Built Heritage

RESEARCH ARTICLE

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Small water structures of the upper Tiber River in the Umbria Region

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Abstract

In the upper Tiber River basin, in the region of Umbria, there are hydraulic works built by the Etruscan and Roman peoples whose origins date back to several centuries before Christ. Some of these structures have been updated over the centuries and are still in use today, and they play important roles in water resource management. Owing to these historical infrastructures, cultural and social collateral activities have developed, which, together with the economic functions of these works, are of enormous relevance to Umbrian populations. However, the history of these hydraulic systems also serves as an example of the evolution of hydraulic engineering for all humanity. This paper is aimed at illustrating four of these fundamental systems: i) The Sportone di Maderno on the Clitunno River, which was named after the architect who designed it. This architect was also responsible for the façade of St. Peter's Basilica in Rome, which is an efficient historical work that enables water drainage. ii) The Marmore Falls, which is an 'artificial' waterfall that exemplifies the global significance of water and its influence on art and technology throughout history. iii) The Monte Pacciano reservoir in Perugia, which has a capacity of approximately 6,000 m^3 and is part of an ancient medieval aqueduct. Finaly, iv) the hydraulic axis of the Clitunno River, which is a key element in the economic development and liveability of the Umbrian Valley over the centuries. This article and the case studies it describes are aimed at highlighting the importance of preserving these ancient hydraulic systems and emphasising the opportunity for extending this study to other historical systems.

Keywords Water and cultural heritage, Water resource management, Water use, Upper Tiber River Basin

1 Introduction

The development of many societies and civilisations has been closely linked to water, and indeed, the term 'hydraulic civilisation' (Wittfogel 2011; Angelakis et al. 2025) is often used to describe this phenomenon. For millennia, water has represented a fundamental element in the establishment of cities from social, economic, and political perspectives (Branduini and Zaina 2023; Bracchi et al. 2024). Historical and archaeological research has shown that activities related to crop irrigation and navigation, as means of transportation and exploration, were already present several millennia before Christ in various parts of the world (Motta and Beydler 2020; Angelakıs et al. 2020; Zhuang 2017).

In this context, many works, particularly works of irrigation (Yoder 1994; Abernethy 2010) and hydraulic reclamation (Linoli 2009; Healy and Hickey 2002), have been developed. These projects represent technological advancements (Mays 2008) but also exemplify the close relationship between humans and water (Mariano et al. 2023; Allan et al. 2024). Over the centuries, this heritage

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has undergone modifications and alterations; however, some hydraulic structures have been preserved over time, and with appropriate updates, some are still serving hydraulic functions today. Their value, which springs from a sociocultural heritage perspective, has been reassessed in recent decades (ICID 2012; Kotzé 2024), and some of these structures have also gained significant touristic importance (Gunatilleke and Gunatilleke 2025; Gómez-Zapata et al. 2024).

This work is aimed at describing some of the historical hydraulic works in the upper Tiber Valley. This area is characterized by the presence of an important watercourse, the Tiber River (Pierleoni et al. 2007), which has shaped the history of this region since Etruscan and Roman times. Pliny the Younger (a Roman lawyer, writer, and magistrate who loved from 61/62 AD to 114 AD) described this landscape as beautiful, comparing it to a vast amphitheatre created only by nature (Braconi 2008). These features of the upper Tiber Valley made it the site of numerous ancient settlements, and these settlements were faced with managing their relationship with water through hydraulic works that were aimed both at the protection of inhabited and cultivated lands from river floods and the utilisation of water for civil and irrigation purposes.

The description of these initial four hydraulic works represents a preliminary step towards the formulation of a methodological framework for the preservation and valorisation of such structures. The historical significance of these works are frequently neglected, particularly those that are no longer operational, or they are recognised only within specific professional circles, such as AIMAS (the Italian Association of Historic Mills).

Furthermore, for this study, these four works are contextualised within the clearly defined historical and territorial framework of the upper Tiber Valley, and the potential network relationships—both physical and cultural—among them are highlighted.

The proposed methodological framework can also be extended to the wider public through the implementation of innovative digital technologies, as exemplified by the case of the Marmore Falls and the HYDRA Multimedia Museum (https://museodellacascata.it/).

In the following sections, the historical characteristics of four of these works are described. All four are still existing and functional, although they have been adapted to modern times. The Sportone di Maderno and the Marmore Falls are two historic hydraulic reclamation works; the former still performs its fundamental function, while today, the latter serves as a major tourist attraction that shares its water for hydroelectric exploitation at the nearby Galleto power plant (Hudson 2012). The Monte Pacciano Reservoir and the hydraulic works on the Clitunno River, on the other hand, are linked to the historic use of water resources—one for civil purposes and the other mainly for irrigation—which is a reflection of the socioeconomic development of their respective areas (Colacicchi and Bizzarri 2008).

2 A collection of historical hydraulic systems in the upper Tiber River basin

The Umbria region is predominantly hilly, partially shaped by the Apennine Mountain range, and covers an area of approximately 8,456 km^2. The Tiber River flows from north to south through the region and, together with its tributaries, serves as an important communication route for both the Etruscan and Roman civilisations (McCallum 2005; Tibbs and Campbell 2023). This scenario favours the presence of both large and small historical hydraulic systems, which are distributed from north to south, mainly along the principal rivers. The locations of the four studied systems are shown in Fig. 1.

2.1 Sportone di Maderno hydraulic system

The 'Sportone di Maderno' takes its name from the architect who designed it, who is known, among other things, for the façade of St. Peter's in Rome (Guerrini 1992). The structure was conceived and constructed in multiple phases between 1600 and 1635 for the purpose of regulating and redirecting the 'low waters' of the Clitunno Alveolo Basin—which originate from lower elevation zones or from more central and internal areas of the basin—to the 'high waters' of the Marroggia-Teverone-Timia system, which drain the higher sectors of the reclaimed land. Simultaneously, it powered two water mills in the municipality of Bevagna (Fig. 2).

This creation effectively mediated two opposing needs: that of the Municipality of Bevagna, which sought a greater influx of water to supply its mills, and that of the Municipalities of Foligno and Trevi, whose primary interest was in draining their plains. The inlet operates through an overflow threshold located 4.28 m below the top of the embankment and 2.72 m above the riverbed. The gate was raised using a mechanism of uncertain operation, which slid along two iron beams maintained by the Municipality of Bevagna and was secured behind the regulator at a height of 0.70 m from the threshold (Fig. 3A).

According to an old regulation, the mobile gate could only be raised on Sundays and always to only a limited extent that allowed the net to be freely unloaded. Over time, it underwent various modifications, the last of which occurred approximately 1925 (Fig. 3B). The modification consisted of a brick bridge obliquely spanning the opening on the right bank of the Timia River to release a portion of the Meander's waters.

