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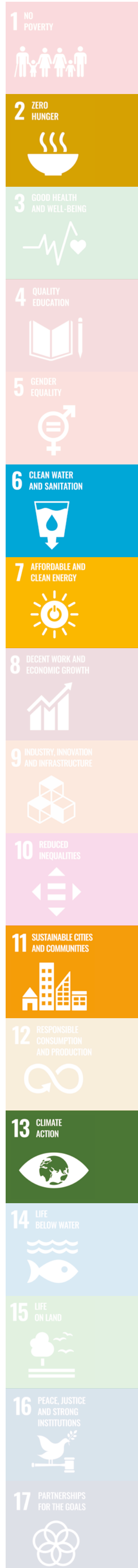


Water Management in a UNESCO Biosphere Reserve: The Village of Pampaneira at the Barranco de Poqueira Heritage Site

Luis José García-Pulido

Abstract

Recent changes in how water resources are managed in the Alpujarra – a vulnerable region on the southern slopes of the Sierra Nevada in Andalusia, Spain – are contributing to the degradation of formerly lush landscapes, which are now becoming increasingly arid under the pressure of global climate change. Poor water management practices risk pushing the environment beyond a point of no return, making recovery impossible unless the current climate emergency is addressed. It is therefore necessary to learn from the millennia-old culture and traditional processes of adaptation and resilience that have enabled communities in this region to thrive without overexploiting or depleting natural resources. This paper examines the village of Pampaneira, located in the Barranco de Poqueira, a heritage site within the Sierra Nevada UNESCO Biosphere Reserve. The village has historically practiced a unique and sustainable approach to water management, supporting human consumption, agriculture, daily activities, energy production and bioclimatic mechanisms established in the municipality.

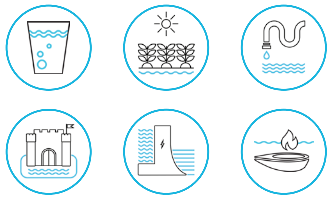
Policy Recommendations

- Promote sustainable water management in inhabited heritage sites to mitigate the effects of climate change and ensure environmental value and comfort for residents and visitors.
- Learn from the historical management of heritage systems in sensitive high mountain environments that adapted to available resources and minimized human impact. Draw on this knowledge to inform future practices.

KEYWORDS

UNESCO Biosphere Reserve
historical uses of water
Andalusian channels
bioclimatism
heat dissipation

WATER ICONS



CLIMATE

A B **C** D E

Csa: Mediterranean climate

< Fig. 1 Ravine from Castillejo de Poqueira; Pampaneira, Bubión and Capileira are in the background (Source: Luis José García-Pulido, 2021).

Introduction

Rising temperatures are making cities in southern Spain increasingly uninhabitable during the summer months. According to the Heat Action Day report by World Weather Attribution (Giguere et al. 2025), human-induced climate change has contributed to an average of 30 additional days of extreme and dangerous heat over the past year. This intensification of heat is particularly severe in urban areas due to the urban heat island effect. However, rural environments are also beginning to experience similar conditions, especially where traditional practices that once helped regulate temperature are being neglected or replaced.

Precipitation over the Iberian Peninsula shows significant variability across different time scales, as demonstrated by the evolution of annual accumulated rainfall from 1900 to 2010 (AEMET 2024). Since the 1960s, a noticeable decline has been observed in peak values, resulting in the most recent figures being the lowest in the historical record. The region has experienced an average temperature rise of 0.1 to 0.3°C per decade since the 1960s, with summer temperatures now more than 2°C higher than historical averages, largely due to climate change. Data from 1965 to 2010 indicates a consistent upward trend in annual average temperatures, especially since the mid–1970s.

