Canal Imperial de Aragón, the functionality of a water infrastructure and the inheritance of a traditional agriculture landscape in Spain

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Abstract
Canal Imperial de Aragón is one of the most significant hydraulic infrastructures in Europe and probable one of the most ambitious projects in the history of Aragón region. This work analyzes the main elements that characterize this infrastructure, including symbolic constructions such as locks and historic buildings, to provide objective reasoning of how these elements have shaped the region's cultural heritage. In addition, this study reconstructs the hierarchy and topological dependencies of the elements that comprise the canal's current irrigation network. The findings contribute to clarify the canal's role as a cultural and territorial asset, while also identifying current actions aimed at ensuring balanced water management without compromising this peri-urban landscape.

Keywords: Agricultural landscapes; GIS; Hydraulic infrastructure; Traditional Irrigation; Aragón

1. Introduction

The Imperial Canal of Aragon — Canal Imperial de Aragón in Spanish — is not only a major hydraulic infrastructure but also one of the main cultural heritage assets of the city of Zaragoza. Water-related assets hold deep cultural significance for the entire region of Aragón, especially for the Ebro River valley, where vast arid areas require the development of large-scale infrastructure to harness the river and its tributaries. The canal was initially conceived to bypass the meanders of the Ebro River in its middle course, making it navigable and providing a connection to the sea for the exchange of agricultural products. It was integrated with existing irrigation canals and extended their reach. Its role as a transportation route became obsolete with the development of railways. Today, the canal is no longer used for navigation; instead, it serves purposes such as irrigation, urban water supply, and electricity generation (CHE, 2025a). Its geographical trajectory is shown in Figure 1.

Figure 1: Geographical location of the Imperial Canal of Aragon in Spain. The map shows the trajectory of the canal and its irrigated region, which runs from the region of Navarre to Aragon, in parallel to the Ebro River, within the northeastern quadrant of the Iberian Peninsula.

1.1 History and Tradition of the Canal

Since ancient times, the use of water resources has played a central role in the development of the Ebro Valley. At least two dams from the Roman Imperial period are known in this area (Beltrán Lloris & Willi, 2012). The dam at Almonacid, on the Aguasvivas River—a tributary of the Ebro—has considerable dimensions and must have been capable of irrigating a vast area between the present-day towns of Quinto and Belchite. Moreno Gallo (2022) believes that the abandonment of the Celsa colony in 70 AD was due to the early failure of this dam, likely caused by rapid siltation. As a result, Caesar Augusta, now Zaragoza, replaced it as the most important city in the region. Of course, it also had a major hydraulic infrastructure for irrigation. In this case, a dam was built on the Huerva River, in Muel. Thus, the availability of irrigation water shaped both the settlement and development of the region.

There is even evidence of irrigation activity prior to the founding of Caesar Augusta. A bronze plaque found in Botorrita, known as the Tabula Contrebiensis, records the first documented legal dispute on the Iberian Peninsula, and the subject of contention was none other than water channeling rights, disputed by the inhabitants of Alaun and Salduie, the two Iberian settlements that once occupied the areas of present-day Alagón and Zaragoza (Giusto, 2006). Dated to 87 BC, it demonstrates, on one hand, the importance of irrigation water in the region since ancient times, and on the other, the extent of Roman resource management, which led them to arbitrate disputes between local populations. Later than this bronze plaque is the so-called lex rivi hiberiensis—the law of the Ebro canal—which documents a similar dispute in the 1st century AD and refers to a canal used jointly by several communities in the valley (Beltrán Lloris, 2006).

During the period of Islamic rule, which lasted for four centuries in this region until the conquest of Zaragoza by the Christian kingdom in 1118, irrigation systems and water channels were also developed. These infrastructures were of a smaller scale than those established by the Roman Empire, yet they left a significant cultural legacy. The invaders brought hydraulic technologies and new crops. Even today, most Spanish terms related to irrigation and water channeling originate from Arabic (Roldán Cañas, Moreno Pérez & del Pino, 2008). For instance, cisterna—like in Latin—means water tank, but when referring specifically to irrigation water, the word aljibe, from the Hispano-Arabic al úbb, is preferred. This is just one example of the Arab legacy in the culture of water and irrigation. They also influenced management practices, administrative systems for water rights, and many other aspects of irrigation activities.

To properly discuss the history of the Imperial Canal of Aragon, starting with its direct antecedents, we must go back to the year 1125, when Alfonso I the Battler, who had reconquered Zaragoza for Christendom, began granting irrigated lands to various knights. Thus, a new network of noble estates and large landholdings began to emerge as part of the colonization of the newly conquered territory (Laliena Corbera, 2011). Other irrigation channels are also known to have existed during the 12th century (Bosque Maurel, 2011: 112). As for the city of Zaragoza, the earliest surviving documents that mention them date from 1184, in which Alfonso II grants the Templars custody of the Celtén Canal—now called Centen.

Zaragoza had undergone significant growth and, by the early 16th century, had become a wealthy Renaissance city. Some texts from the period refer to it with terms alluding to its opulence (Bas Carbonel, 1999: 138). Spain was experiencing a period of splendor in technology, art, and culture, driven by the voyages to the Americas. Advances in navigation and cartography stimulated technological innovation, modern thinking, and the ambition that fostered grand projects. It was in this context that a faction of Zaragoza's municipal leaders, the Jurados, petitioned King Ferdinand the Catholic in 1510 for authorization to divert a navigable and irrigational canal from the Ebro River.