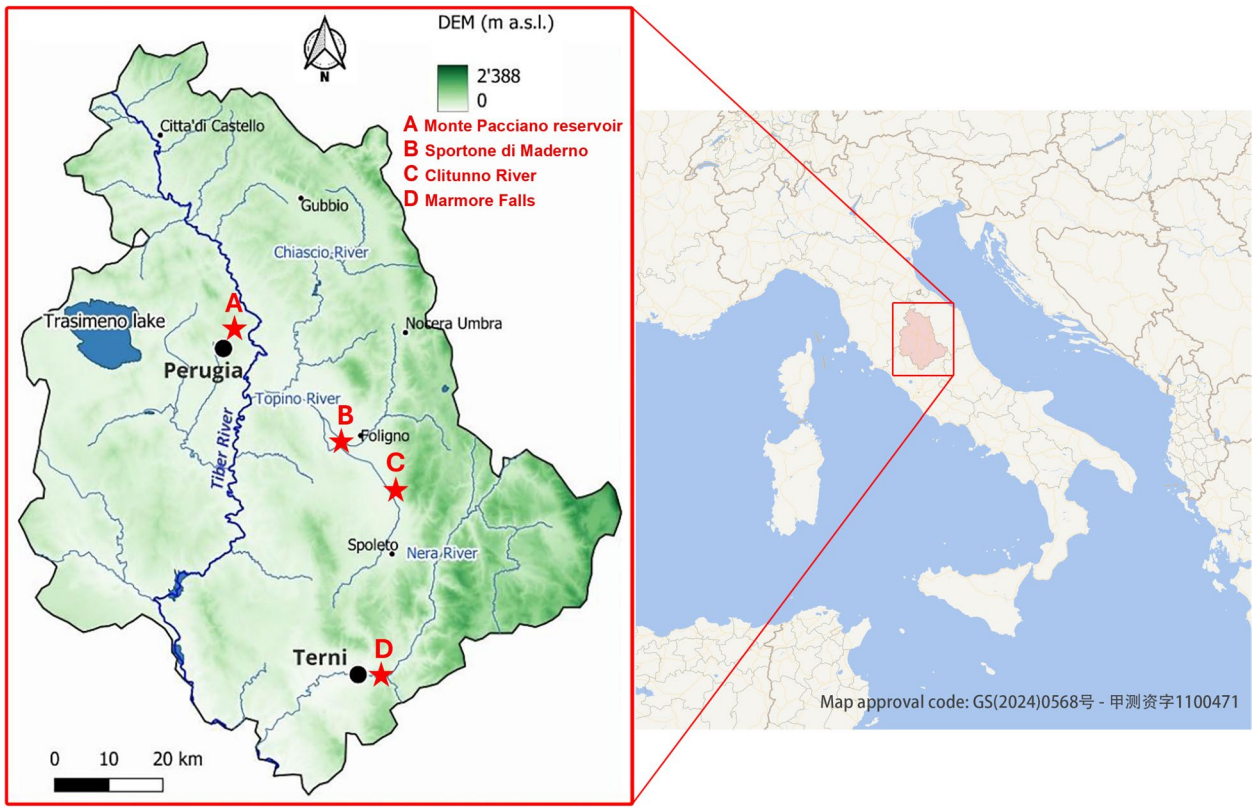


Fig. 1 Umbria region, central Italy. The locations of the four sites are shown in the bounded red box (Source: the authors, the base map was provided by the National Platform for Common GeoSpatial Information Services)

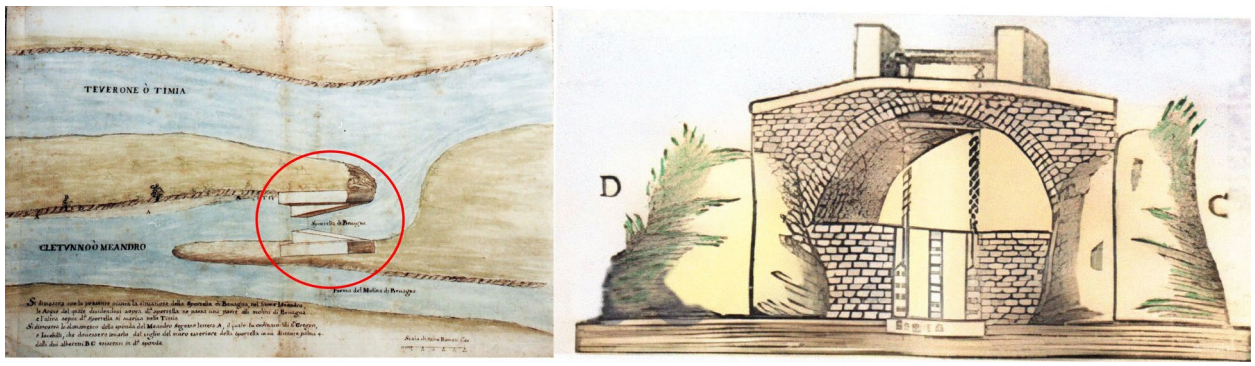


Fig. 2 Left: old plan of the Teverone Timia–Clitunno Meander (Source: Prefettura delle Acque Miscellanea, 84 XLIII.9, reworked by the authors). Right: a prospect view of the old Sportone di Maderno structure (Source: Archivio di Stato Roma)

The area affected by the low-water drainage includes parts of the municipalities of Campello, Trevi, Foligno, and Bevagna, involves the basin of the Clitunno River and its tributaries, and covers approximately 2,800 hectares. There is a particular hydraulic subjection in the area enclosed between the Rome-Ancona Railway, the main Teverone collector, and the Forma Vecchia, which is believed to be the site of Lake Clitorius. Historically, Lake Clitorius extended south of the Bevagna-Foligno line, and it may not have been a true lake but rather a series of discontinuous marshes formed by the waters of Marroggia, Clitunno, and Teverone.

As a demonstration of the historical complexity of water management in the Umbrian Valley, the Gallery of Geographical Maps in the Vatican Museums houses a beautiful representation of this area, which was



Fig. 3 **A** photos from different perspectives of the old intake structure under discussion (Source: Consorzio Bonificazione Umbra-CBU archive). **B** historical photos of the old work in 1925 (Source: CBU archive)

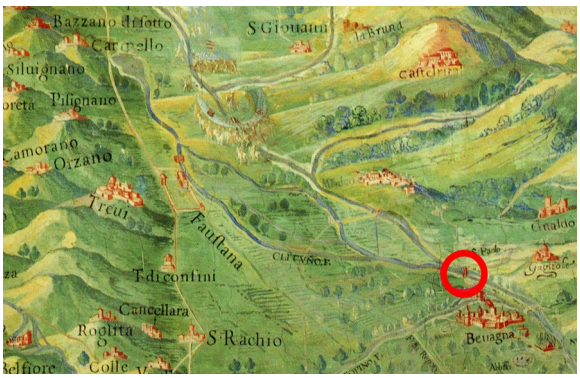


Fig. 4 Area painted by Ignazio Danti and the location of the Sportone di Maderno (source: A. Paolucci Ed. Musei Vaticani and reworked by the authors)

painted by Ignazio Danti between 1580 and 1585. This map illustrates the confluence of the low-water channel (Alveolo-Meandro) with the high-water channel (Marroggia Teverone Timia), which is marked by the red circle in Fig. 4.

