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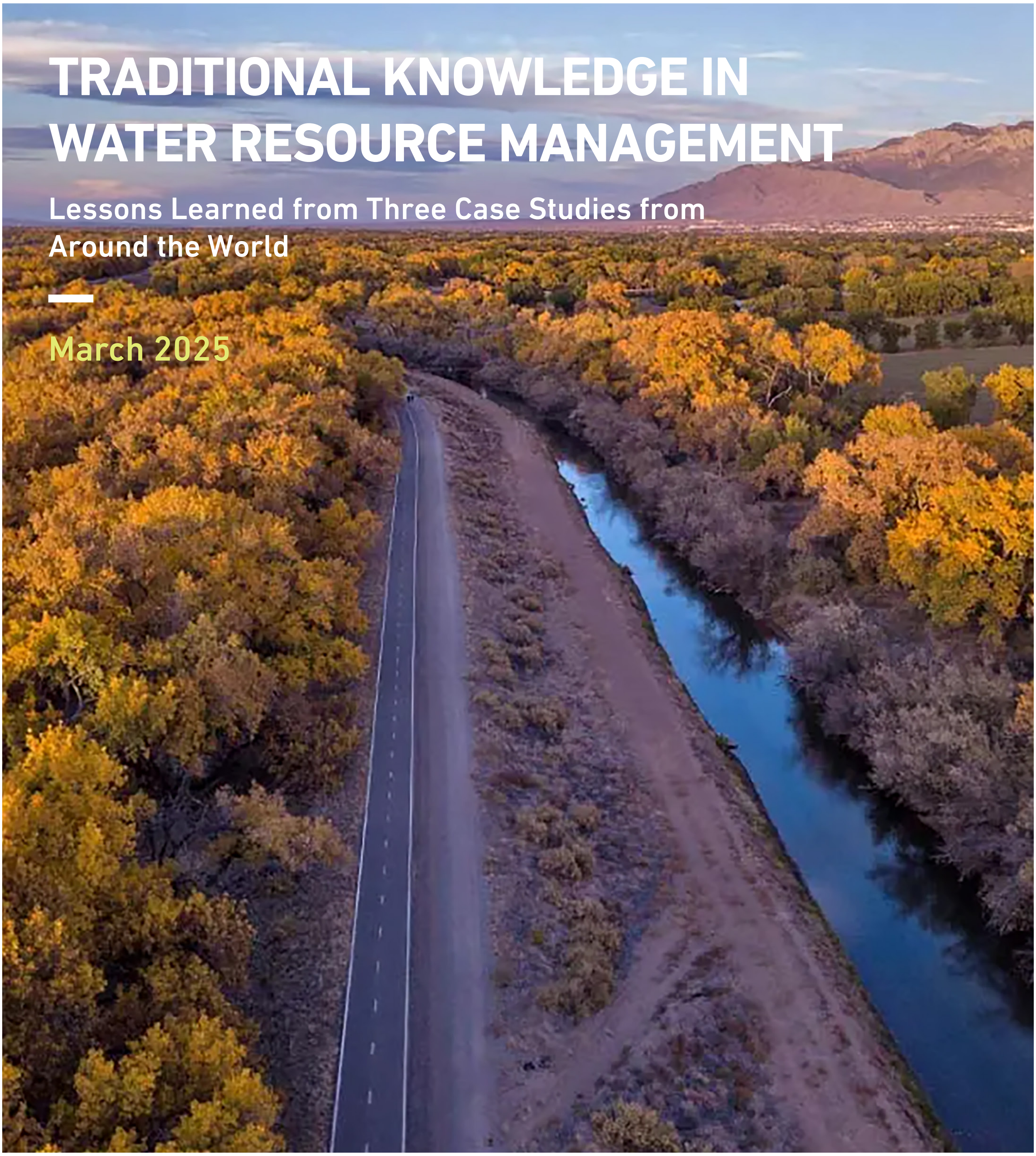

TRADITIONAL KNOWLEDGE IN WATER RESOURCE MANAGEMENT

Lessons Learned from Three Case Studies from Around the World

March 2025

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Member of Qatar Foundation

Traditional Knowledge in Water Resource Management

March 2025

About Earthna

Earthna Center for a Sustainable Future (Earthna) is a non-profit policy, research, and advocacy organization, established by Qatar Foundation to promote and enable a coordinated approach to environmental, social, and economic sustainability and prosperity.

Earthna is a facilitator of sustainability efforts and action in Qatar and other hot and arid countries, focusing on sustainability frameworks, circular economies, energy transition, climate change, biodiversity and ecosystems, cities and the built environment, and education, ethics, and faith. By bringing together technical experts, academia, government and non-government organizations, businesses and civil society, Earthna fosters collaboration, innovation, and positive change.

Using their home - Education City as a testbed, Earthna develops and trials sustainable solutions and evidence-based policies for Qatar and hot and arid regions. The organization is committed to combining modern thinking with traditional knowledge, contributing to the well-being of society by creating a legacy of sustainability within a thriving natural environment.