That project formally began in 1528, when Charles I of Spain—also known as Charles V, Holy Roman Emperor—commissioned three architects to study the diversion dam for the canal. The proposal by Gil de Morlanes was selected, recommending the dam be built at Fontellas, in the neighboring Kingdom of Navarre. Construction began in 1529, resulting in the El Bocal dam, but the canal never reached Zaragoza, halting just 15 kilometers from the city. This canal, known as the Acequia Imperial (Imperial Ditch), encountered numerous operational and maintenance issues. Among them, the original design included a large siphon to cross the Jalón River, which caused leakage and sedimentation problems and had to be replaced with an aqueduct supported by massive walls (Gallardo Pérez, 2024: 104). The challenges were so severe that King Philip II demanded a loan from Zaragoza for its upkeep (CHE, 2025a). The project was ultimately abandoned when a flood from the Ebro River destroyed the dam.

After several failed attempts to launch a new project to replace the Acequia Imperial, responsibility for overseeing the construction of a new one was entrusted in 1772 to Ramón de Pignatelli, with Pedro Herranat appointed as chief engineer (Fernández de Córdoba, 1791). This marked the beginning of the construction of the present-day Imperial Canal of Aragon, which remains in operation to this day.

This project also faced serious challenges during its execution. However, unlike the Acequia Imperial, all of them were ultimately overcome, and it can be regarded as a success in civil engineering. Initially, the canal's diversion dam was to be located upstream of Tudela, but due to technical issues, the new dam was ultimately built slightly higher than that the previous one. A remnant of this early attempt still survives: the ruins of a palace known as Casa de la Obra, constructed near Tudela to serve as the project's headquarters (Carrasco Navarro, 2013). The greatest risk of failure came when a flood from the Ebro River cast doubt on the project's viability. In 1784, engineer Agustín de Betancourt was appointed to inspect the site and evaluate the project. His report was highly favorable, and work resumed. Nevertheless, public opinion had begun to see the canal as a doomed venture. The failure of the earlier Acequia Imperial and the recent destruction of part of the works were seen as ominous signs.

When the water finally reached Zaragoza, Pignatelli ordered the installation of a monumental fountain near the mill and the San Carlos locks. A stone plaque was affixed to it with the inscription INCREDULORUM CONVICTIONI ET VIATORUM COMMODO (For the conviction of the incredulous and the relief of travelers). Today it is known as the Fountain of the Incredulous (Fuente de los Incrédulos). Shortly thereafter, Pignatelli died, having extended the canal beyond Zaragoza. He was succeeded in the project by the Count of Sástago, Vicente Fernández de Córdoba, who did not fulfill the dream of reaching the sea. Ultimately, the canal ends at the Ebro River near the town of Fuentes de Ebro. The Count of Sástago's contribution to the project was less significant, as the major works and engineering feats had already been completed. However, he left behind a highly valuable document: a detailed report on the canal and its construction, containing extensive information on the engineering solutions that had been implemented (Fernández de Córdoba, 1791).

Not long after, the canal and its bridges in Zaragoza became part of the front lines. The sieges that the French army inflicted upon the city in 1808 and 1809 caused damage to the canal infrastructure. Further destruction occurred during the French retreat in 1813. The 19th century was a time of reorganization and restructuring for the canal. In 1813, the Junta del Canal Imperial was established to manage and maintain it. From that point on, the administration and oversight of this hydraulic infrastructure remained under public authority. Since 1985, the Ebro River Basin Authority (Confederación Hidrográfica del Ebro) has been its managing body. Water users, organized into irrigation communities, form the General Community of Users of the Imperial Canal of Aragon. These two entities are today responsible for the infrastructure's maintenance, management, and the allocation of water quotas.

1.2 The Imperial Canal today

The 108 kilometers of the canal's course run parallel to the Ebro River along its right bank. At its origin, the intake dam has a flow capacity of 30 m³ per second, diverted through eleven sluice gates installed beneath the large building known as San Carlos, which has remained operational since the 18th century. Approximately 265 km² (around 65,500 acres) of land are irrigated using this infrastructure. For this purpose, more than 300 water intakes are assigned to irrigation communities, each feeding one of the main ditches (CYA, 2025).

In terms of productive use, irrigation is primarily dedicated to extensive herbaceous crops (alfalfa, maize, cereals, etc.), although there are also areas devoted to fruit and vegetable cultivation (artichokes, cauliflower, onions, etc.). The average annual water demand for irrigation is 417 hm³. Although most of the canal remains unlined earth, a hydrological plan has been approved that includes the modernization of several sections among other improvements (CHE, 2025).

The numerous intakes for irrigation and other services are supplemented by additional infrastructure. Two aqueducts allow the canal to cross the Jalón and Huerva rivers, both tributaries of the Ebro, near Zaragoza. Additionally, a diversion near Gallur channels water to the La Loteta reservoir, which is also fed by other watercourses (Lafuente Dios, 2004).