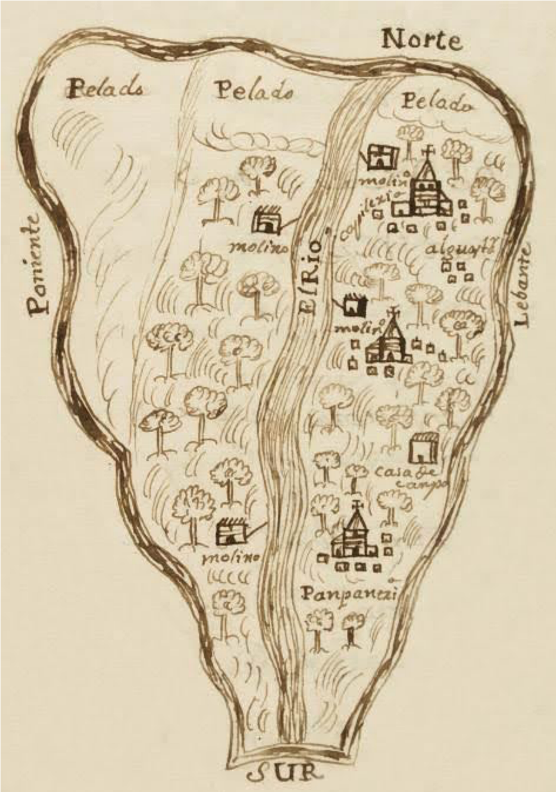
Rainfall data available since 1996 (Dirección General de Infraestructuras del Agua de la Junta de Andalucía 2024) illustrate the high variability typical of the continental Mediterranean climate in the Alpujarra region. Some years receive double or even triple the average rainfall, while the wettest years can receive up to nine times as much rainfall as the driest years. In any case, rainfall records for villages in this region show an increasing number of years with below-average precipitation since 2009–2010, which was the year with the highest recorded rainfall in the series. Consequently, the amount of water available on the region's slopes has been gradually declining.

In addition, reduced snowpack and earlier snowmelt have altered the hydrological regime, resulting in reduced river flows, vanishing springs and decreased freshwater availability. This affects both local ecosystems and downstream water users. These threats are giving rise to several additional challenges, including:

- The Sierra Nevada, a biodiversity hotspot, is experiencing severe impacts on its flora and fauna. Endemic plant species are especially vulnerable, with habitat suitability projected to decline by up to 80 per cent under severe climate change scenarios.
- The breakdown of traditional agricultural resource management systems leading to the deterioration and abandonment of terraces surrounding the villages and the landscape.
- Changes in water management tend to be appropriated and overexploited by large agricultural enterprises rather than small producers or the community as a whole.
- Surface water availability has been reduced, as water is often diverted through long pipelines instead of open channels that facilitate local consumption. This practice dries out normally humid areas and contributes to an increase in temperatures.