For more information about Earthna and to stay updated on our latest initiatives, please visit www.earthna.qa

Report Author's

Dr. Deema Almasri,
Earthna, Qatar Foundation,
Doha, Qatar

Ali Aissaoui,
Leuphana University of Lüneburg,
Lüneburg, Germany

Shahd Enizah
Georgetown University in Qatar
Doha, Qatar

Editorial Board

Expert Reviewers

© Earthna 2025
P.O. Box: 5825, Doha, Qatar
Telephone: (+974) 4454 0242; internet: www.earthna.qa

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Executive Summary

Traditional knowledge and practices, including traditional knowledge holders' holistic perspective on community and environment, are a key resource in adapting to climate change. However, these have not been consistently considered in current adaptation efforts. Earthna is committed to ensuring traditional knowledge is maintained as well as supporting the integration of this form of knowledge with existing practices to enhance the efficacy of adaptation while ensuring ownership is with the knowledge holders.

Water is the core of life, shaping cultures and fueling economic development. Effective water resource management and conservation are vital for arid and semi-arid environments as they help combat desertification, adapt to climate change, and safeguard the health and wellbeing of communities. Accordingly, this report emphasizes traditional knowledge in water resource management as an initial study. Focusing on three case studies—Aflaj in Oman, acequias in Spain and the Southwestern United States, and qochas in Peru —this report elucidates how these traditional practices and knowledge holders address modern environmental challenges.

The ancient irrigation channels in Oman, for example, currently encounter challenges due to climate change, pollution, urbanization, and groundwater over-pumping. In 2017, the government of Oman released the Aflaj Regulation and Protection Law to organize and safeguard Aflaj sites on the United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage List - a commitment to preserve these traditional networks.

Another community-managed irrigation system, the acequia, currently struggles to cope with the impacts of climate uncertainty, inadequate maintenance due to the limited number of knowledge holders, and urbanization. The role of local organizations and the government in maintaining their development is discussed.

In Peru, the qochas are vital for harvesting water in the high-altitude of the Andean Mountains. This practice struggled to persist within the land as well as the community. However, the Climate Change Adaptation Program (PACC), launched by the Peruvian government and the Swiss Agency for Development and Cooperation (SDC), served as a catalyst for revitalizing the development and maintenance of qochas within the region.

To incorporate these practices into modern strategies, policymakers must recognize the significance of traditional knowledge, support community-managed initiatives, ensure that mechanisms are in place for traditional knowledge holders to maintain their rights to intellectual property, and develop legal frameworks to safeguard traditional knowledge. The integration of modern scientific approaches with traditional knowledge could greatly enhance climate adaptation and mitigation efforts in a region. Traditional knowledge empowers local communities by providing them with control over their resources as well as provides them with ownership of the management of their local ecosystem and environment.

Background

For centuries, traditional knowledge and practices played a crucial role in helping communities adapt to a changing environment, particularly in arid and semi-arid regions. The products of traditional knowledge are not only a testament to the resilience of human civilizations in the past but serve as a critical resource for modern efforts to adapt to environmental changes. However, this canon of traditional knowledge and practices of knowledge holders currently lacks global and local support from policymakers, scientists, and civil society.

Traditional knowledge, including various forms of nature-based solutions are being increasingly recognized in sustainability policy discussions. The Convention on Biological Diversity signed in 1992, and the adoption of the Declaration of the Rights of Indigenous Peoples in September 2007 have renewed calls for inclusion of traditional knowledge and practices in decision making processes, specifically in managing natural resources and developing climate change policies. The Local and Indigenous Knowledge Systems (LINKS) was founded by the United Nations Educational, Scientific and Cultural Organization (UNESCO) in 2002 as an intersectoral initiative. It has been designed to bridge the gap between traditional knowledge holders and environmental policymakers to configure an overarching version of multidisciplinary knowledge Current efforts are being led by organizations such as the Commonwealth, UNESCO, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), and The Food and Agriculture Organization of the United Nations (FAO).

Following the launch of Earthna during its inaugural summit in 2023, and in line with Earthna and QF's commitment to sustainability and community development, centered on values and cultural heritage, traditional knowledge is a priority area of focus for the center. Earthna has developed a policy and research track aimed at understanding and promoting the value and relevance of lessons from traditional knowledge and knowledge holders for sustainability policymaking. As part of this workstream, Earthna also launched the Earthna Prize in 2024. It is an initiative aimed at celebrating and supporting projects and actors that are working towards the preservation, integration, adaptation, and adoption of ancestral knowledge and cultural heritage in addressing contemporary environmental challenges. The Prize has four focus areas, one of them being Water Resource Management. It will run on a biennial cycle, with prize of $1M USD shared among four winners. The winners of the first cycle will be announced during Earthna Summit 2025.

This report is the first of a series that aims to shed light on some important traditional knowledge and practices, highlighting their contemporary application, and providing recommendations on mechanisms for their integration into curating policymaking.

It explores traditional knowledge and practices pertaining to water resource management. Water will be the initial focus of the study due to it being the essence of life and the major reason why societies migrated to certain areas and built civilizations. In addition to sustaining life, water was, and is, a mode of transportation and a source for food for communities all over the world (Swain et al., 2006). The focus will primarily be on hot and arid regions but will also include countries where considerable ethnographic knowledge has been amassed from past research.