Regarding hydropower, four plants operate along the canal. In Gallur, where the elevation difference with the river exceeds 20 meters, 20 GWh are generated annually. In Zaragoza, the drop at the Casablanca lock was originally used as a mill in the 19th century. In 1901, a Kaplan turbine was installed in its place, enabling the generation of 650 kW, and it is still used today as an auxiliary system. This small power plant made Zaragoza the first city in Spain—and the second in Europe—to receive high-voltage alternating current. The other two power stations in operation are the Jalón plant, producing 3 GWh annually, and the Valdegurriana plant, near Zaragoza, generating 1.1 GWh.

The total elevation drops along the entire length of the canal is 125 meters. Since it was originally designed for navigation, the gradient of all sections is only 0.08%. The elevation is overcome by a system of lock groups installed in three locations on the outskirts of Zaragoza, although one of these areas has since become a highly developed urban neighborhood. This reflects how the rest of the canal's route successfully bypasses the natural terrain using well-engineered valleys and aqueducts. The first group, located in the Casablanca neighborhood, consists of two locks known as the San Carlos locks. Adjacent to them is the sluice house, which diverts water toward the urban center of Zaragoza. It is also at this location, taking advantage of the drop in elevation, where the first hydroelectric power station was installed. Eight kilometers downstream lies the Valdegurriana lock group, situated in the Torrero hills. These are imposing oval-shaped locks, built with ashlar masonry and flanked by stone staircases. The final group is the Torrecilla locks, which overcome a vertical drop of 9.75 meters. Due to the abandonment of navigation and lack of maintenance, they had fallen into disrepair. Currently, a system of four sluice gates has been installed to allow navigation once again, serving as a replacement for the original locks.

2. Canal Elements and Cultural Heritage

2.1 Architecture and Engineering

Most of the buildings and major engineering works of the Canal have been preserved. As expected for an infrastructure that has remained in continuous use for 225 years, many of these elements have been modernized or adapted. Only those components dedicated to navigation have suffered significant general deterioration, in some cases reaching total ruin. This is also understandable after more than a century of neglect of that activity. Nevertheless, especially in recent years, restoration efforts have been undertaken to recover what is now a recognized and highly emblematic cultural heritage site for the region.

All elements of the canal —locks, guardhouses, ditches— form part of an integrated system, whose coherence is not only hydraulic but also topological. Their spatial and functional interdependence allows the infrastructure to be understood and managed as a network, with upstream and downstream relationships that reflect both physical flow and institutional coordination. This systemic logic can be mapped and studied using GIS and historical cartography, offering tools not only for conservation, but also for maintaining operational continuity in the face of change. This network logic becomes especially evident when analyzed using Geographic Information Systems (GIS), which allow mapping the hierarchy and interconnections of primary and secondary ditches, sluices, and intake points. Understanding these dependencies is essential for both conservation and adaptive management, particularly in times of increasing climate uncertainty and regulatory demands. The canal is not a linear infrastructure, but a spatially distributed and functionally interlinked system, shaped by both hydrological and social flows.

The list of elements we present here to highlight the legacy of the Canal is based on information gathered by the authors during numerous visits to the facilities and analysis of three key documentary sources. First, the document prepared by the Count of Sástago (Fernández de Córdoba, 1791) is undoubtedly the most detailed description of the Canal at the time, including highly precise technical and graphic information. The second source is primarily visual: in 1833, a collection of landscape engravings of the Canal was published by order of King Ferdinand VII, accompanied by a descriptive text of the construction project and its uses (Blanchard & Alexis, 1833). It includes 37 plates, showing the state of the facilities and buildings during the first third of the 19th century, each with an explanatory caption. The most recent source is a publication offering a detailed account of the Canal's current elements (Pallarés Jiménez, 2011).

The Casa de la Obra is a palace built as the Canal>s headquarters at the start of the project, when the dam was initially planned to be located upstream from Tudela. Although this location was ultimately abandoned, some structures remain at the site (Carrasco Navarro, 2013). The palace is considered one of the finest examples of Baroque architecture in the city of Tudela. Its imposing facade adorned with noble coats of arms and its interior with carved stone columns reflect the magnitude of the project. This is one of the so-called Canal Palaces. The term also refers to two large buildings that can be admired at El Bocal dam, both of which are well preserved. The so-called Palacio de Carlos V was the seat of the Acequia Imperial, home to its governor and the access point to the dam's four sluice gates. Built in the 16th century, it was renovated in the early 19th century. Of Aragonese style, it combines ashlar masonry on the ground floor with Mudéjar brickwork on the upper two floors and side towers. It forms a complex with other structures, such as the neoclassical Chapel of San Carlos Borromeo (Pinilla Gonzalvo, 2022). A few meters upstream, the Palacio de Compuertas is the building associated with the current Canal dam.

The El Bocal dam includes additional buildings, and an important settlement developed around it at the beginning of the Canal's construction. Families of the construction workers settled in the area, which still retains residential buildings, a school, and workshops maintained and periodically restored by the Ebro River Basin Authority (CHE, 2022).

