. In practice, they were only used between July and October. All these inconveniences relegated windmills to a secondary position compared to watermills. The monastery's watermills, which were either operated directly or entrusted to third parties, stood out for their locations, the size of their built structures and the number of millstones. On average, they turned three or four pairs of millstones for wheat (known as *trigueiras)* or millstones for lower grade grains such as rye and corn, or even sometimes barley (known as *segundeiras*). The mills were located on watercourses with the highest capacity and made use of the waterfalls to increase the flow of energy. Sometimes, the mills' channels functioned together, carrying water to other devices and, thanks to small, appropriately located branches, they contributed to the corn revolution (17th to 18th centuries) and the rice one (19th century) in the fields of Cela, Valado and Alfeizerão[7].

[7] A.V. MADURO, *Cister em Alcobaça. Território, Economia e Sociedade (séculos XVIII-XX),* Porto, ISMAI, 2011, 173-197.

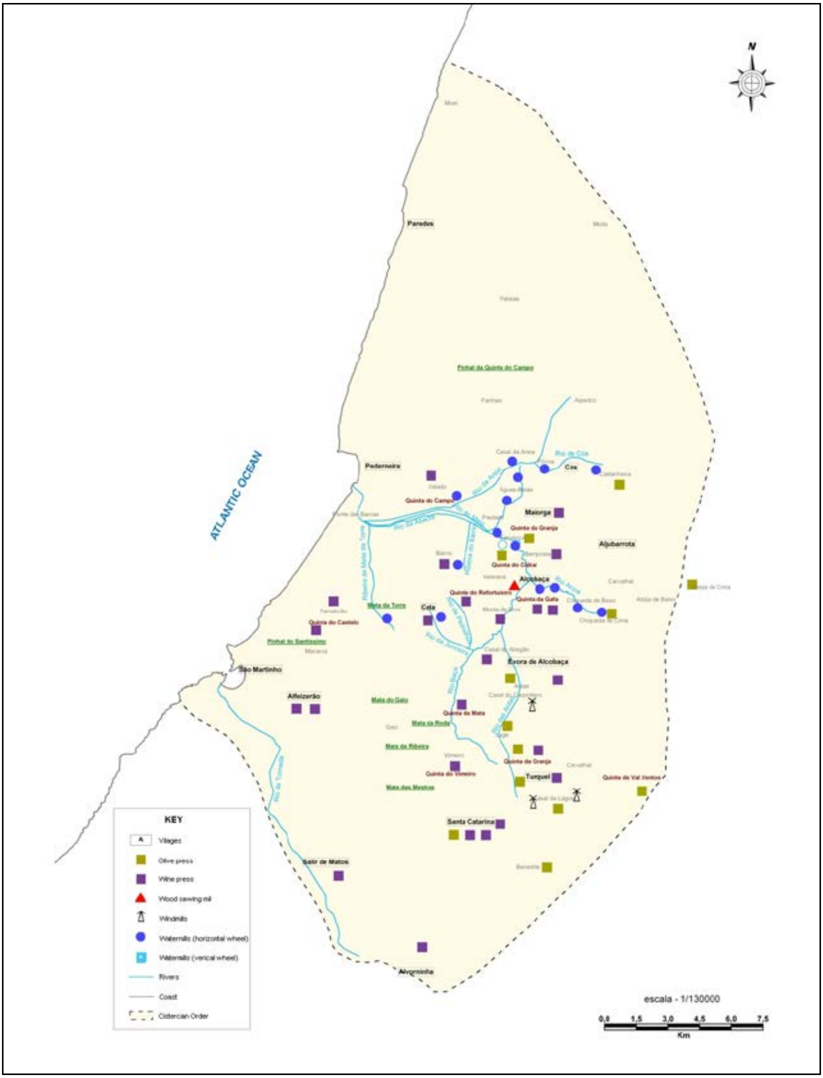

Fig. 5. *Map showing Alcobaça Abbey's means of production (A. V. Maduro)*

The spread of corn and its high productivity rates (thirty-two bushels were obtained for each bushel sown) changed rural people's eating habits. The transformation was also felt in changes to the structure of tenure and rents that favoured deliveries of corn bushels and an increase in *segundeira* millstones in mills. There was also growth in the number of barns and the introduction of new mills, vertical wheels and weirs.

The riverbed generally benefits from weirs, since they both provide water and are a form of protection against floods; the pools also usually serve as a home for fish and poultry farming.