As the needs of modern society evolve, particularly via increased urbanisation, the old hydraulic structure has required adaptation. Specifically, the flow regulation threshold, which had previously included both fixed and adjustable elements, was modified by lowering it by approximately 1.50 m and removing the regulatory mechanism. The new inlet, which was designed in 1985 and built in 1996 (Fig. 5), was intended to meet these updated requirements—namely, the elimination of regulatory components while ensuring the continued conveyance of 'low water' to areas that are now affected by urban development.

The project also achieved important objectives for the municipalities of the Umbrian Valley.

The Municipality of Bevagna optimizes its water flow to supply its two downstream mills and to improve the water quality of the right branch of the Clitunno River by diverting low-quality wastewater carried by the Alveolo channel. For the municipalities of Foligno and Trevi, the objective was to maximize the flow of 'low water' for the prevention of flooding.

To verify the effectiveness of these interventions, and considering the importance of modifying a hydraulic



Fig. 5 Above: photos showing the construction phases of the new structure. Below: photos of the completed structure (Source: CBU archive)

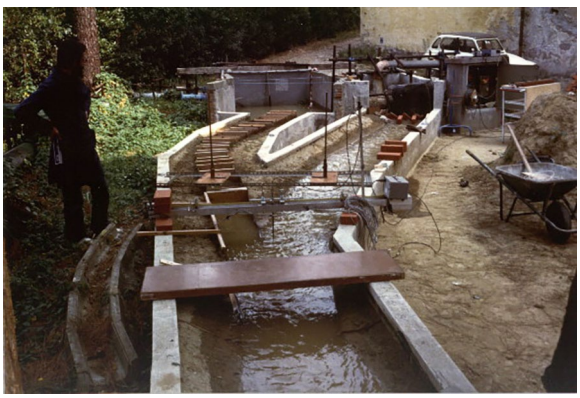


Fig. 6 Photo of the hydraulic model at the Engineering Department of the University of Florence (Source: CBU archive)

structure dating back to 1600 that regulated valley water drainage, tests were conducted on a physical model at the Department of Engineering of the University of Florence (Fig. 6). The two main points of analysis are as follows:

- Studying the backflow effect on the tributary during the flood of the container.
- Studying the tributary flood in the presence of a predetermined water level in the container.

From the results obtained, it was found that the confluence of the new drainage collector in Timia moved approximately 600 m farther downstream (Fig. 7A) than the old confluence at the Sportone di Maderno. This was done to gain the greatest possible elevation and in consideration of the presence of three small bottom drops in the Timia Basin, which have a total height of 1.50 m.

With the construction of the new inlet, rapid water flow (within 24–48 h) during floods and subsequent flooding events was achieved, in contrast to the previous situation in which the area transformed into a lake that remained for months. Therefore, the new inlet provides direct benefits for the regular functioning of activities in the area (such as agriculture, purification plants, waste composting plants, slaughterhouses, and the site of a former landfill) and consequently benefits all the inhabitants of Foligno, Trevi, Bevagna, and Campello.

Its effectiveness was demonstrated by the flood events that occurred in the years immediately following, which served as a real test of the system and resulted in an absolutely positive outcome (Fig. 7B).

The old hydraulic structure, the 'Sportone di Maderno', was decommissioned and is now preserved as a historical monument, like the nearby Torre di Montefalco, which in the past was used to control these reclamation works and the navigation on the rivers.



Fig. 7 **A** location of the new (red circle) and old (yellow circle) Sportone structures (Source: Google Earth Image, May 2025 and reworked by the authors). **B** photos of the new Sportone taken during flood events in October 1998 (Source: CBU archive)

2.2 Marmore Falls

In this central region of Italy, close to the paths and places that recall Saint Francis and Saint Benedict, lie the Marmore Falls, which are the highest falls in Europe. They feature three waterfalls with a total height of 165 m and a flow rate of 15 m^3/sec (Fig. 8).

The waterfall originated with the reclamation of the Piana Reatina and represents multimillennial hydraulic engineering work. Its construction began in Roman times and continued over the centuries (Lorenzetti 2021), with the aim of protecting Rome from floods and making a vast area, which was largely occupied by the 'Lacus Velinus', cultivable (Fig. 9).

The Rieti valley, part of the 'Lacus Velinus', is quite extensive, and it covers approximately 90 km^2 at an altitude of between 370 and 380 m above sea level. In 271 BC, the Roman consul Manlio Curio Dentato began the first reclamation interventions by cutting through the calcareous sediment barrier at Marmore to drain the lake and create fertile land.

Before the Roman intervention, the waters of the Velino River flowed freely into the Nera River across the entire width of the cliff. The construction of the Curiano canal lowered the water level in the Rieti plain, thus creating large areas that were suitable for agriculture. Additionally, by diverting the Velino River and its stagnant waters near the cliff, the Marmore Falls were formed, which concentrated the hydraulic flow at a single point. The Velino River, together with the Nera River, collects water from a large catchment basin of approximately 1,600 km^2 that flows into the Tiber River, Rome's main river. In the past, during seasonal floods, this caused devastating floods in the 'Eternal City'. To address these issues—which had been exacerbated by the construction of the Curiano canal and the Marmore waterfall—Romans built numerous lamination basins in the upper part of the waterfall's cliff. These basins, which were surprisingly advanced for their time, were equipped with bottom drains dug into the cliff. They still exist today, although they are no longer in use. To achieve hydraulic reclamation and flood regulation, further important works, such as a canal bridge and diversion channels, were built in the valley below. These works are still perfectly functional today, serving as an



Fig. 8 Photo of the Marmore Falls (Source: the authors, taken in May 2025)



Fig. 9 Extension of the ancient 'Lacus Velinus' (light blue area), which occupied much of the current Rieti valley (Source: Tozzi and Lorenzetti, Rieti e il suo territorio)

excellent example of effective artificial drainage and reclamation.

After the fall of the Roman Empire, these hydraulic works were neglected, and it took centuries to restore proper water management and functionality. The cliff of the waterfall, which is made of calcareous sedimentary travertine, gradually grew over time and formed new rock. During the Middle Ages, the initial rock barrier reformed, leading to a partial reconstitution of Lake Velino. Over the following centuries, through the late 18th century, restoration work was conducted on the waterfall. After numerous interventions and significant resource expenditure, the structure we admire today was ultimately restored. In particular, in 1422, Pope Gregory XII ordered the construction of a new canal to restore the original course. Later, in 1545, Pope Paul III commissioned another canal, and in 1598, Pope Clement VIII inaugurated the new structure. Over the next two centuries, the canal's presence caused problems for the surrounding countryside, as the Nera River often flooded the area. In 1787, Pope Pius VI ordered modifications to the jumps under the waterfalls, which gave them their current appearance and effectively solved most of these issues.