The Poqueira Ravine, a Cultural and Environmental Protected Area

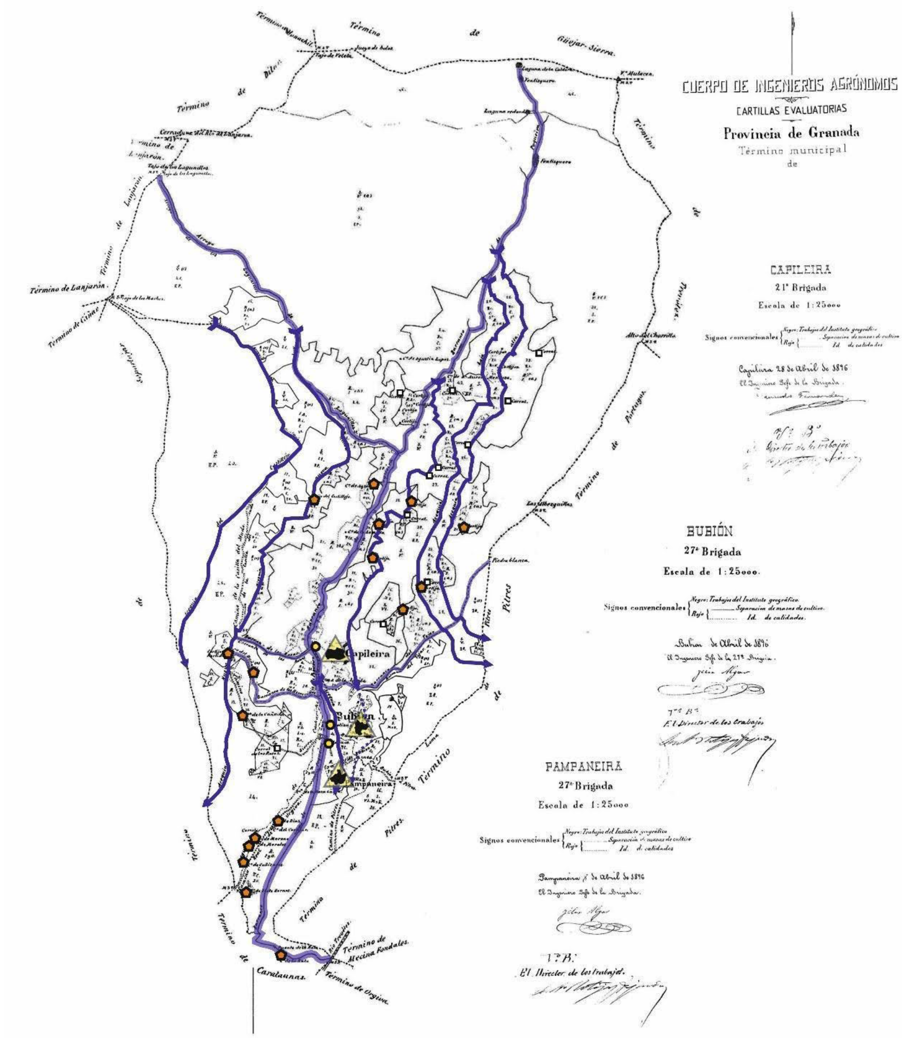
The Barranco de Poqueira heritage site (fig. 1) is located in the western Alpujarra region, just south of Mulhacén and Veleta, two of the highest peaks on the Iberian Peninsula (3,479



^ Fig. 2 Sketch of the Poqueira ravine included in the documentation of the Ensenada Cadastre from 1752 (Source: Instituto de Estadística y Cartografía de Andalucía. Archivo Histórico Provincial de Granada. Hacienda/Administración de Rentas Públicas/ Catastro de Ensenada. Libro 1046, f25r. CC BY 4.0).

and 3,392 m AMSL). The lower section of the Poqueira ravine, where the local population resides, lies within the Sierra Nevada Natural Park, a UNESCO Biosphere Reserve since 1986. In 1999, the upper section of the site (above 1,800 m AMSL) was also incorporated into the Sierra Nevada National Park. The Poqueira watercourse descends through a steep ravine dotted with pastures and scattered holm oaks (*Quercus ilex*), making it one of the most distinctive features of Spain's stratified mountain landscapes. Today, the entire gorge forms a part of the Natura 2000 ecological network. Human activity has played a decisive role in shaping the region's ecological and cultural diversity. The Natural Resources Management Plan (Plan de Ordenación de los Recursos Naturales, PORN 2011) for the Sierra Nevada National and Natural Parks recognizes the landscape as a fundamental part of both the natural and cultural heritage. The designation of the Historic Site of the Middle Alpujarra (Sitio Histórico de la Alpujarra Media Granadina y La Tahá) in 2007, along with the creation of the Inventory of Cultural Heritage of the Sierra Nevada (Inventario de Bienes Culturales de Sierra Nevada) in 2011, adds further layers of protection through varying levels of regulation. The Master Plans for Use and Management (Planes Rectores de Uso y Gestión, PRUG 2011) of the Sierra Nevada National and Natural Parks define the instruments and actions required to enforce protection, conservation and recovery of environmental and cultural values. In 1982, when Pampaneira, Bubión and Capileira, three traditional mountain villages located in the Barranco de Poqueira, were declared Sites of Cultural Interest (Bienes de Interés Cultural), their urban regulations were integrated into the management framework of the natural park. These provisions aim to preserve the historical integrity of the villages and safeguard the surrounding ravine landscape (Instituto Andaluz de Patrimonio Histórico 2016, 12–14).