The monastery's mills are solid, raw, sometimes plastered, stone buildings with tiled roofs. They are located at favourable positions on the watercourses, the flow of which limits their operations to a period of no more than three or four months per year[8]. The monastery levied a charge on mills for using the water.

To be able to operate, mills had to be fitted with a set of specific equipment. The deeds for watermills only refer to (three or four) pickaxes and an iron lever for raising and lowering the millstones, but they fail to mention other equipment used for cleaning the channels. The deeds mention measurements, endless pieces of equipment for cleaning the grain, the goatskin half-bushel or bushel receptacles for carrying grain and flour, the granaries for storing grain.

Grain for milling, after the stones have been worked on using the pickaxe, belonged to the mill owners, because unsuitable stones could ruin the flour.

The payment of rent included the delivery not only of grain but also of dried legumes and animals (chickens, capons, sheep and pigs) and other goods, such as wax and olive oil. The

[8] M.O. GIL, "Engenhos de moagem no século XVI (Técnicas e Estruturas)", *Do Tempo e da História*, nº 1, 1965, 167.

grain transported to the Order's barns had to be clean and come from the ground and not the granary, i.e., it had to be from the current harvest. Delivery could be made in one go, coinciding with the harvesting and threshing period on dates defined by custom and the calendar of saints, but it was also common to split payment of the rent[9].

Repairing, cleaning and opening ditches and channels "by scythe and axe", removing silt and clearing weirs of vegetation, "taking stones" from the beds of rivers and streams and restoring riverbanks were the tenants' responsibility and appeared in the contracts. More extensive works to buildings or damage caused by natural accidents, such as breaches of weirs or the destruction of equipment driving the mill, were paid for by the landlord and executed by the tenant. However, tenants were also called upon for other tasks in mills and enclosures where cattle was kept, such as plastering and whitewashing walls, repairing beams and roofs, placing new stones in the mills, replacing and repairing waterwheels, and introducing blocks and slits used to increase the pressure and spray of water[10]. Tenants were sometimes even made responsible for the upkeep of pine forests, in order to avoid the theft of firewood, and for supervising the olive oil presses attached to mills.

Periods dedicated to channels cleaning could mean less rent was due. The same was true during corn and vegetable irrigation, which took place from May to September and left many of the millstones at a standstill. Another condition established for reducing the amount to be paid was during the olive oil production season, particularly in November and December. The monks excluded other situations from being used to lower rents, such as the effects of droughts or floods on

[9] A.V. MADURO, *Cister em Alcobaça...*, 359.
[10] A.V. MADURO, *Cister em Alcobaça...*, 273-275.

cornfield development. Nonetheless, they considered allowing rent to go unpaid if the channels and weirs burst, when the mills flooded and the vertical wheel was locked by the action of the current. To stop this from being used unduly, notification of the event had to be made immediately and the millrind had to be handed over as proof that the stones were not in use.

Under the terms of the agreements, as observed in the contact conditions for the Freiras de Cós mill, the tenant had to deliver the mill with the "running and milling" equipment, leaving the stones able to mill grain for a period of six months and the iron utensils (pickaxes and levers) as they received them.

With the decree extinguishing the religious orders on 28 May 1834, orders' assets were sold at public auction with the aim of funding the legal and political system of the emerging liberal society. The new actors strategically concentrated the means of production and transformation of the fruits of the earth. The owners at the time then had to work with freedom of waters and a profusion of mills. According to the 1839 farming report, the district had 40 watermills and 17 windmills, which were responsible for milling 180,000 bushels of grain. But the 1862 statistics confirms the democratisation of milling, recording 159 watermills and 85 windmills[11]. Competition with the people imposed some reforms on the mills of the former Alcobaça Monastery, with works on weirs and more waterwheels or, when the location was suitable, entirely replacing the watermill powered by a horizontal waterwheel with a mill powered by a vertical one. These were the last reforms in traditional milling technology because from the last quarter of the 19th century onwards many

[11] T. LARCHER, Diccionário *Biographico Chorographico e histórico do Districto de Leiria e Concelho de Villa Nova* D'Ourém, Leiria, 1907, 183. João Maria Baptista, in *Corografia*, mentions that the Alcobaça district had more than 277 mills. J.M. BAPTISTA, *Chorographia Moderna do Reino de Portugal*, vol. IV, Lisboa, Typographia da Academia Real de Ciências, 1876, 10.

mills were abandoned or demolished, and some transformed into industrial mills that kept up with technological progress.