Today, in a beautiful natural setting, we can admire this extraordinary feat of human intelligence and operational capability, which is comparable in terms of engineering complexity and construction time to the great Gothic cathedrals. This artificial waterfall is a perfect example of the global value of water, as it has influenced many generations throughout its long history. The Marmore Falls have also inspired renowned artists and writers, including Leonardo da Vinci, with his drawing Landscape with River (Fig. 10), and Lord Byron, who, in the fourth canto of Childe Harold's Pilgrimage, described the falls as 'horribly beautiful'.

The Marmore Falls is an obligatory stop on the Grand Tour, influenced social and political development, served as the engine of scientific research and the use of water for energy purposes, and ultimately contributed to the development of sustainable and spiritual tourism. The history of the Marmore Falls has been characterized by three main periods: the first, which was the longest and most exciting, was dedicated to water reclamation and management to promote agriculture and ensure the safety of the area's populations (Ricci 2018); the second was driven by human pride as an engine of science and



Fig. 10 Leonardo da Vinci, Landscape with River, 1473 (Madonna et al. 2021) (Source: Florence, Uffizi Gallery, Gabinetto dei Disegni e delle Stampe—Department of Prints and Drawings)

the industrial revolution (Biscarini and Testa 2011); and the third, which was the most recent, was focused on attracting environmental and spiritual tourism to a territory that is unique in terms of both history and natural beauty (Falcetti et al. 2014).

The reclamation system is divided mainly between the upper part of the cliff, where the Rieti plain is located, and the lower part, which is in the Terni valley. The most significant technological element of the Rieti reclamation project is the pumping station at Lake Ripasottile (Fig. 11A).

The Ripasottile pumping station, which is one of 32 in the valley, is crucial for regulating water flow in the most depressed part of Conca Reatina. It works by pumping water from Lake Ripasottile directly into the Velino River to maintain the hydrostatic level of the lakes at approximately 2 m below their natural level. The reclamation system is completed by a complex network of canals and other hydraulic interventions, which are currently managed by the local reclamation consortium.

In the 1940s, two dams were built upstream of the Rieti reclamation area, with a total reservoir capacity of approximately 600 million cubic metres. These reservoirs are connected by an underground canal of approximately 9 km, which effectively enables the management of the two lakes as if they were one. A 50 MW hydroelectric plant uses the water of the reservoirs to produce clean energy. The Rieti plain ends near the Marmore Falls at Lake Piediluco, which is a remnant of the ancient Lake Velino. Lake Piediluco currently serves as a loading basin for the Galleto hydroelectric power station (Fig. 11B) and is also a site of high environmental value due to its landscape, pristine area, and lush nature.

The valley of the city of Terni, which is downstream of the Marmore Falls, is characterized by impressive hydraulic works and a complex system of canalisations that date back to Roman times. From an industrial perspective, the most notable element is the Galleto hydroelectric plant, which was built in 1929 and has an installed capacity of approximately 400 MW. This plant represents the final part of a complex hydroelectric system that is capable of producing approximately 300 GWh per year.



Fig. 11 **A** photo of Lake Ripasottile. **B** photo of the Galleto Monte S. Angelo Power Plant (Source: Lorenzetti R., Rieti e il suo territorio)

The entire 'Opera della Cascata' can be compared to the construction of medieval cathedrals in that it is remarkable for its hydraulic engineering, its thousand-year history, and its foundation of human ingenuity and effort—all while preserving the beauty of the landscape and the poetry of the surroundings. This approach, for which we should be grateful to the generations that preceded us, needs to be studied and explored for developing the mindset of future 'cathedral builders'.

2.3 Monte Pacciano reservoir

The Monte Pacciano reservoir in Perugia, which has a capacity of approximately 6,000 m^3 and is known as the 'Conservone', is part of an ancient medieval aqueduct. As of February 17, 1280, this aqueduct consisted of two miles of lead channels that fed the Fontana Maggiore in Perugia from Monte Pacciano (De Felice 1995) (Fig. 12).

In fact, in 1254, the city of Perugia was faced with completing the square located between the Cathedral and the Palazzo del Capitano (Palazzo dei Priori). This square was made magnificent by a fountain that was created by the



Fig. 12 Historical print showing the route of the Monte Pacciano aqueduct from the 'Conservone' (red circle) to the Fontana Maggiore in Perugia (blue circle) (Source: A. De Felice, L'antico acquedotto della Fonte di Piazza di Perugia, reworked by the authors)

Pisano workshop. This fountain, however, required pressurized water to reach its full splendor. Thus, the aqueduct was built, which was an element that later became vital to the city and its surrounding rural communities. It was developed several times beginning in 1254, and it was always a central part of both city life and the countryside because of the value of the water that it transported.

Considering its year of construction, the storage capacity of the Conservone was certainly important, and it served multiple purposes. The Conservone was primarily used to supply the Fonte di Piazza in Perugia (which is known as the Fontana Maggiore today). Additionally, it supplied water for agricultural use by small plots of land dedicated to fruit and vegetable production as well as for the many fountains along the route to the Fontana Maggiore, from which citizens drew water, animals were watered, and crops such as hemp were cultivated.

The work was quite large for its time, costing approximately 4,000 pounds of Ravenna denarii, which is equivalent to more than two quintals of pure silver in coins. In reality, the aqueduct was part of a broader system that included other structures that fed its flow. These included a drainage tunnel called the Barigiana, which crossed three hills; five springs that were connected and joined together; a tank of more than 6,000 cubic metres of rainwater collected and properly filtered from its basin; a collection and loading basin; and two support channels that were connected through tunnels following the limestone side of the hill.

The importance of this work is demonstrated by the fact that there are actually two tanks on Monte Pacciano: the older medieval tank and a more modern tank from the 19th century. Both tanks are located on the Monte Pacciano, approximately 5 km from the historic centre of Perugia.

The first is formed by two barrel vaults that are set on the two sidewalls and the central wall (with a thickness of 3.00 m) (Fig. 13A). The structure somewhat resembles the Roman cistern in Istanbul (143 m long and 70 m wide), which supplied water for the Imperial Palace and other important buildings in the historic centre of Istanbul—then named Constantinople—with a reservoir of 80,000 m^3 fed by an aqueduct that spanned several kilometres.

The second, which dates back to the early 1800s, is made up of cross vaults (Fig. 13B).

Together, these two reservoirs, along with other tanks and wells, formed part of the drainage basin of the Rio Torrent. This river provides water resources for agriculture, industry (such as hemp and flax weaving and other plants), drinking, and livestock. After travelling approximately 5 km, the Rio Torrent flows into the Tiber River.