Traditional knowledge in water resource management is rooted in the development of many ancient civilizations regardless of their size and sophistication. Hence, many countries with rich historical backgrounds possess several traditional water management techniques. A list below highlights a few of these traditional methods:

Traditional Water Management Technique	Selected Example Region
Aflaj	Oman
Acequias	Spain, Southwestern United States
Qochas	Peru
Clay pot irrigation	Ethiopia
Qanats	Iran
Aqueducts	Jordan
Rainfed terrace systems	Yemen
Khettaras	Morocco
Sand dams	Namibia, Tanzania
Zai pits	Mali, Morocco, Burkina Faso
Fog harvesting	Chile, Peru, Morocco
Bamboo irrigation	India
Dujiangyan irrigation system	China

This report will discuss the Aflaj, the Acequias, and the Qochas. For this report, these were selected based on availability of research and to maintain brevity, not due to any ranking of importance. By examining these practices, we can understand their current relevance, the existential challenges these practices face, the reasons behind these challenges, and the local and global efforts needed to preserve them. Lessons learned from these case studies will be captured to inform future policy adaptations.

1 Traditional Knowledge

"Traditional knowledge" is a term that is commonly used interchangeably with "Indigenous knowledge". It is the sum of knowledge and practices developed and preserved by societies with a vast history of interaction with the natural environment. Traditional knowledge serves as the foundation for contextual, local decision-making for the survival and development of a community when handling day-to-day aspects of life. This includes water and food detection, collection, and storage; treatment of ailments; identification and prediction of meteorological and climate events; craftsmanship of materials and tools; land and sea navigation; management of relations between people and the ecosystem; adaptation to environmental and social changes, to name a few (International Council for Science, 2002).

The repercussions of climate change, like droughts, temperature rise, and environmental degradation have pushed us to reconsider our current relationship with nature. According to a recent publication by (Saif Al-Ghafri et al., 2023), throughout the course of history, traditional or indigenous knowledge has gone through several existential phases. The first phase included the sole governance of traditional knowledge and the only means available for humans to understand the world. The second phase is sought to happen with the rise of positivist science, or science based on empirical data and observable methods, that made traditional knowledge appear as a subjective, irrational, and outdated form of human reasoning (Nakashima, 2015). The third phase, which could be identified as the current phase, has a more postmodern approach in which current civilizations were faced with the consequences of disconnecting science from nature (Nakashima, 2015; Saif Al-Ghafri et al., 2023).

Traditional and indigenous knowledge has existed since the dawn of humanity. However, what is new is the growing interest by scientists and policymakers alike in recognizing it and acknowledging the administered division by empirical science centuries ago (Nakashima, 2015).

The Fifth Assessment Report by the Intergovernmental Panel in Climate Change (IPCC) (Pachauri et al., 2014), *Synthesis report: summary for policy makers*, highlights the importance of traditional knowledge:

> *Indigenous, local, and traditional knowledge systems and practices, including indigenous peoples' holistic view of community and environment, are a major resource for adapting to climate change but these have not been used consistently in existing adaptation efforts. Integrating such forms of knowledge with existing practices increases the effectiveness of adaptation.*

The Sixth Assessment report by the IPCC (Lee et al., 2023) added a valuable and necessary aspect towards the recognition of Indigenous knowledge (IK):

> *This knowledge is integral to cultural complexes, which also encompass language, systems of classification, resource use practices, social interactions, values, ritual and spirituality.*

Traditional knowledge systems comprise unique skills, philosophies, and understandings of the interaction between social, cultural, and ecological domains. The communities that curate, administer, and transfer these systems of knowledge and practices are often stewards of diverse and unique ecosystems worldwide. Traditional knowledge is often applied with distinctive frameworks that represent the deep-rooted cultural and historical connections to the land which influences the sustainability and longevity of interventions. Practices inherent in these connections may not usually be aligned with the empirical benefits methods but are instrumental in maintaining a socioecological balance in local communities. Hence, it is of utmost importance to integrate these perspectives into any developed frameworks to ensure that key findings and support are culturally resonant as well as sustainable.

While traditional knowledge is rooted with specific societal, environmental, and economic context, it may offer valuable insights and approach that could benefit other contexts. For example, IK has made numerous contributions to the interpretation of ecology, evolution, physiology, and applied ecology (Jessen et al., 2022). These are sometimes distinct from conventional science in terms of incentive and methodology and are deemed as intellectual property of the knowledge holders. However, there exist shared conceptual fundamental basis that promote productive and mutually constructive collaborations.

Experts have emphasized that intellectual property ownership of traditional knowledge systems, including water resource management practices, should lie with the knowledge-holding societies themselves. These communities are the rightful custodians of their unique skills, philosophies, and ecological understandings, which have been developed and refined over generations. Any outputs of this report must acknowledge intellectual property ownership, ensuring that these rights remain with the knowledge-holding societies. While research support may be employed to validate traditional knowledge and learn from it, it must then be returned to the knowledge-holders for determination of how and whether to disseminate it to others. This is critical to creating an equitable, non-exploitative, and sustainable collaboration between traditional knowledge-holders and research bodies. Recognizing and respecting their intellectual property rights is essential to ensure the protection and continuation of these invaluable practices. This approach not only honors the intellectual contributions of indigenous peoples but also fosters equitable and sustainable partnerships in the pursuit of global sustainability goals.