Less monumental than the palaces but no less important as heritage is the San Carlos Mill in Casablanca. Today, Casablanca is a district within the city, and its name—meaning the white house—derives from this building, which was coated and painted white. A visual comparison of its historic and current state is provided in Figure 2. The mill serves multiple functions. It houses the Community of Users of the Imperial Canal of Aragon (CYA) and was formerly part of the Canal›s management infrastructure. Located next to the dock and locks, it also served as the administrative house for these facilities. It harnessed the water drop to grind wheat and today contains a small hydroelectric plant. Beneath the building, a structure of large ashlar blocks forms the sluice gates that once supplied Zaragoza with water—its only source for many years. The building also has significant historical value: it was here that the capitulations of the city of Zaragoza were signed in 1809, ending the second siege during the Peninsular War against Napoleon›s army. Currently, the building also houses a Canal museum featuring historical artifacts and interpretive models. Next to it is the Fountain of the Unbelievers.


Figure 2: Historical and current view of the San Carlos Mill. Comparison between an archival image and a contemporary photograph of one of the key buildings linked to the Canal's infrastructure, located in the Casablanca district of Zaragoza. Sources: archival print (Blanchard & Alexis, 1833); authors' photography.

Currently, the Canal has 300 sluice gates that divert water into irrigation ditches. Initially, there were fewer, and the oldest ones feature access buildings used to manage the infrastructure. Twenty of these structures, known as almenaras, are preserved along the Canal. As the water has been spordically used for industrial projects, industries powered by water can be found at its side. The most important are the Imperial Flour Mill of Zaragoza and the Imperial Ceramics of Ribaforada.

2.2 Landscape and Cultural Heritage

Both Zaragoza's population and public institutions are increasingly aware of the value of the Canal's facilities as cultural heritage. In recent years, significant efforts have been made to restore all the locks to make navigation possible once again (CHE, 2025b).

Along the Canal, historical bridges built from various combinations of ashlar masonry, brick, and concrete are still preserved. Some stand out their elegant arches, such as the Formigales Bridge, Cortes Bridge, and Clavería Bridge in Garrapinillos. Some bridges remain incomplete or in ruins, often because they had wooden decks, sometimes temporarily constructed. A good example is the Jubo Bridge in Pinseque, which preserves only its side plinths. These old bridges are an essential part of the Canal's landscape, as shown by their inclusion in the

1833 collection of picturesque views (Blanchard & Alexis, 1833).

Also notable are the aqueduct segments. In the section crossing the Jalón River, the Canal runs elevated over a monumental ashlar wall known as Las Murallas de Grisén (The Walls at Grisén). Nearby is a natural area called El Caracol, where tourism is encouraged to enjoy the landscape formed by the immense aqueduct, a large tower with a spiral staircase that leads to the elevated Canal, and the slender gate San Martín almenara, which, being on the elevated canal, rises like a tower on the horizon. The water flowing from it cascades down a stepped channel. These visible walls conceal earlier ones built for the Acequia Imperial that provided access to the siphon (Saenz Ridruejo, 2004: 356). The nearby crossing over the Jalón River, with the large openings of the aqueduct, is also part of this setting. Other elevated aqueducts on large walls exist in Zaragoza, such as the Barranco de la Muerte.

Elsewhere, the Canal's contribution to the landscape is less monumental but no less significant. Its route through Zaragoza is especially visited where it integrates with the city's large park. In this area, it crosses the Huerva River via another elevated aqueduct known as El Ojo del Canal (the eye of the Canal). Less integrated into the city is the linear PLAZA park, a newly created green space bordering a large industrial and business area, where the Canal plays a key role in shaping the park's landscape.

The Canal's contribution to the urban landscape goes beyond parks. As mentioned earlier, the Casablanca district grew around the Canal's facilities. Another major urban district, Torrero, is also closely tied to the Canal. The large América Bridge connects this district with its southern area and the rest of Zaragoza. Torrero's initial growth was driven by Canal-related construction. Pignatelli commissioned the construction of a large church for the workers, the Church of San Fernando. Today, located within a military compound, the 19th-century district was then connected to the city only by a rural road. The church marked the consolidation of this new population center and it features a large dome and two towers, reflecting the importance of the growing community. The commission for the interior paintings went to Francisco de Goya y Lucientes (Marías et al., 1984). During the sieges of Zaragoza, French troops looted the church, and the paintings were lost. However, Goya's preparatory sketches are still preserved.

The ecological value of the Canal is indisputable. It has helped sustain a vast irrigated area on the southern side of the Ebro River. Although irrigation has existed since ancient times, the Canal's infrastructure and steady flow ensures the ecosystem's maintenance. Notably, the water serves as a reservoir for endangered species such as Margaritifera auricularia, a rare freshwater mussel also known as the river pearl (Araujo & Ramos, 2000).

As presented, the Imperial Canal of Aragón is a cultural asset of special significance for the region due to its connection with the water culture, a recognized part of the region's identity. In such an arid area of Aragón, yet rich in difficult-to-access water resources, it is no surprise that the region closely identifies with its rivers and canals. This water and irrigation culture, inherited from Romans and Arabs, survives in local traditions affecting both irrigation techniques and water governance. For instance, in a town near Zaragoza, an ancient system of irrigation rights allocation known as El Trallo is still in use. It involves throwing a bundle of plants into a ditch and depending on which direction they take at a fork, water is allocated to one village or the other (Pérez Viñuales, 1989).