From all this, it is clear that Perugia has not suffered from a lack of water since the Middle Ages. The Roman tanks, Etruscan wells, and emergency sources all testify

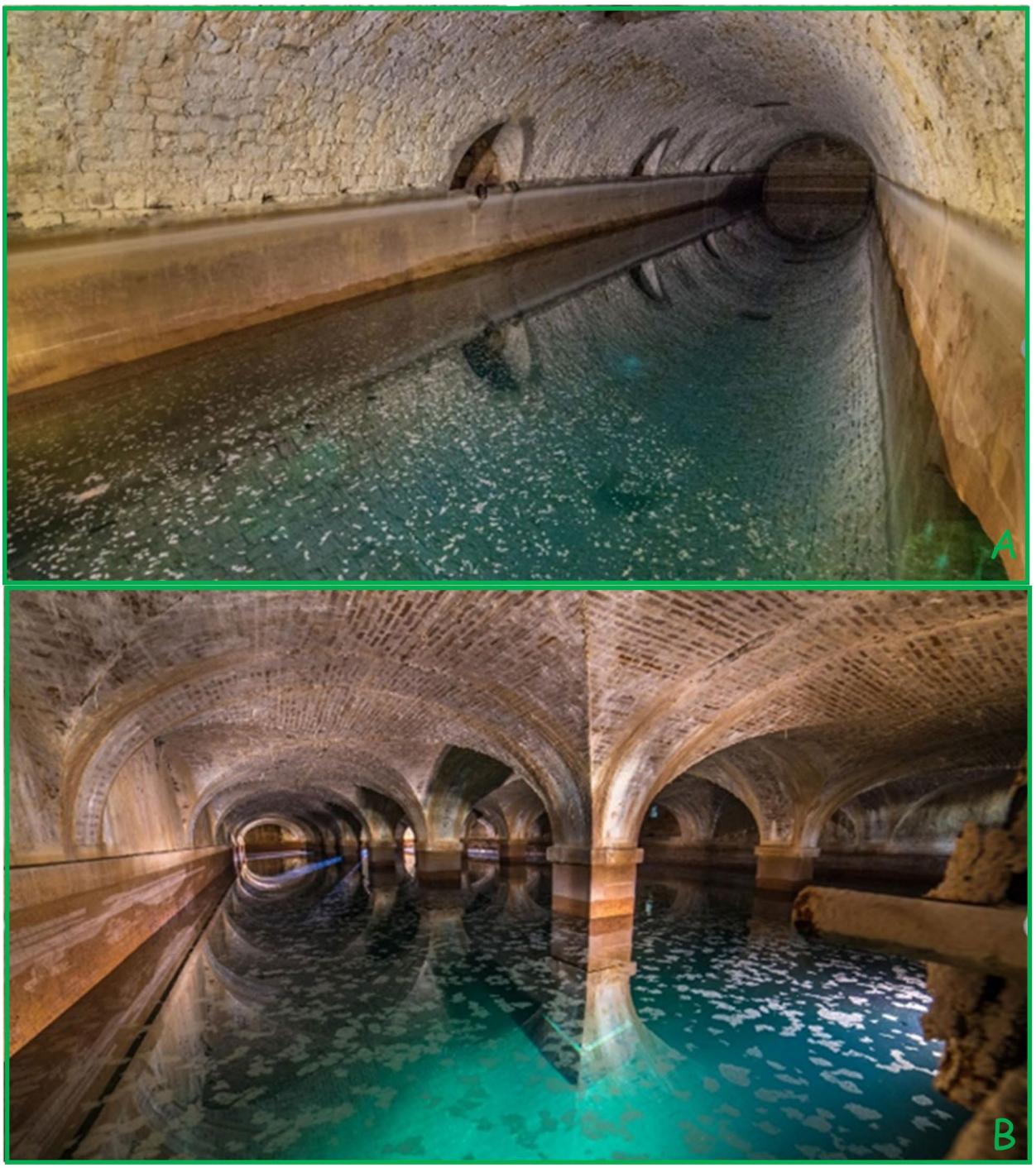


Fig. 13 **A** photo of the Medieval Reservoir, 1257. **B** photo of the 1800's reservoirs (Source: A. De Felice, L'antico acquedotto della Fonte di Piazza di Perugia)

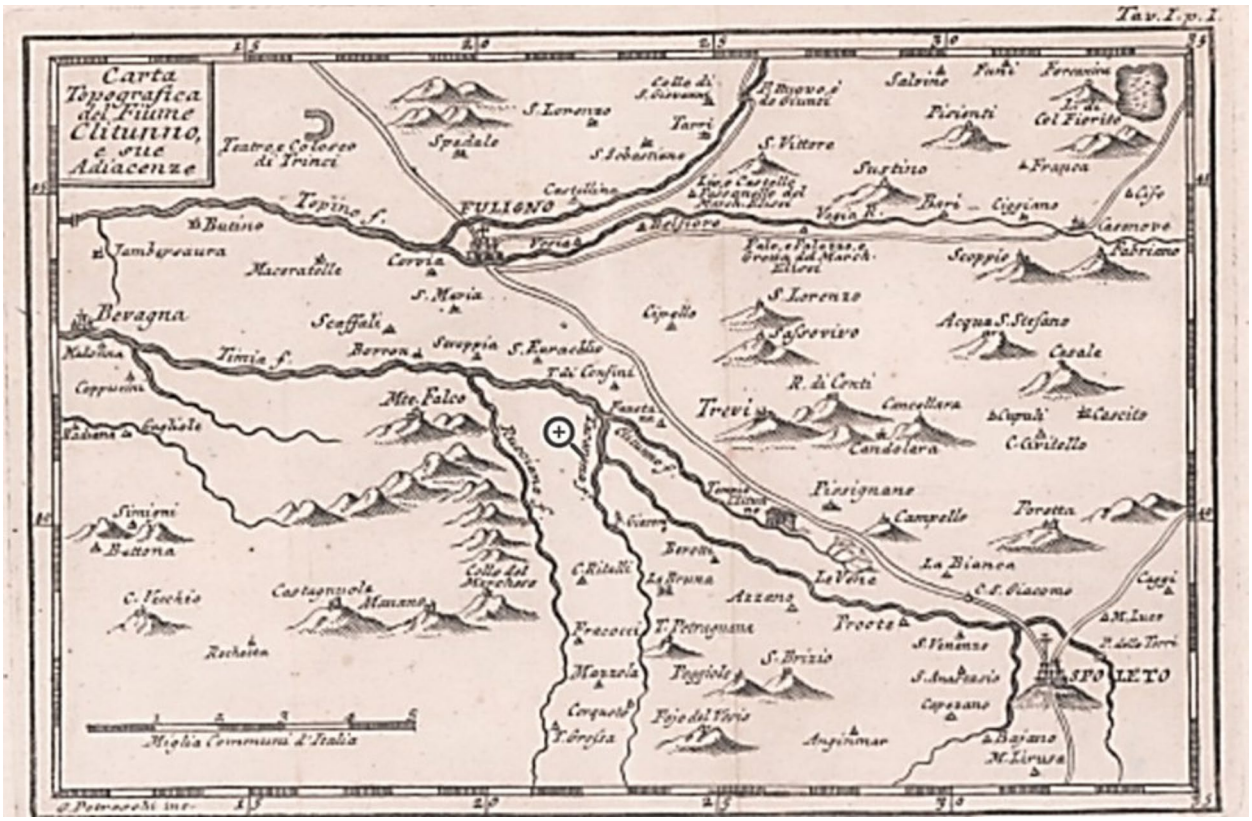


Fig. 14 Map of the Clitunno River by Giovanni Petroschi (Ridolfino Venuti Cortonese 1753) (Source: Venuti R. 'Osservazioni sopra il fiume Clitunno')

to the presence of important water supplies that ensure the city's security.