2 Case Studies

This chapter will present three case studies on traditional water resource management practices: the Aflaj, the Acequias, and the Qochas. These case studies were selected based on availability of research and to maintain brevity in this report, not due to any ranking of importance. Each case study will begin with examining these practices and their current relevance, challenges faced by these practices, and the policy efforts done or required to preserve them.

2.1 The Aflaj in Oman

Oman is currently considered to be one of the most water-stressed countries in the world. In 2022, the average annual rainfall was estimated to be about 76 mm. Considering its semi-arid and sub-tropic climate, most of the agricultural irrigation relies on freshwater sources (IEA, 2023). Freshwater in Oman primarily comes from groundwater sources, which account for nearly 94% of Oman's total water consumption. Of this, 90% is used to meet the agricultural sector's water demand (McDonnell, 2016). Centuries ago, Omanis designed and developed an effective system to supply their communities with water (Badr, 2021).

Branching along the northern part of Oman are the country's symbolic ancient water systems, the Aflaj, through which 38% of the country's groundwater is extracted (Aziz, 2015). These are canal networks that supply water to communities for both domestic and agricultural usage. Dating back to approximately the eight century B.C., during the Iron Age of Oman, Aflaj were considered to be the veins supplying "blood" to Omani civilization (Al-Ghafri, 2018). The development of Aflaj allowed ancient Omanis to settle around them, inaugurating agricultural and industrial activities which created the advancement of the ancient Omani civilization (Badr, 2021) .

Most of Oman's water supply is sourced from groundwater through wells or Aflaj systems, which are mostly located in the Batinah, Sharqiyah, and Dakhiliyah districts (UNESCO, 2006). In larger cities such as Muscat, desalination plants also contribute to the urban water supply. Oman has 4,112 Aflaj, out of which about 1000 are considered 'dead' or dried up. The operating ones irrigate approximately 26,500 hectares of land. These Aflaj are managed by farmers, but the local community controls the decision making with regards to water management (Al-Ghafri, 2018).

The Aflaj systems are managed to prioritize domestic use over agricultural use. Although 99.8% of the total Aflaj water demand is for agriculture, the water is initially allocated for drinking purposes (Al-Ghafri, 2018). Once domestic needs are fulfilled, the *falaj*, the singular form of Aflaj, is used to irrigate permanently cultivated lands, mainly date palms, followed by seasonally cultivated lands called *awabi*. In this matter, farmers maintain control over the water use in times of drought. When there is a higher flow rate of water in the *falaj*, more water is allocated to lands that can grow seasonal crops, whereas that area's water is cut off during droughts. However, in times where there is excess water in the Aflaj, the water is drained out of the system. Apart from their agricultural and domestic functions, Aflaj systems serve industrial and miscellaneous purposes as well (Al-Ghafri, 2018). For instance, the falaj al-Mutaridh, located near Sohar in northeastern Oman, possessed four water mills along its channel, primarily utilized for grinding grains (Birks and Letts, 1977; Wilkinson, 1977).

Aflaj can be categorized into three types: Aini Aflaj, Ghaili Aflaj, and Iddi or Daudi Aflaj (Figure 1). The major difference between the three lies in the source of water or collection method. The source of Aini Aflaj is natural springs. These Aflaj draw water directly from a spring through channels; as long as the springs are active, these serve as a reliable and continuous water supply. Aini Aflaj also comprise of 28% of the total Aflaj in Oman (Al-Ghafri, 2018). Ghaili Aflaj, on the other hand, collect water from seasonal runoff, channeled from wadis which are recharged by rainfall; this resembles spate irrigation which is also commonly found in the Yemen (Figure 2). Hence, these are considered to be

Figure 1: Aini Aflaj, Ghaili Aflaj, and Daudi Aflaj (UNESCO, 2006).