The Imperial Canal traverses a highly dynamic peri-urban area where rural practices, metropolitan expansion, and ecological values intersect. This landscape is not a passive buffer but a space of tension, where different land uses and temporalities coexist —productive agriculture, infrastructural heritage, and urban transformation. The canal, by sustaining agricultural activity and offering ecological continuity, becomes a structural element of resilience in this context. Its preservation is not only a matter of heritage, but of territorial balance and environmental justice as well.

Zaragoza, as the regional capital, embraces and promotes this legacy. In 2008, it hosted an International Exposition whose central theme was water and sustainable development. The event addressed the challenges of water under climate change and its role as a shared resource, while supporting a landscape intervention and management project that has contributed to improving the city's environmental quality (Alday, Jover y Dalnoky, 2009). Today, Zaragoza has a vast riverside park dedicated to water and water resource issues often shape the region's political discourse. The Imperial Canal of Aragón remains one of the most cherished assets, representing Aragon's heritage of traditional and responsible water use.

3. Challenges to traditional practices amidst Peri urban dynamics

The irrigation system is managed through a shared institutional structure. While the physical infrastructure is owned and maintained by the Confederación Hidrográfica del Ebro (CHE), the distribution and operational management of water is carried out by the user community, represented by the Canal Imperial de Aragón entity (CYA). CYA is the organisational body that brings together the various irrigation syndicates along the canal, coordinating the use of water resources and ensuring compliance with the regulatory framework established by the CHE. Within this model, CYA is responsible for implementing irrigation schedules, mediating local governance, and maintaining the traditional practices that structure daily water management. The main structure of this irrigation system and its extent can be seen in Figure 3.

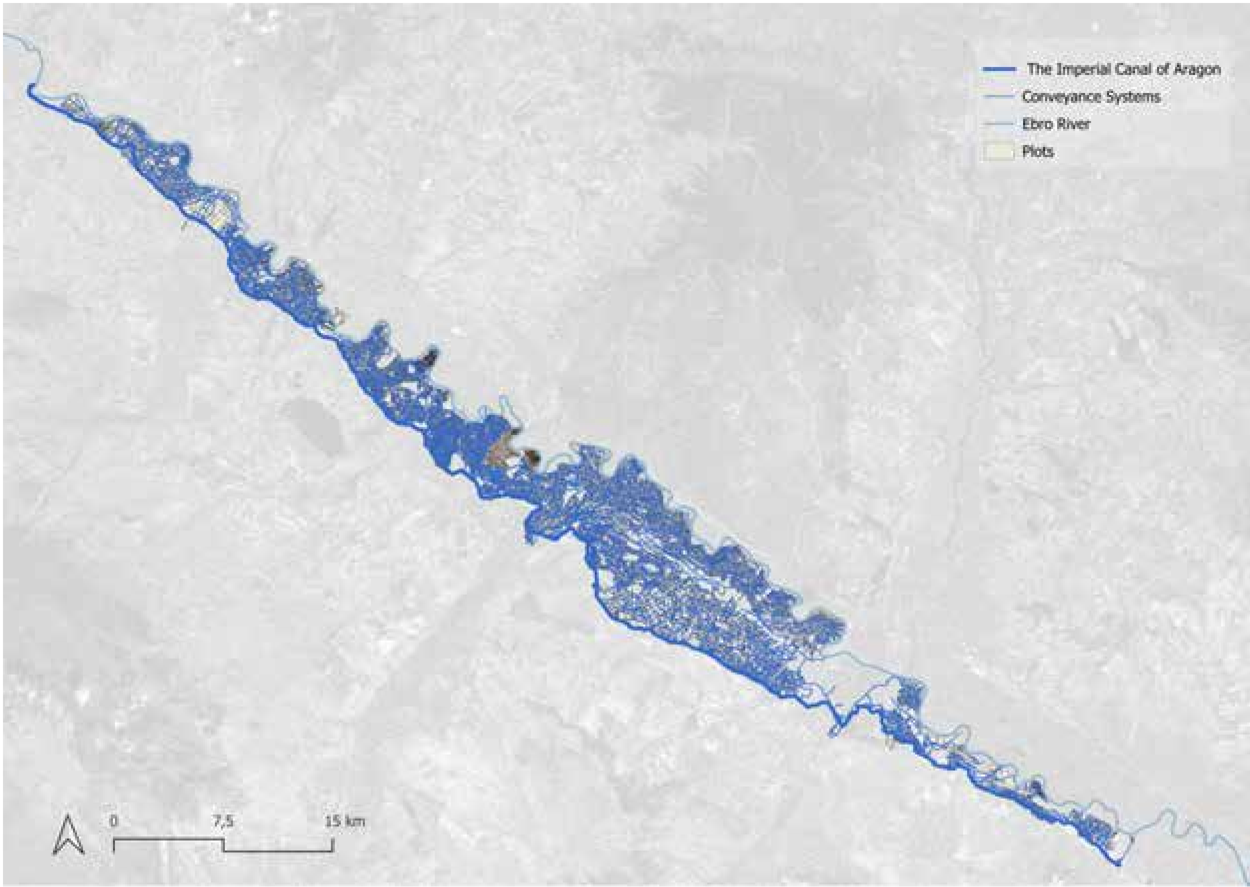

Figure 3: Irrigation infrastructure of the Imperial Canal of Aragon. The map shows the main canal, the network of conveyance systems, and the agricultural plots it serves. This layout reflects the extensive spatial organization of the irrigated area.