Systems for retaining water on the former abbey site

Water often trickled through cavities in the rock – pit caves – possibly produced by collapsed domes in underground caverns. Obstructions in these pit caves allowed small lagoons to form, which were very useful for the local population[12]. However, farmers conserved water in *pias*, or tanks, during the summer. Two important *pias* can be seen in the grounds of the Vale de Ventos Estate, a former monastic farm in Alcobaça: the Pia da Serra and the Pia do Olival (or Pia das Obras). The former is situated on the western slope of the Serra dos Candeeiros and is rectangular, measuring approximately 15 x 9m, with a maximum height of roughly 3m. It is made of limestone blocks and is covered by a barrel vault. One of the most curious features of the roof is its water collection system. The rocky surface that forms the floor of the patio has furrows scooped out of it that allow rainwater to flow into the inside of the tank[13]. The tank was used for watering mountain livestock as well as irrigating the lime and orange orchards that could be found on the hill slopes.

The Pia do Olival, in the foothills of the *serra*, is an imposing rectangular tank made of stone and split into two connecting compartments. The outside measures 56 x 29m and it has a maximum height of 3.5m. Little can be seen of the water supply system other than the very end of the channel which can be observed half-way along the north-facing wall. Regarding the outlet system, a discharge outlet has been identified at the base of the west wall, which feeds into a channel that is visible for only about 20m of its length. The structure was used to provide water

[12] J.V. NATIVIDADE, *A Região de Alcobaça. Algumas Notas para o estudo da sua Agricultura, População e Vida Rural*, final report for the Agronomy Engineering Course, Lisbon: privately printed, 1922.
[13] Like the many *aiguiers* in Provence (France).

for farming, probably to irrigate the extensive olive grove that covered the mountain foothills and the land used for other crops, such as vegetable gardens and orchards[14]. These *pias* would have been made by the monks of Alcobaça[15], and it is known that the Pia do Olival was commissioned in the third quarter of the 18th century by the Abbot Luiz Pereira[16].

Systems of agricultural recovery of marshlands[17]

There are few monastic references to water regulation works during the medieval period. Most of the work carried out was not recorded and we only have sporadic documents or notes in contracts from the end of the Middle Ages between leaseholders and the monastery. Nonetheless, with the foundation of the Cistercian Order in Alcobaça, which led to an increase in agricultural activities and the use of wood and other natural resources, thereby increasing soil erosion, there was a "significant change in the deposit situation" from the 17th century onwards[18].

If we look at the floodplain of the former "sea" of Pederneira, formed by three "alveoli" that were connected by

14 J.P.S.O. SOUZA, *Coutos de Alcobaça: as cartas de povoação. Subsídios para a História da Agricultura em Portugal*. Lisbon: Tip. Inglesa, 1929. The plantation of large olive groves, begun as early as the seventeenth century, occurred under the government of Abbot Manuel de Mendonça. See J.V. NATIVIDADE, "As Granjas do Mosteiro de Alcobaça", Off-print *Boletim da Junta de Província da Estremadura*, nº 5, Lisbon, 1944, 49.

15 J.P.S.O. SOUZA, *Coutos de Alcobaça...*

16 J.D. RIBEIRO, *Memórias de Turquel*. Porto: Typ. Universal, 1908, 154.

17 The study presented in this chapter is the result of documentary analysis and studying aerial photography and maps and was carried out in the 1990s. During the study, several important water planning works and the initial position of certain water courses were identified, particularly in the Valado dos Frades, Alfeizerão and Salir de Matos areas (Figs. 7-9).

18 M.V.F.J. HENRIQUES, "O Litoral dos Coutos de Alcobaça. Evolução sedimentar e histórica da Lagoa da Pederneira", in J.A. CARREIRAS (dir.), *Mosteiros Cistercienses. História, Arte, Espiritualidade e Património*, vol. III. Alcobaça: Jorlis-Edições e Publicações, Lda, 2013, 436.