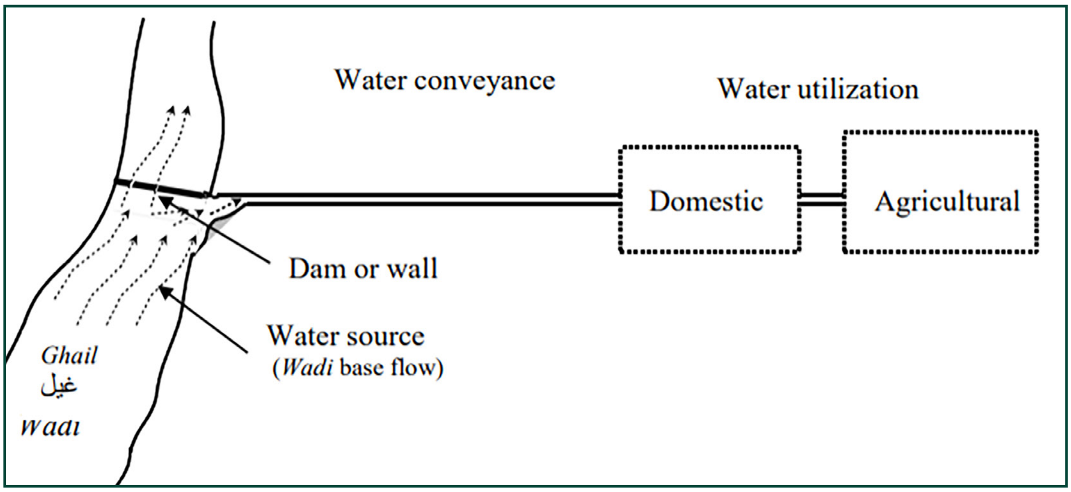

Figure 2: Schematic of a Ghaili Falaj (Al-Ghafri, 2018).

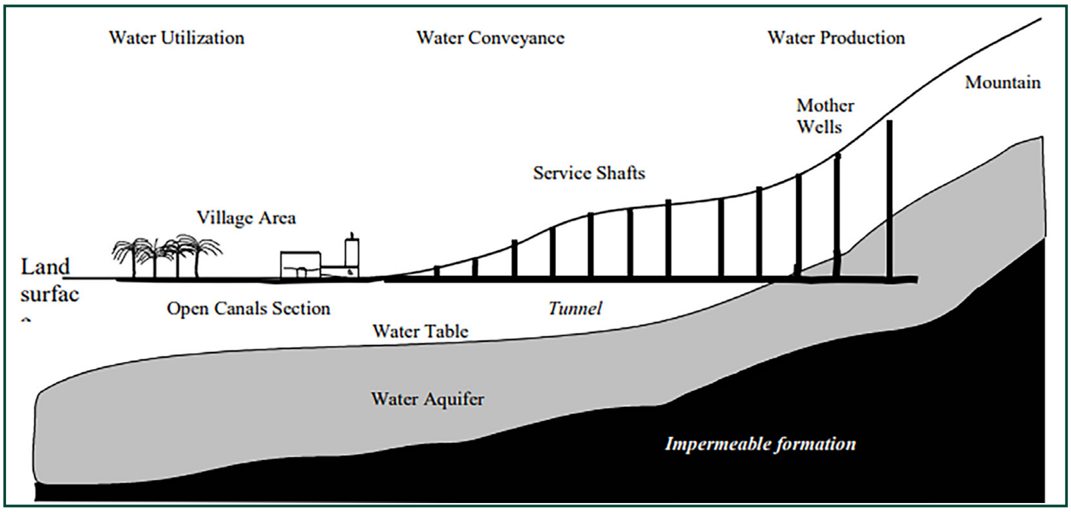

Figure 3: A cross section of an Iddi Daudi Falaj (Al-Ghafri, 2018).

a seasonal source of water supply as these Aflaj dry up shortly after the rain ceases. Ghaili Aflaj, the most common type of Omani Aflaj, are usually located nearby or on mountains where rainfall occurs more frequently and make up about 49% of Oman's total Aflaj.

Lastly, Iddi Aflaj represent about 23% of the total Aflaj in Oman, which tap into a nearby groundwater source through the construction of a subterranean gallery along with a series of access wells, collecting and transferring water from aquifers to the ground surface (MRMEWR, 2001). This is considered to provide the most reliable and least polluted source of water supply compared to the other types of Aflaj (Alsharhan et al., 2020a; Badr, 2021). It is essential that the tunnel's gradient is shallower than that of the groundwater table or the ground surface to prevent water erosion in the tunnel. Constructing such Aflaj is a laborious task, requiring substantial financial resources, time, and manpower (Al-Ghafri, 2018).

2.1.1 Administration and Water Rights of Aflaj

The provision of water rights in Oman is administered by customary law (ourf), Islamic law (Shari'a), and tribal authority, with customary law and community consensus having a strong influence (Al-Marshudi, 2007) . The Aflaj are considered to be amongst the oldest community-managed systems for managing water in the world (Tayara, 2015). Traditionally, the maintenance and operation of Aflaj were managed by tribal groups, however, over the past several decades, the local government became more involved in supplying technology and financing for routine maintenance of Aflaj and distribution of water (Al-Marshudi, 2007).

The multifaceted relationship between tribalism and falaj water management proves to be the cornerstone of Oman's socio-economic evolution. Tribalism, which involves territoriality, and falaj system, which entails trans-boundary cooperation, seem to be at odds at first glance. However, falaj system and its socio-economic peculiarities have given rise to a different variation of tribalism in Oman, called "hydro-tribalism", which has historically cemented strong bonds between multiple social groups. Hydro-tribalism re-arranged Oman's social composition in a "solar system model" in which many distinct groups remain in the orbits of their own tribal identities around a central falaj system and its water management, such that they closely cooperate and converge without melting into a homogenous social unity (Khaneiki et al., 2024).