Some of the village names in the Poqueira ravine – Pampaneira, Bubión and Capileira – suggest that settlements may have existed here as early as late antiquity. Others, now disappeared, are believed to have been established during the al-Andalus period (eighth to fifteenth centuries), when much of the Iberian Peninsula was under Muslim rule; these include Arrabal, Beniodmín, Alguazta and Benzeyt (Trillo San José 2014, 37). All the settlements were located on the eastern slope of the Poqueira ravine (fig. 1), where the terrain is less steep and receives more sunlight from the west.



^ Fig. 3 Montage of the maps of the municipalities of Pampaneira, Bubión and Capileira (yellow triangles), showing the main irrigation channels (dark blue), farmhouses (*cortijos*, orange pentagons) and farmyards (*corrales*, yellow circles) (Source: Instituto de Estadística y Cartografía de Andalucía. Gerencia Territorial del Catastro de Rústica de Granada [folders of Pampaneira and Bubión, Busquistar, Cañar and Capileira]. Authors: Eduardo Fernández [Pampaneira] and Félix Algar [Bubión and Capileira], 1896).

A hydraulic system, likely dating to the tenth or eleventh centuries, has survived to the present day, largely due to continuous use and maintenance by the local population. Although it gradually expanded over the centuries, significant degradation has only occurred in recent decades. A shared irrigation channel, known as the Acequia de los Lugares, connects the villages within the ravine, running just above them as it descends the slope (fig. 3). Of the three villages, Pampaneira lies at the lowest altitude in the Poqueira ravine, between 1,130 and 1,040 m AMSL. It features a unique and sustainable water management system, presenting an exceptional case of utilizing water and other methods traditionally employed on these mountain slopes to regulate

^ Fig. 4 Water running slowly in an acequia alongside the fast current riverbed downstream of the Poqueira ravine (Source: Luis José García-Pulido, 2025).

temperature and protect humans and animals from excessive heat. The techniques are both passive (use of water and vent flows, orientation of the municipality and materiality of the buildings), as well as active (infiltration in the aquifers, regulation of fountains inside the municipality, conduction of surface water, creation of fixed shaded spaces, such as porches and passageways, and temporary ones such as trellises and communal awnings). Analysis of these systems allows for a better understanding of why their conservation is a priority and how their methods can be applied in other municipalities. Pampaneira receives water from two irrigation ditches, which enables to replenish and sustain several natural springs within the hamlet. In addition, it is the only village in the Alpujarra that still allows the excess water from these springs to flow through the streets in open channels, separated from the sewage systems, rather than having it run through pipes. The moving water provides the village with a bioclimatic device shared by the entire community, while contributing to its sensory, acoustic and optical well-being.

In the past, the settlements in the Barranco de Poqueira obtained their drinking water from fountains fed by irrigation channels that ran above the population centers. This suggests that the canal system may have been constructed after the villages were first established (Delaigue 1995, 144). The name Pampaneira is derived from the Latin word *pampinarius*, meaning "land of vines," referring to a type of dry crop likely cultivated during the village's foundation in late antiquity. During the Islamic period, however, these dry crops were replaced by irrigated agriculture. The introduction of terraced cultivation around the village enabled the integration of orchards within the settlement, helping to moderate local temperatures. Water for these gardens was supplied by diversion channels or by overflow from nearby springs.

The highest channels collect water from snowfields or high-altitude springs. As the water descends the slopes, it travels along irrigation channels that pass through areas with cracks in the walls or permeable soils. In these sections, water seeps through and infiltrates the ground, contributing to the recharge of underground aquifers.