The oldest Conservone was accessed through a tunnel located in the stone house next to it, which was once the home of a farmer who also served as the custodian of the waters. Today, this building houses the Water Museum, which, precisely in the context of this study, is meant to be expanded into a research centre for lesser-known historical hydraulic works at the national and international levels. This expansion is aimed at deepening our understanding of their technical and social value and reevaluating their possible functions.

For example, by comparing works with similar structures, such as the Roman Cistern in Istanbul or the Piscina Mirabilis (12,000 m^3) in the Phlegraean Fields, and considering the proportion of the volumes of water stored to the population at the time, we find capacities of approximately 270 L per day per inhabitant for Istanbul,



Fig. 15 Left: photo of the Sources of the Clitunno. Right: photo of the Temple on the Clitunno (Source: the authors, taken in March 2025)

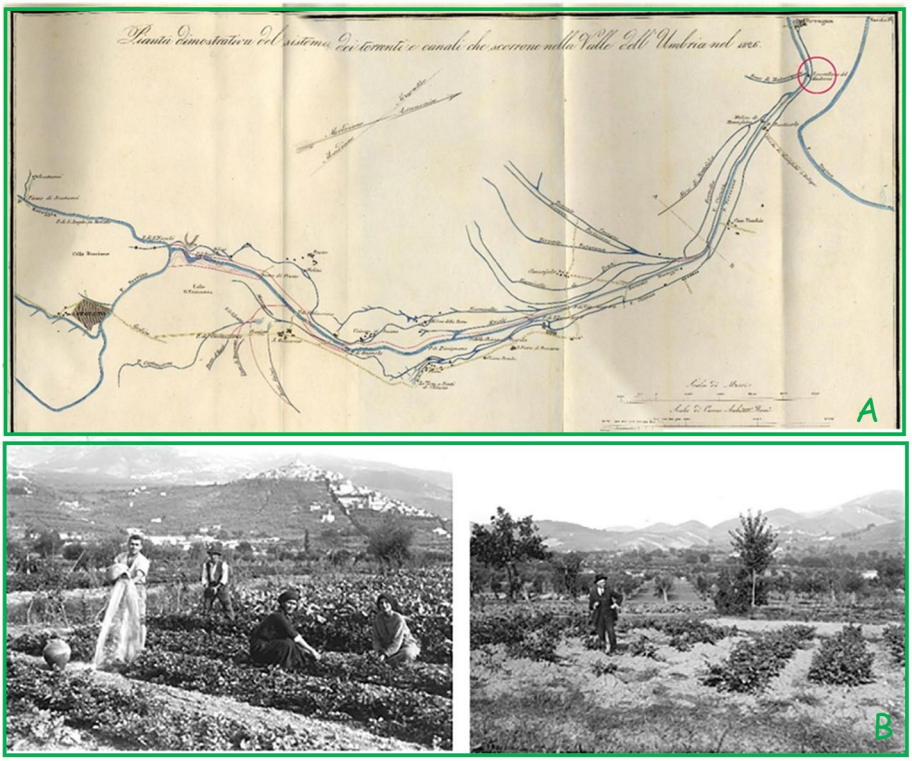


Fig. 16 **A** Historical map of the system of streams and canals that flowed in the Umbra Valley in 1826 (Source: Archivio di Stato Roma). **B** Historical photos of the cultivation of black celery in Trevi dell'Umbria (Source: Municipality of Trevi archive)

300 L per day per inhabitant for the Piscina Mirabilis, and 340 L per day per inhabitant for the medieval Monte Pacciano reservoir.

These data demonstrate a comparable capacity for the planning and estimation of overall water needs, which highlights the era's impressive ability to conceive and implement such significant works (which is perhaps also driven by powerful families' desires to demonstrate their influence).

The medieval aqueduct of Monte Pacciano was the city's main water source for nearly six centuries. However, in 1899, owing to ongoing operational and maintenance problems, a new aqueduct was built to carry water from the Bagnara springs in Nocera Umbra to the Monte Ripido Reservoir. However, owing to new connections made in the 20th century, the two 'Conservoni' have remained operational and have the potential to be integrated into Perugia's water distribution system. In emergencies, they provide a water reserve that is sufficient to supply the entire city for approximately eighteen hours in the winter and approximately six or seven hours in the summer.

2.4 Clitunno River and its history

The Clitunno River flows through the Umbrian Valley between Spoleto and Foligno, encompassing the urban centres of Trevi, Montefalco, Bevagna, Cannara, Spello, and other smaller towns in Umbria (Fig. 14).

Some of these cities have received UNESCO recognition as cities of art that preserve a cultural heritage, both for artistic and archaeological values (such as the ancient Roman Flaminia and the Tempietto del Clitunno) and for those linked to local and cultural traditions. One of the most significant examples of the 'continuum' of cultural heritage (Settis 2004) is shown in Fig. 15.

The historical link between water use and this territory is strongly represented by the dense network of canals that crisscross it, many of which still exist and are well preserved. The management of these canals also represents a unifying force underlying the way that people inhabit this area, where for example, the use of ancient communal mills—many of which are still relatively well preserved—has shaped the demographic structure of the settlements (Maurer 1953) (Fig. 16A).

The Clitunno River splits into two branches at Casco dell'Acqua. Before this division, the river widens enough to almost form a small lake, which was created with bulkheads that served to regulate the river's flow and feed the Casco dell'Acqua mill. The bifurcation of Casco dell'Acqua was created by humans through masonry and sluice gates, and the dam, which was built to regulate water distribution, forced the construction of a jump in the river, which is called a 'casco', and from which this area takes its name.

The main branch of the Clitunno (also called Clitunno-Meandro) continues towards Bevagna. As we have seen, the new Sportone Maderno, which directly regulates the flow of water from the Alveolo into the Teverone torrent, was created near this city. After these interventions, the Clitunno River was cleaner as it reached Bevagna, as it no longer received drainage water from the valley that was collected by the Alveolo or Alviòlo (which also collects water from the city housing Foligno's purification plant).

Notably, over the centuries, roman popes sent Rome's best architects and engineers to design the hydraulic system of the Valle Umbra. When Pope Leo XII della Genga intervened directly in the 19th century through a general reclamation operation, he followed the 'house and state' intervention model, giving ownership of the central mill of the system, which was near Trevi, to the Genga family.

Along the routes traced by the course of the waters, there are buildings of historical importance: the villa and the small villa of Faustana in Trevi, Umbria; the hydraulic siphon of the Casco dell'Acqua from the Renaissance; the mill and the tower of Montefalco; the site of the Sportone di Maderno; and the ancient dam of the mills of Bevagna. These sites are associated with the water exploitation activities that have occurred in this dense hydrographic network for centuries, such as the cultivation of particular vegetables, e.g., black celery in Trevi and red onion in Cannara.