Falaj Management Committees (FMCs) consist of a director, or *wakil*, two assistants for underground and above ground services, a banker, and a labor force (Sutton, 1984; Wilkinson, 1977). The number of administrators largely relies on the size of the falaj, however, having a *wakil* is necessary (Figure 4). The *wakil* is elected by the falaj owners from the community based on the *wakil* possessing specific qualities: respectability, honesty, literacy, and basic numeracy. Moreover, the *wakil* should have a sociable demeanor enabling effective communication with all community members. Tasked with overseeing the falaj's overall administration, the *wakil* acts as its executive director. Although the government doesn't intervene in the FMC's organizational structure, the *wakil* maintains significant authority. Amongst the *wakils* responsibilities include managing water distribution, collecting water rent, handling the falaj budget, resolving water-related disputes among farmers, addressing emergencies, and making key decisions concerning the falaj's operations (Al-Ghafri, 2018).

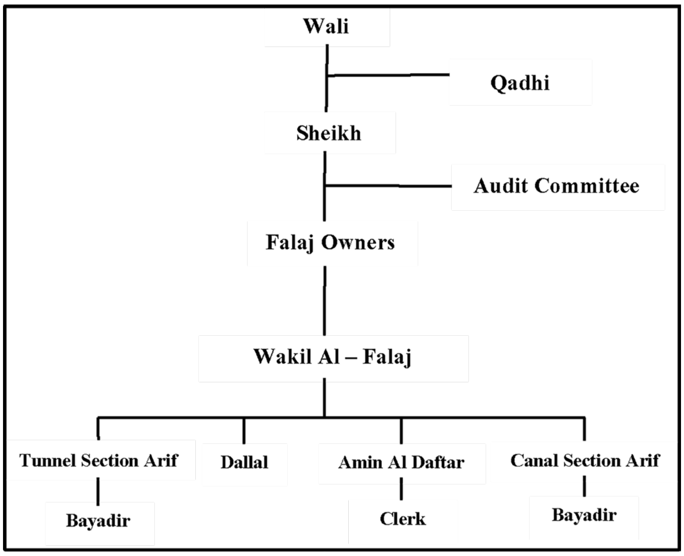

Figure 4: Typical administration of a large Falaj(Al-Saleemi and Abdel Fattah, 1997).

2.1.2 Challenges Affecting Aflaj

There are several challenges that are currently affecting Aflaj systems in Oman. Pollution - biological, chemical and physical, leaking into Aflaj from different contamination sources highly impacts downstream Aflaj quality. Such a pollution can be caused by a wide range of contaminants from agricultural drainage laced with chemical fertilizer and pesticide to urban and industrial sewage. The country's rapid urbanization and progress towards heavy industry, tourism, and economic activities, combined with other social issues, impact the Aflaj ecosystem as well (Al-Ghafri, 2018; Al-Kindi et al., 2023).

In the 1950s, rapid modernization and development in the country prompted farmers to switch to working in the oil sector or government offices due to higher income prospects. Hence, farmers relied less on Aflaj as an economic source. This led to a decrease in proper maintenance as there was not enough experienced manpower required to regularly maintain the Aflaj, driving farmers to hire non-experienced laborers, mainly expats, who lacked the necessary knowledge needed to properly manage the Aflaj. The lack of traditional knowledge exchange was exacerbated by the fact that the knowledge to handle the Aflaj largely remained with the older generation, as the youth did not express interest in Aflaj (Wushiki, 1997). The 1970's renaissance era in Oman brought about a rapid growth in the agricultural sector as well as urban development. With the introduction of modern technology such as high-capacity water pumps, citizens established their own farms outside of traditional farming zones. This created an imbalance in Oman's groundwater resources (Deadman et al., 2016; Schütze et al., 2012).

Although Aflaj have survived centuries, many are currently considered to be endangered. This is due to the destruction of channels or water level drop instigated by over-exploitation from excessive pumping and effects of climate change (Alsharhan et al., 2020b). Such exploitation of groundwater has been estimated to be 1,645 million cubic meters per year, whereas annual groundwater recharge is only around 1,267 million cubic meters, resulting in an annual deficit of 378 MCM in Oman (Aziz, 2015). Recognizing the need to protect eh Aflaj, the Omani government took numerous measures and implemented regulations to mitigate the impact of these numerous challenges facing the Aflaj.

2.1.3 The Aflaj Protection Law in Oman

In August 2017, Oman established the Ministerial Decree No.39/2017 issuing the Law on Regulation and Protection of Aflaj Sites, implemented by the Ministry of Water, to organize and safeguard the Aflaj sites registered as the UNESCO World Heritage. This Aflaj Protection Law aims to protect the historic and cultural heritage of the irrigation system.

The law contains twenty articles, of which several important ones include (UNEP, 2017):

> *Article 4: The traditional system of distributing and managing falaj water is followed in accordance with the inherited customs in dividing water and the names of its time periods, etc., and the Ministry has the right to put in place the necessary measures to maintain this system.*

The customs' mentioned are traditional customs, not religious or political, but rather what people in Oman have agreed upon for centuries.