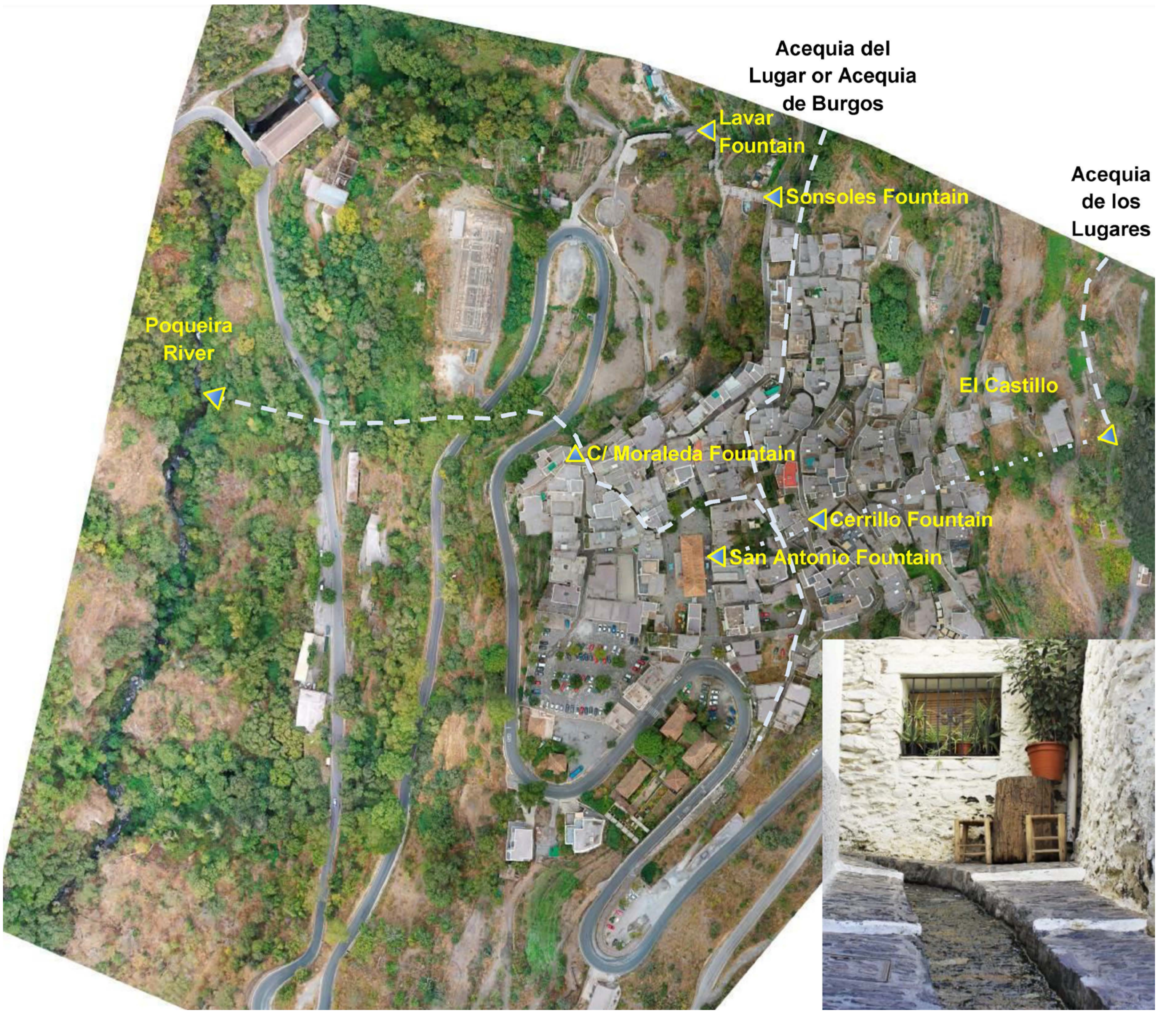
This technique of replenishing water tables, known in the region as *careo*, is still in use and promotes the growth of vegetation and pastures, slowing the transit of water from the peaks to the bottoms of the valleys. With this method, it is possible to maintain the flow of springs downhill during periods of low water levels and increase the concentration of salts in the water, thereby improving its quality for consumption (Pulido-Bosch and Sbih 1995). This water management is a clear example of symbiosis between humans and their environment, as its maintenance is essential for conserving soil, vegetation and fauna (Plaza-García and García-Rubia 2010). It is an ingenious aquifer recharge system developed over centuries (Martos-Rosillo et al. 2019, 1–4). It regulates the transit of water from the high mountains to the sea, raising the water table from the bottom of ravines and valleys to the slopes, which would otherwise dry out quickly once the dry season (from May to October) begins.