From a cultural point of view, accurate historical reconstructions of medieval and Renaissance crafts, such as the Gaite di Bevagna, are conducted annually in the villages along with many other events meant to promote typical agricultural and artisan products. Recently, important mosaics were discovered in Pietrarossa, which is a town near Trevi. This archaeological finding testifies to the Roman history of the area and its close connection with the Clitunno River. These mosaics, which were found inside a Roman villa, reveal the economic and cultural importance of the territory during the imperial era.

The mosaics belonged to a Roman villa dating from between the first and second centuries AD, which was likely owned by an aristocratic family. It served as a centre of agricultural production and a residence. The mosaics are characterized by geometric motifs and stylized figures, demonstrating both a high level of artistic skill and the wealth of the owner. The decorations reflect the aesthetic taste of the time and the importance that was attributed to luxury and comfort.

The villa was located in a favourable position, being close to both the Via Flaminia, which was the main artery of the time, and the Clitunno River, which provided water resources and fertility to the surrounding fields. This demonstrates that the use of the waters of Clitunno for irrigation has been practised by the inhabitants of the area since ancient times.

The cultivation of 'black celery' in the Trevi plain represents excellence in ancient agricultural production (Fig. 16B). Here, it takes place in a narrow flat area of the Umbrian Valley, located between Borgo Trevi and Santa Maria di Pietrarossa with the Roman road Flaminia to the east and the Clitunno River to the west. This area is commonly called 'canapine', which is a toponym that most likely originates in the ancient cultivation of hemp in these lands.

The first evidence of celery cultivation in these areas dates back to the second half of the 19th century. In the municipal archive of Trevi, celery seeds were requested from the mayor in letters dated from 1889. The requests came from the Colonia Agricola Collegio degli Artigianelli della Badia di San Pietro in Perugia.

The Clitunno River also represents a historical resource for enabling motive power.

In the Middle Ages and later, the water of the Clitunno River was used to power water mills and other industrial plants. The mills were particularly important for the grinding of cereals, which served as essential food resources for the population. The river therefore not only provided agricultural resources but also resources for the premodern industry of the region.

There are five mills along the course of the Clitunno:

1. The Molino della Torre, located near the Torre di Montefalco, was used to exploit the waters of the Clitunno and is often mentioned in historical documents related to the area.
2. The Molino di Bevagna, which is located in the territory of Bevagna, is fed by the waters of Clitunno and represents an important centre for cereal grinding in the area.
3. The mills along the Canale dei Molini in Torre di Azzano, which used the water of an artificial canal derived from the Clitunno that powered various production activities, including a mill for grain and oil.
4. The Molino Nuovo in Trevi, which, although it was rebuilt in the 14th century, acts as a testament to ear-

lier milling activity along the Clitunno in the Trevi area and exemplifies a mill of considerable historical importance.
5. The mills in the area of the Clitunno Springs are no longer present but were likely located near the springs to exploit a more constant water flow.

To provide an idea of the energy produced at the time and its economic significance, some simple considerations are needed. Currently, a hydraulic turbine at Molino Nuovo produces approximately 200,000 kWh per year through the use of modern technology (Fig. 17A). To compare this with that of historical times, when the mechanisms of the mills were very rudimentary (Fig. 17B), it is reasonable to estimate a reduced production of approximately 80 percent in the past. Therefore, the old mill would have produced approximately 40,000 kWh per year. Assuming the same production levels for all five of the mills, the total would be approximately 200,000 kWh. This value would have played a significant role in driving the activities of the entire Valle Umbra.

The model of small hydraulic works on the Clitunno River is based not on the size of the structures but rather on their number. By replicating these small systems, it is possible to create extensive networks that offer greater efficiency in terms of environmental conditions and increased resilience to seasonal and climatic changes.

The result of this centuries-old relationship between humans and water has produced some of the most beautiful landscapes and territorial contexts in central Italy, where it is possible to find a 'continuum' that characterizes (Settis 2004) the specificity of Italian cultural heritage compared to that of the rest of Europe.

Currently, in Valle Umbra, the Consorzio della Bonifica Umbra provides drainage and irrigation services for the entire valley, continuously strengthening the ancient network of hydraulic works with new technologies such as sprinklers and precision irrigation. Some ancient mills, grinding flour with traditional stone systems, are still in operation, while those that are no longer in use are still preserved, including their machinery, hydraulic works, and buildings, which are sometimes converted for cultural activities. The hydraulic network of Valle Umbra is also enhanced through activities that are aimed at increasing our knowledge of it, such as the use of green cycle paths and the provision of training support for ecological tourism. These include the planning of a periodic calendar of historical and technical dissemination activities for citizens and tourists and the organisation of meeting places inside and near ancient buildings.

Another important aspect of the Clitunno River is its symbolism and religious significance. In ancient times, the river was associated with the cult of Jupiter Clitunno, who was a Roman deity worshipped along its banks. According to historical records, the waters of the Clitunno were considered sacred and purifying and were used in religious rituals. The presence of temples and altars along the river underscored this sacred connection. On a more contemporary note, these initiatives are aimed at raising public awareness of the importance of the sustainable yet modern management of this territory, which is carried out by figures and organisations with high technical and scientific expertise.

3 Discussion and conclusions

The examples presented in this paper represent a notable sample of the small hydraulic structures found in the upper Tiber River in the Umbria Region. These structures differ in purpose, history, and environmental and social value.

The Sportone Materno hydraulic system is an historical and still functional hydraulic work that is essential for water reclamation and flood control in the Umbrian Valley. While this structure has historical importance, its modern version continues to perform its hydraulic function. However, the modernisation of a physical structure should not cause us to forget its history. The original design by architect Carlo Maderno was aimed at meeting the dual needs of water resource utilisation for agriculture and as a driving force for industry while also reclaiming the Umbrian Valley between the cities of Spoleto and Foligno. This vision remains highly relevant today, but it presents ongoing challenges, as shown by the increasing difficulty in balancing environmental and social considerations with the construction of works that serve the goals of both water resource management and flood risk mitigation. Therefore, reconstructing the history and evolution of this work can serve as a moment of reflection within the broader public debate regarding the building of similar structures in the future.