Articles 9 and 12 from this decree aimed at protecting the water quality of Aflaj are:

> *Article 9: It is prohibited to carry out any action that leads to contamination of falaj water by causing a physical, chemical or organic change in its properties that makes it harmful to public health or renders it unfit for use.*

> *Article 12: It is not permissible to establish wastewater detention tanks in the watershed or the falaj site or its sanctuaries before obtaining approval from the Minister.*

Articles 9 and 12 are crucial for protecting Aflaj from anthropogenic pollution from entering the water.

The Aflaj in Oman continue to face challenges but are supported by both government initiatives and cultural recognition. This aims to and hopefully succeeds in maintaining their preservation as vital components of Oman's heritage and water management systems.

2.2 The Acequias in Southwestern United States

Acequias are community-managed, gravity-driven irrigation systems that have played a crucial cultural and agricultural role in several parts of the world. Acequias divert water from the main stream (surface water) and deliver it downstream to agricultural fields via low dam structures (Rango et al., 2013). These communal irrigation systems have existed in Southwest North America for over 4 centuries. The term "acequia" is derived from the Arabic word *as-saqiya*, meaning water carrier (Martínez Sanmartín, 2020). This ancient irrigation technology dates back to at least the 8th century when Muslim Moors brought the science to Spain. This irrigation custom was identified as sustainable and valuable; hence it was preserved by the Spanish kings upon expulsion of the Moors. In the 17th century, Spanish conquistadors brought this practice to the Southwest, U.S., where it can be mainly found in Mexico, New Mexico (Figure 5), Colorado, and in the Americas (Hutchins, 1928).

Figure 5: An Acequia in New Mexico (Audubon Magazine, 2021).

The acequias in northern Rio Grande are the oldest water management systems in the U.S., coming from an Eastern origin, and dating back to the first Spanish settlement by Juan de Oñate in 1598 (Saldaña and Rivera, 2008). This region, a semiarid area rich in resources but short on water, spans the area where Colorado's Rocky Mountains meet the Chihuahuan desert and Texas's Llano Estacado. The Rio Grande flows through this area from Creede, Colorado, to El Paso, Texas. Spanish colonization required communities to be near water sources due to arid conditions. Settlers used gravity-flow irrigation, diverting river water through the acequias. These networks were built across the southwestern U.S., especially effectively in La Provincia de San Felipe del Nuevo México along the upper Rio Grande (Peña, 1999).

Historically, traditional acequia communities remained engaged through two main factors. Firstly, families benefited from agricultural activities in the acequia and nearby lands, providing resources such as timber, grazing, and hunting. This connection fostered a shared love for their land, known as *querencia*, reinforcing acequia culture. In Spanish, *querencia* describes a place where one feels at home, a safe place from which one's strength of character is drawn. Secondly, high costs and limited resources outside the community discouraged emigration (Turner et al., 2016). The local acequias united settlers into a hydraulic society, highlighting the mutualism captured by the phrase, "Water is the lifeblood of the community," a principle still alive today. A key standard of this mutualism and its unions was pooling resources to protect members from poverty, unemployment, healthcare emergencies, and funeral expenses. The core belief was that assistance should come from within the community for the benefit of society and the common welfare (Aguilar Rivera et al., 2011).