narrow spaces between rocks[19], it is likely that at the end of the 18th century most of the land in the Valado dos Frades – Maiorga "alveolus" had already been recovered as a result of drainage, desalinisation and drying of the wetlands[20]. The first known document on the water engineering works dates from 1187, and in the 14th and 15th centuries there were references to several "*abertas*", which were important channels created by the Alcobaça Monastery[21]. The "*testadas*", or secondary, channels were the responsibility of tenants, who were meant to build them or keep them in good condition. There were other water engineering works for recovering land for agricultural use carried out during the 14th century in the areas of São Martinho, Aljubarrota, Maiorga and Alfeizerão, and others throughout the 15th century in the Cós and Alfeizerão regions[22]. In the 16th and 17th centuries, there are references to maintaining the "*abertas*" and "*testadas*" channels, which can be explained by the fact that the monastery had lost a great deal of direct exploitation of its domain and by the introduction of the commendam. It is known, however, that another structurally important project was carried out in the area in the mid-16th century while Cardinal-King Henrique was abbot[23]. This was the alteration of the course of the Rio da Areia ("sand river"), which was initially mixed with the course of the Rio do Meio ("middle river")[24]. It was completely diverted and formed a canal (called Vala Velha or Rio do Cardeal), which ran around half-way up the slope near Valado. This work created a

[19] They are the coastal "alveolus", the middle "alveolus" (Ponte das Barcas – Valado dos Frades) and the east "alveolus" (Valado dos Frades – Maiorga).

[20] M.V.F.J. HENRIQUES, "O Litoral dos Coutos ...", 436.

[21] I. GONÇALVES, *O Património do Mosteiro de Alcobaça nos Séculos XIV e XV*. Lisbon: Universidade Nova de Lisboa, 1989, 237-239.

[22] I. GONÇALVES, *O Património do Mosteiro...*

[23] A.V. MADURO, "O Inquérito Agrícola da Academia Real das Ciências de 1787. O caso da comarca de Alcobaça", in J.A. CARREIRAS (dir.), *Mosteiros Cistercienses...*, 352.

[24] The River Meio was formed by the confluence of several watercourses close to the site of Torre (the rivers São Vicente, Seco, Aberta Nova, etc.), as can be observed on the map cited in the following footnote.

ditch that received some of the Rio do Meio's basin and joined the river close to the sea[25].

Fig. 6 . *Rio da Areia ("sand river") or Vala Velha ("old ditch"). (J.M. de Mascarenhas)*

From the 18th century, several news pieces began to appear about technical water engineering works. In 1770, a contract was concluded between the monastery and the people of Maiorga to open a channel for a new course of the Rio Novo ("new river"), which then became known as the Rio do Meio ("middle river") because it passed between the Alcoa and the Areia, joining the Alcoa shortly before its confluence with the

[25] It does not seem possible to accept that there was an absence of important works in the 16th and 17th centuries, which would have meant "the loss of technical control of the waters of the Cistercian monks", as stated in J.P.G. CORDEIRO, *Voltar ao rio para (re)descobrir a porta de Alcobaça para o mar. Uma proposta para o território do rio Alcoa na antiga Lagoa da Pederneira.* Dissertation for a Master's in Architecture, Coimbra: Universidade de Coimbra, 2015, 79 (unpublished).

Areia[26]. The study about the recovery of Alfeizerão and Valado lands, with urgent diversion of the rivers, the construction of tide gates, a way of transforming the great marshlands and crop fields, was due to the actions of the Marquis of Pombal and his family ties to Abbot Manuel de Mendonça[27]. Because the water-related works in the fields of Valado/Maiorga, São Martinho/Alfeizerão and Mata were urgent, a report was drawn up in 1759 that proposed the construction of Vala Nova ("new ditch"), with a tide gate and a bridge in Barquinha. It was proposed that Vala Nova would flow into the river Alcoa after the confluence with Vala Velha ("old ditch")[28] or Rio da Areia, with the aim of better controlling water flow and floods. In 1814-1830, major works were executed to divert the mouth of the Alcoa, which from then on had a straighter course to the sea[29].

Regarding the former "sea" of Alfeizerão, information available on how it developed and how the fields were recovered is still vague and scattered. During the country's early days, the creek formed of the joint mouth of the river Alfeizerão and the river Tornada enabled a double port to operate until the beginning of the 17th century: Salir royal harbour and Alfeizerão harbour, dependant of the Alcobaça Abbey.