The uniqueness of CYA lies not only in its technical scale but in its organisational model. Governed by communities of irrigators, grouped into irrigation syndicates (sindicatos de riego), the system operates according to a set of practices developed through centuries of shared use. At the heart of these practices is the notion of equity, embedded in a rotation-based method of distribution—known as adores—that assigns water to users in a cyclical and public manner. Each day, the head canal guard oversees water distribution, records which plots have received water, and ensures compliance with the schedule. This structure has generated a strong sense of collective responsibility and reciprocity, contributing to the social resilience of the communities that depend on the canal.

This model of self-managed irrigation, developed long before the rise of contemporary resource governance theory, provides an exemplary case of what Elinor Ostrom termed a "common-pool resource institution" (Ostrom, 2002). It is governed by rules devised by the users themselves, enforced through mutual monitoring, and adapted to environmental fluctuations. Yet, despite its adaptability and effectiveness, the CYA system is increasingly seen as insufficient from the perspective of modern water management standards and regulations.

3.1. The Need for Water Consumption Management

Across Europe and other parts of the world, the discourse on water governance has shifted significantly over recent decades. The focus has moved from access and equity toward efficiency, accountability, and technological innovation. This transition is linked to broader concerns over climate change, water scarcity, and environmental sustainability. Under new regulatory frameworks, irrigation communities are now expected to provide detailed data on consumption, report crop types and schedules, and demonstrate improvements in water use efficiency. These expectations arise from both legal requirements —such as the EU Water Framework Directive— and growing public pressure to justify the use of shared natural resources.

In this context, the traditional operational logic of CYA appears increasingly out of step with institutional demands. Water is not allocated based on volumetric measurement or per capita quotas. Instead, distribution is guided by historical entitlements associated with plots of land, and turns are coordinated through informal negotiations and routine practices. While this system has ensured equitable access over centuries, it offers limited capacity for real-time monitoring or precise accounting.

The disconnect between traditional logic and regulatory expectations poses both technical and political challenges. From a technical standpoint, it becomes difficult to evaluate the relative performance of CYA in terms of water efficiency or productivity. Statistical comparisons with pressurised or automated systems often favour the latter, especially when data availability is unequal. From a political perspective, the lack of data can be interpreted as a sign of opacity or inefficiency, reinforcing the notion that traditional systems must be replaced or overhauled to meet contemporary standards.

Yet, such assumptions overlook the complexity and functionality of systems like CYA. Despite its informality, the canal's distribution mechanism operates with remarkable precision, guided by generations of experience and local knowledge. The guards responsible for opening and closing the main gates often know each plot, user, and ditch intimately. Their role, though rarely digitised or standardised, ensures the system's daily operation and reflects a form of expertise that cannot be reduced to sensor readings or remote monitoring dashboards.

The need to manage water consumption more effectively is not denied within the community. Many users and administrators of CYA recognise that the pressures facing the system today are different from those of the past. They are aware of the demands for transparency, the importance of sustainability, and the necessity of adapting to a changing climate. However, they also argue that solutions must be adapted to the context. What works in drip irrigation schemes or highly mechanised farms may not apply to a flood irrigation system rooted in collective action and territorial history.

Moreover, the scale and heterogeneity of the CYA system further complicate the implementation of standardised monitoring tools. The network of ditches and secondary canals is complex, and many plots receive water from more than one intake point, depending on the topography, the time of day, and the specific irrigation cycle. The idea of installing a flow meter at each individual gate is not only financially unfeasible, but also socially disruptive, as it would alter the balance of trust that underpins the existing order.

In this scenario, the goal is not to reject the call for better water management, but to reframe it in ways that respect the system's cultural and operational integrity. What is needed is a form of adaptive governance that improves data availability and reliability without undermining the principles of collective management. Such an approach would seek to enhance, rather than replace, the mechanisms already in place, and to work from within the system's logic instead of imposing an external model.

The adoption of new tools and methods must be aligned with the principle of subsidiarity—where decision-making is kept as close as possible to the local level. This means recognising the guard's observations as valid inputs, structuring the existing libros de adores (ador logbooks) in ways that allow for systematic analysis, and combining this information with basic hydrological models that account for the physical characteristics of the network. In doing so, CYA could generate more accurate estimates of water consumption while maintaining the community-led structure that has sustained it for centuries.

3.2. Challenges of Measurement in Traditional Systems

The traditional structure of the CYA irrigation network presents inherent limitations for measuring water consumption using conventional technical tools. Unlike modern irrigation systems that rely on pressure lines, digital meters, and automated control, CYA operates entirely through gravity-fed flow, distributed via open ditches of varying construction types and dimensions. This complexity is illustrated in Figure 4, which shows the dense conveyance system and the parcel fragmentation. The physical configuration of the network, along with the rotational logic of water allocation, makes precise and continuous measurement a difficult task.