The Unique Use of Water in Pampaneira

During the Nasrid period (part of the al-Andalus era between the thirteenth and fifteenth centuries), the area experienced considerable economic and social development, largely due to its agricultural wealth and thriving silk industry (Padilla Mellado 2019, 56–60). After the Alpujarras Rebellion (1568–1571) and the subsequent expulsion of the Moriscos (former Nasrids, who were forced to abandon their religion, language and traditions), Christian settlers arrived in the region from various parts of the Iberian Peninsula. In general terms, they continued the sustainable water management practices and bioclimatic architecture. The regulation, use and maintenance of the network of irrigation ditches (fig. 4) continued and even expanded, with new *careo* channels that contributed to retaining water on the slopes instead of letting it rush down the ravine after the thaw. Diversified crops were reestablished, in contrast to other regions where monoculture eventually prevailed, a consequence of the hydraulic network and land arrangement established during the Islamic period. Natural springs were continuously maintained, and their recharge was supported through the use of *careo* water channel systems. The increase in the use of this snowmelt catchment in the modern period, especially in the seventeenth and eighteenth centuries, could be related to the greater cooling experienced during the Little Ice Age, when the snow on the high peaks of the Sierra Nevada became perennial again.

This relationship with water is not only evident in agricultural and hydrological systems but is also embedded in the Pampaneira's urban layout, which facilitates the flow of water into the very heart of the village (fig. 5). The most significant hydraulic structures are connected to different water sources linked to the infiltration system from the Acequia de los Lugares, coming from Capileira and Bubión. Additionally, the Acequia del Lugar, also known as the Acequia de Burgos, runs directly into Pampaneira, possibly marking an upper boundary of the village. Today, this hamlet is the only settlement that has maintained excess water flow from the fountains through its streets without covering the water course. This helps maintain a fresh and humid environment in summer, while in winter, the quick evacuation of water reduces humidity problems caused by water infiltrating the area under the houses. To the west of the village, the water flows into the Poqueira riverbed, which is surrounded by riparian plants, blackberries, chestnut trees and pastures.

The settlements of the Alpujarra region typically developed around one or more springs, which were often valued and even ranked based on the quality of the water or their specific uses. In Pampaneira, several sources can be found (Baena Fernández 2009, 303–8), each serving different functions. Some springs are used for drinking water. The main one is located at the San Antonio Fountain (1,060 m AMSL), which



^ Fig. 5 Aerial view of Pampaneira with the main water sources and the routes of water on the surface and underground (Source: Luis José García-Pulido, 2024).

has three spouts and is next to the church and the site of the former mosque (Castillo Martín and Sánchez-Díaz 2006). Other springs are used as washing places. The Cerrillo Fountain (1,080 m AMSL) has four spouts that pour water into a small basin below (Robles-Arenas 2009) and feed the Lavadero del Cerrillo, a washhouse elevated on a podium above the hamlet (López-Osorio et al. 2020, 403–4). The Lavar Fountain (1,040 m AMSL) has also been used as a washing site and is located to the north of Pampaneira, in a small ravine (Sánchez-Díaz and Peinado Parra 2015). There are also springs with mineral-medicinal properties. The Sonsoles Fountain (1,065 m AMSL) is divided into two individual terraced springs. The water flowing from its spouts is slightly ferruginous and carbonated. Next to it, there is another source with normal mineralization (Castillo Martín and Sánchez-Díaz 2006).

The point where all these springs are recharged is located above Pampaneira, in the area known as El Castillo ("The Castle," 1,150 m AMSL), a name that likely refers to a historical site of control over this vital hydraulic resource.