This creek led to others, used for navigation by ships and where shipbuilding was carried out. One of them reached Alfeizerão[30]. This port, which primarily exported wood and salt,

26 M.V. NATIVIDADE, *Mosteiro e Coutos de Alcobaça*. Alcobaça: Tipografia Alcobacense, 1960, 107. Initially, the Rio Novo would have flowed into the Alcoa close to Fervença, as can be seen in the aerial photographs.
27 M.V. NATIVIDADE, *Mosteiro e Coutos...,* 54. The channelling works for the River Alcoa in the fields of Maiorga and Valado are mentioned in *Memórias Paroquiais de 1758*.
28 M.V. NATIVIDADE, *Mosteiro e Coutos...,* 107.
29 M.V. NATIVIDADE, *Mosteiro e Coutos...,* 109.
30 *Foral de Sellir da Foz*, in L.F.C. DIAS, *Forais manuelinos do reino de Portugal e do Algarve: conforme o exemplar do Arquivo Nacional da Torre do Tombo*, Tomo 3 – *Estremadura*, Beja: privately printed, 1962. According to Luís Cardoso, in *Dicionário Geográfico*, there were

was part of a coastal shipping trade between Lisbon and Galicia, particularly during the 15th and 16th centuries[31].

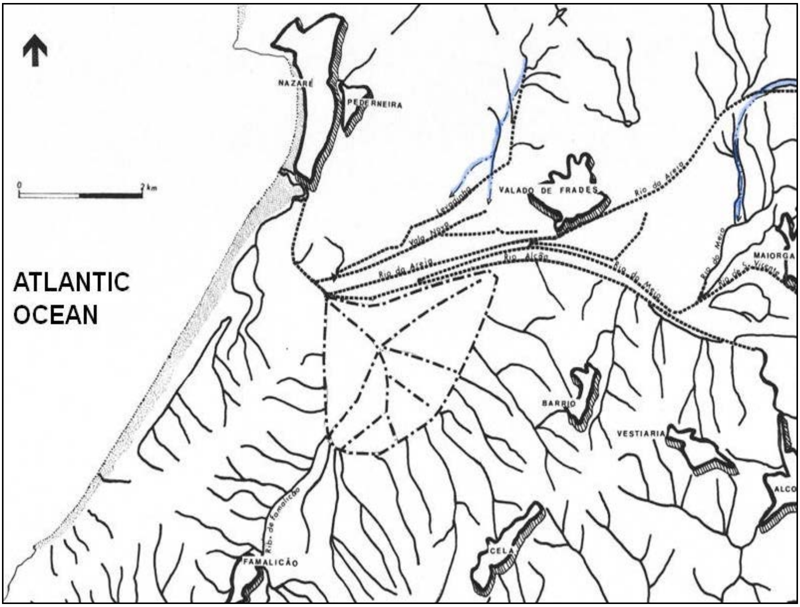

Fig. 7. *Main channelling and recovering works on watercourses in the fields of Valado dos Frades, Maiorga and Cela (J.M. de Mascarenhas). Dash-dot-dot (blue colour): likely original route followed by the watercourses; Dotted line: channelling works certainly carried out before 1834; Dash-dot: channelling works carried out between 1935 and 1939; / Tide gate.*

In the 14th century, shipbuilding in Alfeizerão took place at an intense pace[32], with production peaking during the 15th and

traces of the quay near Alfeizerão. See A.J. FIGUEIREDO, "Alfeizerão, centro portuário da Antiguidade por revelar", *Cadernos de Estudos Leirienses*, 4, Maio 2015, 156.

31 J. LOPES, *Alfeizerão e o mar. Os nautas*. See https://alfeizerense.blogspot.com.es/2015/09/notas-avulsas-sobre-os-barcos-e-o-porto_24.html?m=1 (visited on 21 June 2016)

32 King Afonso IV ordered that his galleys be built there (see following footnote).

16th centuries[33]. Until the mid-16th century, up to 80 tall ships[34] moored here and used the harbour as a safe anchorage spot and a possible location for loading and unloading goods[35]. However, during the 17th century, as a result of silting up, the port's lifetime got shorter as São Martinho's importance as a centre for shipbuilding and as a port grew[36].