Each intake along the main canal diverts water into a local conveyance system, which then branches into numerous ditches and ultimately reaches individual plots through gates operated manually by irrigators. These gates are not fitted with meters or sensors, and their opening levels are rarely recorded with engineering precision. Instead, guards and users rely on experience, visual inspection, and habitual knowledge to manage the distribution. This results in a system that is functionally effective, yet difficult to capture in standardised data formats.

Water losses between the canal intake and the destination are significant and variable. They depend on several factors, including the material and age of the ditches, the slope and distance of the flow path, and weather conditions that affect evaporation. Conveyance losses are generally assumed to be high —sometimes exceeding 40%— (Serra, 2016) but no direct measurements are made on a daily basis. The inability to account accurately for these losses complicates efforts to assess how much water each plot receives.

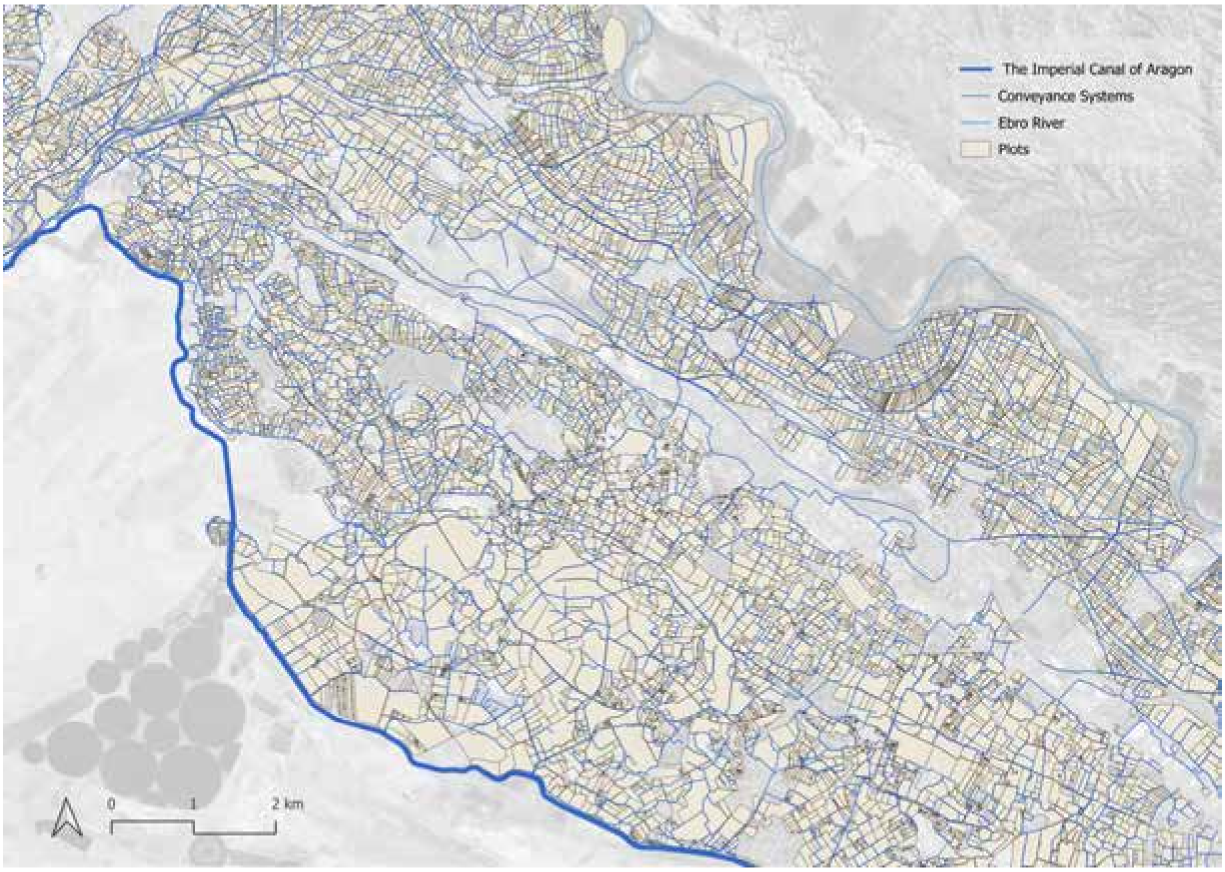

Figure 4: Detailed partial view of the irrigated area. The image illustrates the high density and complexity of the conveyance system and the parcel fragmentation.

Another issue is the temporal dimension of flow. Because of the slow movement of water through the ditch system, there is always a delay between the moment water exits the main canal and the moment it reaches the plot. This delay, known as conveyance time, can range from 90 minutes to over two hours, depending on distance and conditions. As a result, any time-stamped measurement at the canal level does not immediately correspond to what happens downstream. Synchronising flow data with plot-level activity requires not only physical modelling but also reliable information on irrigation schedules—information that, in the CYA context, resides primarily in the daily notes of the guards.