Today, the modern water tank that supplies drinking water to the entire village is filled from this same irrigation channel, highlighting its continued importance for the settlement's survival. However, the future of this ancestral water system faces significant challenges due to declining rainfall, reduced snowfall and increased evaporation driven by rising temperatures. In addition, the overexploitation of local water resources in other Alpujarra's areas, especially through intensive monoculture and groundwater extraction for commercial greenhouses, is leading to the collapse of traditional systems that had remained sustainable for centuries. It is therefore urgent to preserve and maintain these networks, both to prevent further degradation and to ensure that they can continue to be used sustainably in the future.

The surplus water mixes with the flow from the irrigation ditch. It continues along open channels running through various main streets of the village before exiting the municipality and heading toward the Poqueira River. Downstream, it passes beneath a more recent infrastructure development: the Poqueira Ravine Hydroelectric Power Plant, built in 1957. Its intake point is located at 1,520 m AMSL. From there, the diverted channel runs approximately 6 kilometers along the eastern slope of the ravine until it reaches a reservoir situated above Pampaneira at 1,502 m AMSL. The water is then released through a pressurized pipe to 952 m AMSL, where the engine room of the Pampaneira Power Plant is located. This facility generates electricity for the entire population of the valley (García Moreno and Arredondo Garrido 2007). In the future, the industrial use of water in the hydropower plant should be combined with efforts to replenish the aquifers around the municipalities, rather than returning it directly to the river.

Conclusion

The communities of the Poqueira ravine still benefit from a hydraulic system that has transported water to the upper edge of the urban area for over 1,000 years. As this water descends the slopes through irrigation ditches and terraced fields, it promotes infiltration, reduces surface runoff and limits soil erosion, helping to prevent landslides. Within the villages, the water continues its journey, supplying fountains, feeding washhouses, flowing through streets and ultimately draining into nearby hydrological basins. This dynamic system exemplifies the principles of "integrated aquifer management" (Vivas et al. 2009) within a living cultural heritage landscape. The history of the management of these hydraulic systems allows us to understand how this management has been carried out in harmony with available resources and the populations' adaptation to their environment, minimizing human impact in these sensitive high mountain areas.

Despite growing tourism and environmental pressures, Pampaneira has managed to preserve its unique character and its historical connection to water. Keeping the full hydraulic cycle active, from snowfields to channels, terraced fields, aquifers, urban fountains and ultimately to the Poqueira River, ensures that water is retained in the highlands during the dry season. This, in turn, helps cool the ecosystem, allowing a wide variety of plants and animals to thrive. Distributing water across the slopes instead of at the bottom of the ravine also provides another benefit in summer, as evaporation contributes to cloud formation. Ultimately, rain from those clouds and storms over the mountains restarts the water cycle. However, pressures on the system are intensifying as reduced rainfall, declining snowpack, increased evaporation, and overexploitation by commercial agriculture and wells threaten both water availability and the traditional resilient management practices.

Preserving this ancestral network requires recognizing the human dimension of water governance. The role of the irrigation communities, and in particular of the *acequiero*, or channel keeper, is essential, along with the role of environmental groups, researchers, Sierra Nevada National Park technicians and local initiatives of municipal authorities. Equally important is the intergenerational transfer of traditional agricultural knowledge and land-use practices, to prevent the adoption of intensive or harmful practices that overexploit and deplete the system. In a region where tourism is a major economic driver, promoting greater awareness of the shared responsibility for water resources among visitors is also important. Active policies are required at all levels for the local actors involved in their use to safeguard and promote the sustainable use of these resources, ensuring that these systems can remain interconnected and flexible, and preventing overexploitation of the aquifers.

Ultimately, the protection and sustainable management of these heritage water systems offer one of the most immediate and locally controlled strategies for adapting to climate change, particularly in the face of reduced water resources and increased pressure for their exploitation. The continued use of this hydraulic system demonstrates how human societies can live in balance with their environment, drawing on centuries of knowledge.

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