As the silting up continued, making the lagoon less and less navigable, more cleaning works were carried out, with diversion ditches opened and streams channelled[37]. By order of the king, the river Alfeizerão was channelled in 1650[38], and its initial bed was abandoned to better support the salterns in the nearby area[39]. It is also known that the river Tornada underwent water engineering works during the reigns of King Pedro II and King João V[40]. Most of the interventions carried out by the Alcobaça Monastery took place in the 18th century, as mentioned

[33] I. GONÇALVES, M.S. SILVA, *A Baía de S. Martinho do Porto. Aspectos Geográficos e Históricos*. Lisbon: Ed. Colibri/Associação de Defesa do Ambiente de São Martinho do Porto, 2005.
[34] I. GONÇALVES, *O Património do Mosteiro...*
[35] M.L.P. BLOT, "Os portos na origem dos centros urbanos. Contributo para a arqueologia das cidades marítimas e flúvio-marítimas em Portugal", *Trabalhos de Arqueologia*, 28, Lisbon: Direcção-Geral do Património Cultural, 2003, 218.
[36] V. RAU, *Estudos sobre a história do sal português*. Lisbon: Editorial Presença, 1984, 62.
[37] V. RAU, *Estudos sobre a história...*
[38] L.F.C. DIAS, *Forais manuelinos do reino...*
[39] Alfeizerão had saltpans since at least the 13th century, and they are mentioned in its charters of 1332, 1442 and 1514. See J. LOPES, *Alfeizerão e o mar...*
[40] In the vast floodplain area, roughly within the São Martinho – Alfeizerão – Tornada triangle, large-scale water engineering works were identified by examining photographs. The courses followed by the River Alfeizerão and the River Tornada are artificial and are channelled downstream from the settlements with which they share their names. The initial courses followed by these rivers can be deduced from photographs and an understanding of the area's topography (Figs. 8-9.). As well as the above-mentioned channels, there are many other less important ones related to field drainage or water for agricultural uses.

above, during the administration of the Abbot Manuel de Mendonça (1768-1777)[41].

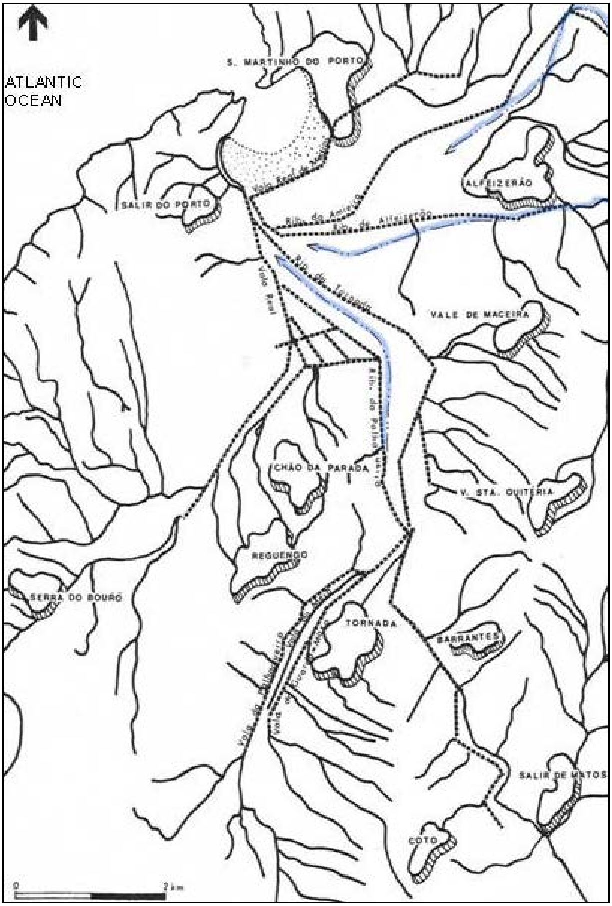

Fig. 8. *Main channelling and recovering works on watercourses in the fields of São Martinho, Alfeizerão and Tornada (J.M. de Mascarenhas). Dash-dot-dot (blue colour): likely original route followed by the watercourses; Dotted line: channelling works mostly before 1834.*

[41] The use of bodies external to the Order at this time probably means that control over the waters had been lost, as mentioned in, J.P.G. CORDEIRO, *Voltar ao rio…,* 81.

Identification of hydraulic planning works after 1834

It was assumed that several of the works observed in the aerial photographs and on the topographical maps were carried out relatively recently, so documentary research was used to try and identify them. References were found to works on the mouth of the Alcoa in 1814 and in 1822-1826 and 1833-1838 that aimed to regulate its sandbank, which was indispensable to recovering the waterlogged inland fields[42], but such works did not yield significant results. In Adolfo Loureiro's opinion, the fields were abandoned "mostly after the religious orders were extinguished", and the former regulations for conserving drainage channels were no longer observed[43].