The adores logbook is the only consistent record of water distribution in the system. It is maintained manually, often with limited detail, and varies from one syndicate to another in structure and style. Despite this, it offers valuable insights into how water is used: which plots were irrigated, in what order, and for how long. However, because the data is subjective, based on observation or user reports, and not standardised, its reliability for estimation purposes is variable. Some entries are precise, while others may be incomplete or rely on assumptions. The lack of systematic archiving or digital transcription further reduces its analytical potential.

The core issue concerns the coexistence of two distinct approaches to managing irrigation. One is based on lived experience, observation, and collective coordination; the other relies on measurement, standardisation, and external monitoring. Bridging these perspectives requires not just methodological innovation but also institutional awareness of the system's cultural and operational specificities. Traditional data should not be dismissed as unreliable, but rather understood in its context and translated into forms that can inform practical decision-making. Ultimately, the goal is not to quantify every detail, but to generate sound and consistent estimates of water consumption—estimates that reflect both the physical dynamics of the system and the way it is used and governed.

CYA presents a powerful case for rethinking how we define and measure water use. It invites a broader reflection on the role of tradition in contemporary water management, and on the need to adapt our tools to the systems we are working with, not the other way around.

3.3. Heritage Dimensions and Pathways for Protection

Beyond its operational challenges, the CYA irrigation system must be understood as part of a broader cultural and territorial heritage. Its ditches, gates, pathways, and guardhouses form part of a historical landscape shaped by centuries of interaction between people and water. The rules of rotation, the figure of the guard, and the communal management model are all expressions of intangible heritage that reflect a collective memory and a shared sense of belonging.

These dimensions are often overlooked in conventional water policy, which tends to favour efficiency over continuity and data over meaning. Yet, safeguarding traditional irrigation systems is not only about preserving old techniques. It is about recognising the value of a way of managing land and resources that remain socially relevant and ecologically adapted. Systems like CYA have persisted precisely because they respond to the complexities of their environment with flexibility, embedded knowledge, and low-cost operation.

However, this heritage is increasingly under threat. Regulatory frameworks rarely account for the specificity of traditional systems, and funding programmes for irrigation modernisation often prioritise technical upgrades that are ill-suited to the logic of collective governance (OECD, 2006). Meanwhile, generational renewal is limited. Young people are less involved in farming and less connected to the values and practices that sustain traditional water management. Without targeted support, much of this knowledge may be lost within a generation.

To address this risk, heritage protection should be redefined to include not just monumental structures or historic canals but also living practices and institutional arrangements. Recognising the ador rotation system, the adores logbook, and the figure of the guard as heritage assets could open new possibilities for institutional support. This recognition does not mean freezing the system in time. On the contrary, it involves empowering communities to adapt their practices while maintaining their identity. It also involves documenting existing knowledge, promoting intergenerational transmission, and creating spaces for dialogue between users, researchers, and policymakers.

The future of CYA depends on the capacity to evolve without losing its core. Protecting the system means more than preventing physical decay. It requires creating conditions for social, institutional, and technical continuity. Only then can the canal continue to irrigate not only crops, but also the cultural and civic fabric of the territory it sustains.

Striking a balance between technological innovation and traditional knowledge is essential. Maintaining the canal's use should not imply transforming it into a mechanised or hyper-technified system at the cost of its ecological and cultural integrity. Rather, adaptation must work within the system's own logic, respecting the territorial and environmental values that give meaning to its operation. The canal is not only an infrastructure. It is a socio-ecological ecosystem shaped by collective practices and historical memory. Any modernization strategy must recognize this complexity and avoid interventions that might simplify or fragment it. Protecting this equilibrium is the real challenge of contemporary water governance.

4. Conclusion

The Imperial Canal of Aragón constitutes a unique case of territorial continuity, where an infrastructure designed in the 18th century remains both operational and socially embedded in the contemporary landscape. Heritage, ecology, and agricultural functionality intersect in the peri-urban fringe. Its hybrid nature —as both a functioning irrigation system and a cultural-historical landscape— challenges conventional modernization approaches that often prioritize technical metrics over historical resilience and socio-ecological integration.

The peri-urban context of Zaragoza plays a crucial role in this complexity. As urban pressures intensify, the canal landscape has become a buffer zone between agricultural persistence and urban expansion. This spatial tension must be addressed not only through land-use regulation, but also through policies that recognize the cultural, ecological, and social functions of traditional irrigation landscapes.

Efforts to modernize water management must be carefully adapted to these specific contexts. Rather than imposing volumetric control through high-tech systems, governance frameworks should pursue compatibility with the collective, experience-based logic of flood irrigation. Adaptive models that integrate community records, observational practices, and targeted monitoring can improve accountability without dismantling historically grounded practices.

Protecting the canal requires more than preserving its physical elements. It demands a commitment to maintaining the social fabric that gives it life: the irrigation communities, the guards, the rotation schedules, and the lived knowledge embedded in each ditch and gate. These are not relics, but assets of a flexible, robust, and living rooted system.

In a time of climate uncertainty, biodiversity decline, and urban sprawl, infrastructures like the Imperial Canal offer a roadmap for ground sustainability. It demonstrates that resilience can be built not only through innovation, but also through memory, reciprocity, and rootedness in territory. It stands as evidence to how infrastructure, tradition, and landscape can coexist in dynamic balance. Recognizing and supporting these qualities will be key to ensuring their continuity into the future.

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