The Marmore Falls, with its rich history and present-day significance, is a work of extraordinary complexity. Often, visitors are captivated solely by the breathtaking waterfalls proceeding from the Velino River to the Nera River, without fully perceiving all of its aspects. The current environmental beauty is actually the result of past environmental upheavals that, over the millennium, have affected the plains of Rieti upstream (Sabini) and the Terni downstream (Interamna), with repercussions dating back to Roman times, including flooding of the Tiber River in Rome. In the 20th century, the Marmore Falls were integrated into the Nera-Velino hydroelectric system, which was among the largest in Europe at the time of its construction. This raises a fascinating question: what would this entire area look like today without

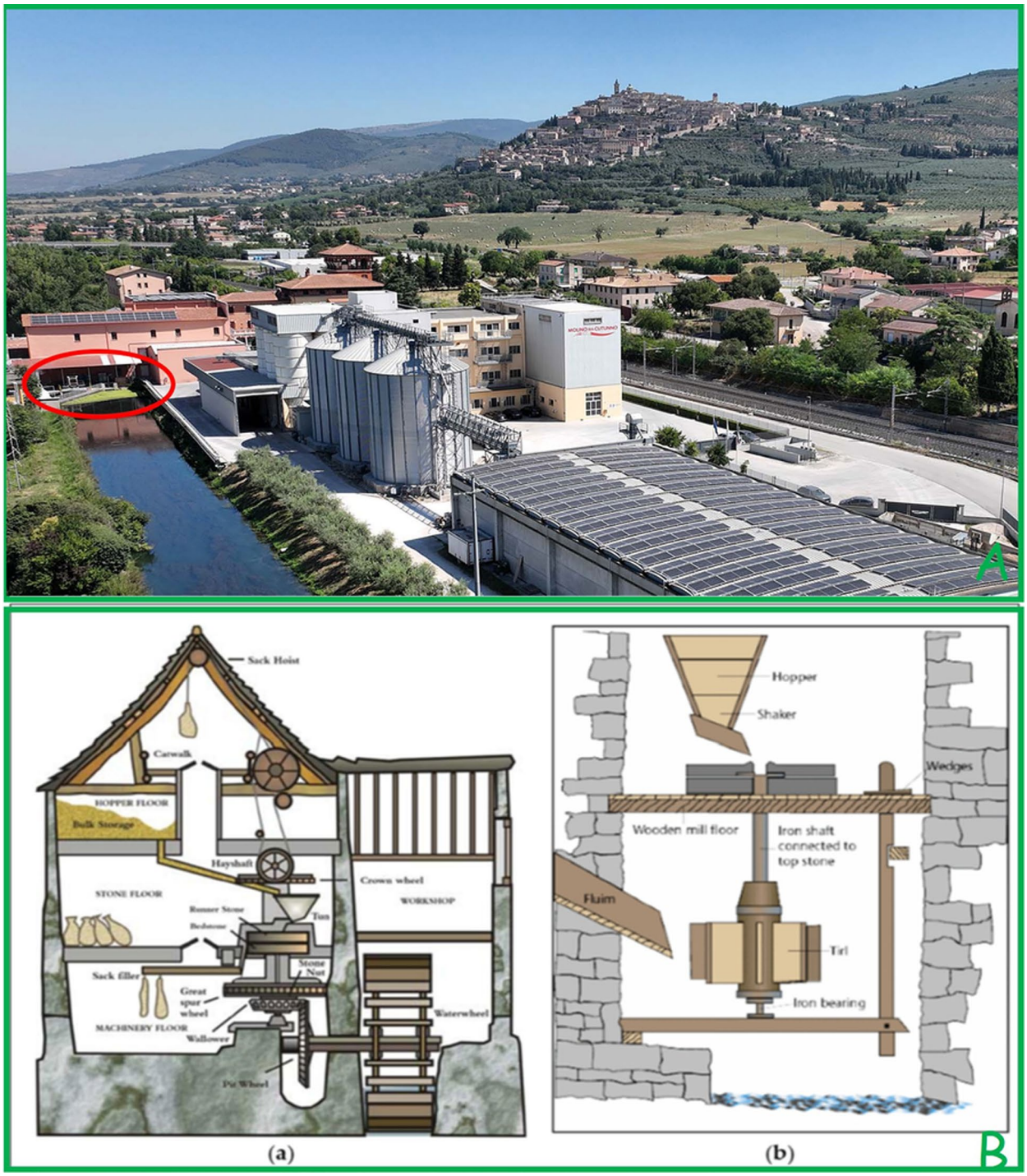


Fig. 17 **A** photo of the new mill on the Clitunno River (red circle) (Source: the authors, taken in May 2025). **B** basic types of water mills: (a) mills powered by a vertical water wheel, and (b) those equipped with a horizontal water wheel (Sources: Angelakis et al. 2022)

all of these human interventions? There is probably no definitive answer to that question, but it is clear that the socioeconomic development of these regions was heavily influenced by these works. Such works can be seen as an international model for addressing technical challenges—which were sometimes enormous relative to the times—and for understanding the long-term effects, which can span centuries.

The Monte Pacciano Reservoir is a testament to the importance of water storage reserves, which remains a very relevant topic today. It also highlights the remarkable efforts of the public administrators and technicians of the mid-13th century, who undertook demanding projects with limited available operational means, in a hilly area such as Perugia. Owing to the good preservation of the structures—which serves as an indication of solid construction skills—the Monte Pacciano reservoir remains a functional water storage tank. Although it is modest in size compared with modern tanks, it can still be used in emergency situations. The promotion of its management and conservation in the future is one of the goals of this article.

Along the course of the Clitunno River, not only were there hydraulic structures for irrigation and water flow regulation but there was also a society that developed in close relationship with the watercourse. The river was seen both as a primary resource for production activities and as a place of worship, thereby demonstrating a deep bond between humans and rivers. This cultural heritage deserves attention—not only for its historical and social value but also as a source of inspiration for current and future efforts to protect these places and their natural resources. The Clitunno River and its sources continue to demonstrate the immense resources that nature offers us. We must bear witness to this so that its beauty and history can be preserved for future generations.

In conclusion, the aim of this article is to highlight, through these four case studies, the rich heritage of small-scale hydraulic works in the upper Tiber region of Umbria. This heritage is valuable not only from a technical perspective but also from historical and social perspectives. By connecting these aspects, we can define a new approach to modern development that is no longer focused on a single sector (water, energy, agricultural production, or manufacturing) but rather on a holistic vision of the territory.

The development of this methodological approach can be tested over time to verify its tangible socioeconomic benefits. It can serve as an example of the increasingly careful and sustainable management of natural resources and the effective balancing of developmental and environmental needs.

For this reason, future developments of this study should be focused, on the one hand, on the technical and scientific research aimed at the restoration of small-scale hydraulic works, even those in poor condition, and their correlation with historical and social aspects. On the other hand, future studies should involve the expansion of the knowledge of this subject through the exploration of a larger sample of similar situations, maintaining close synergy with the World Heritage Irrigation Structures (WHIS) program of the International Commission on Irrigation and Drainage (ICID). The national committee, ITAL-ICID, should then promote this specific study approach within the small-scale hydraulic works sector.

Abbreviations

ICID International Commission on Irrigation and Drainage
WHIS World Heritage Irrigation Structures

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Giovannini, Barbanera and Fioretti made substantial contributions to the acquisition, analysis, and interpretation of data. Casadei and Venturi contributed to conception design. Casadei and Giovannini drafted the work. Biscarini, Casadei and Proietti contributed to the manuscript revisions. All authors read and approved the final manuscript.

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