In the first quarter of the 20th century, several technicians pondered these agricultural water engineering problems. On Licínio Valença's map, drawn up in 1927[44], two tide gates can be seen close to Ponte da Barca. In 1932, a new study was carried out for this marshland[45]. Work was executed between 1935 and 1939, and more than half of the formerly flooded area was then used for agriculture[46]. The river Alcoa (with higher dykes) and the river Famalicão were straightened and part of the latter eliminated. Two drains were installed on the slope, one to the north and one to the south, and were later joined to form a waist channel. A general drainage channel was also introduced, starting

42 A. LOUREIRO, *Os Portos Marítimos de Portugal e Ilhas Adjacentes*, vol. III. Lisbon: Imprensa Nacional, 1904. The sandbank closed itself constantly, so it generally needed to be opened three times per year.

43 A. LOUREIRO, *Os Portos Marítimos...,* 265.

44 See L. VALENÇA, "Um problema de Hidráulica Agrícola". *Agros*, IV, 2, nº 7-8, 1928; ID. – *Subsídios para o Estudo dos Problemas de Hidráulica dos Terrenos Alagados das Freguesias de Cela, Valado, Pederneira e Famalicão*. Relatório Final do Curso de Engenheiro Agrónomo. Lisbon: Instituto Superior de Agronomia, 1929.

45 According to A. CASIMIRO, *Conquista da Terra (Hidráulica Agrícola Nacional) 1140-1940*. Lisboa: Ed. Inquérito, 1940.

46 C.B. NEVES, "Do Porto da Pederneira e da sua Lagoa". *Gazeta das Aldeias*, nº 2769, 1974, 762.

in the central part of the Cela fields, in a place called Roseta, where four ditches came together[47]. In the land alongside the river Meio, drainage ditches were also opened[48].

Fig. 9. *False colour infra-red aerial photograph (1990 mission) of the fields of São Martinho, Alfeizerão and Tornada (source: ACEL, Lisbon). Key – 1: Alfeizerão river, channelled; 2: early course of the Alfeizerão riverbed; 3: Tornada river, channelled; 4: Palhagueira river, channelled.*

47 P.F. COSTA, *Estudo e Projecto da Segunda Fase da Obra da Cela*. Relatório Final do Curso de Engenheiro Agrónomo, Lisbon: Instituto Superior de Agronomia, 1960.
48 A. CASIMIRO, *Conquista da Terra…*

There was a second stage to this improvement work in 1960[49], with the aim of bettering drainage conditions and building primary and secondary irrigation networks, and this is generally the state it is in today.

Final considerations

In this collaborative study, the aim was to highlight the importance of the water engineering legacy started by the Cistercians at their former Alcobaça estate. The many uses and needs for water were analysed, primarily dealing with domestic uses (human consumption, cooking, personal hygiene, washing, etc.), industrial and technical uses (mills, manufacturing, etc.) and agricultural uses (irrigation, horticulture, etc.).

The water planning of this agrarian monastic land required structures to be built to bring, use and manage water, and this required indispensable specialist knowledge and skills. The main work carried out by the monks and lay brothers included digging shallow wells, building channels and ditches, building aqueducts, dykes, weirs, bridges, machines and mills, shifting and straightening watercourses, removing silt from lakes and draining land.

The water engineering strategy used to drainage and recover land for agriculture was, at least since the mid-16th century, based on the following actions: channelling watercourses, installing tide gates, controlling water flow (and therefore floods) by subdividing river basins with new watercourses and creating confluences of the different channels as far downstream as possible; organising an effective drainage network; cleaning riverbeds and clearing obstacles at river mouths.

[49] P.F. COSTA, *Estudo e Projecto da Segunda...*

This historic utilitarian work to design and transform the wild environment shows the Cistercians' modernity in terms of water engineering, which is reflected in the cultural landscaping values and the way fruits of the earth were grown. The final agrarian framework plan that the Cistercians implemented on the estate was based on water-intensive crops, spreading the prolific American corn (17^{th}-18^{th} centuries), which would later be joined by rice (start of the 19^{th} century) in the fields of Maiorga, Valado and Alfeizerão. Alongside this intervention, which revolutionised the water landscape and the range of crops to achieve an enviable level of production for the time, the monastery planted thousands of olive trees in the foothills of the Serra dos Candeeiros, and also introduced water engineering devices to the karst terrain to assist the agriculture and the cattle.

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