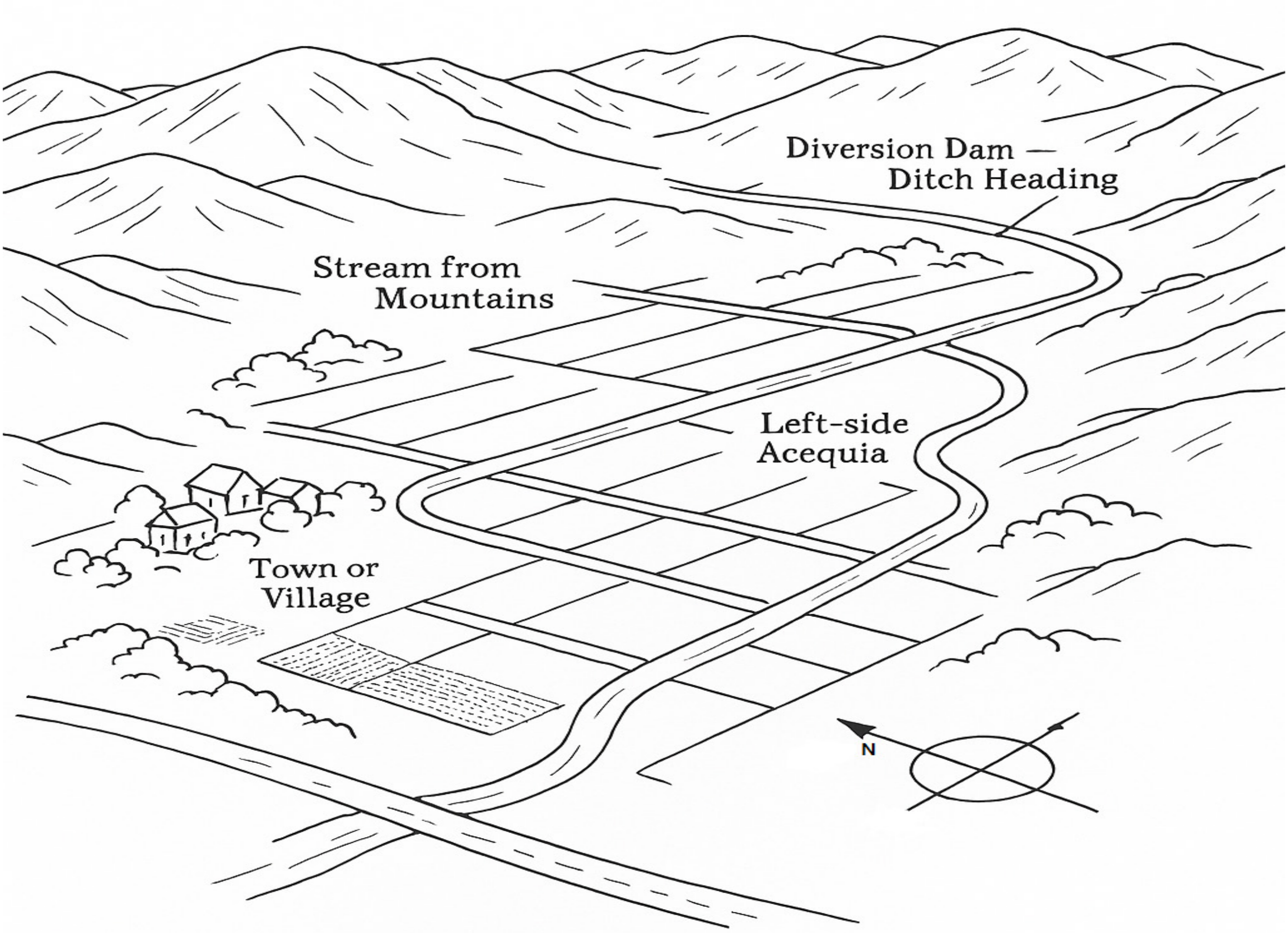

Figure 6: A Diagram of an acequia system (Oglesby and Bushnell, 2015).

2.2.1 Challenges Confronting the Acequias

Although acequias have historically played a crucial role in water supply, today, acequia communities encounter multiple sustainability challenges, including climate change impacts, population growth, economic pressures in agriculture, urbanization pressures in surrounding areas, and demands from downstream users for increased water supply (Mayagoitia et al., 2012).

However, they remain essential for sustaining agricultural and cultural heritage. Current perseverance of acequias comes with challenges, such as maintenance and financial support. Acequias require constant maintenance to ensure adequate water quality, infrastructure integrity, and effective flow management. Major maintenance tasks involve frequent water testing, vegetation management, infrastructure assessment, erosion control, sediment control, debris clearing, and flow monitoring often supervised by the ditch manager (Jensen et al., 2016). Current maintenance costs for acequias could reach up to 7.5 million USD annually, specifically after substantial damage from extreme events such as flooding or wildfires. This funding comprises a 5 million USD one-time allocation for acequia building and maintenance, in addition to 2.5 million USD provided by teg Acequia and Community Infrastructure Fund (ACDIF) for planning, developing, and construction (NMISC, 2021; U.S. Congress, 2023). Damage repair from topical disasters could cost each acequia at least 250,000 USD (U.S. Congress, 2023).

Acequias are currently confronted with challenges stemming from the intricate interaction of environmental, social, and technological variables. These challenges have made it increasingly difficult to sustain and protect the acequias (Roybal, 2012). The main social challenges confronting acequias today are law violations. Landowners' unethical use of acequias for personal or commercial purposes results in uneven and ineffective water distribution among the settlements crossing acequias. Acequia easement laws are violated through blockages placed by landlords, which can directly or indirectly impact acequias. These violations include building fences that obstruct equipment, walking alongside the ditch, building gates to block machinery, and blocking regular access locations. Violations are often discovered when an acequia official or maintenance staff attempts to cross a property and faces resistance from new owners who are unaware of established easement rights. Other issues include keeping gates locked to the easement, letting animals run wild, and ignoring overgrown flora along the Acequia (Ramo, Olivia, 2016).

When addressing acequias' environmental challenges, it is crucial to highlight the impact of climate change, which is leading to increased temperatures and greater evapotranspiration. This issue is especially pressing in the water-stressed Southwestern U.S., including New Mexico. The elevation of an acequia plays a crucial role in its vulnerability to climate change. A higher acequia experiences less evapotranspiration than a lower one, which is expected to change with increasing temperatures. While the impact of changing precipitation is yet unknown, the recent increase in rainstorms is expected to augment water precipitation. However, an increase in intense storms does not translate to an increase in water supply for crops, as acequia valleys lack major water storage infrastructure (Rango et al., 2013). In fact, the community's reliance on water supply from melting snow will add more stress over time in maintaining acequias.

Another critical point to consider is how modern technology has impacted acequias. Traditional earthen acequias provide numerous ecological advantages often sacrificed by modern irrigation methods. Although cement-lined ditches and pipes enhance water delivery efficiency, they diminish the beneficial environmental effects of traditional approaches. Past and current field research results show that acequia seepage enriches riparian vegetation and wildlife habitat along ditches, boosts recharge to shallow aquifers and improves water quality. Modern systems are not environmentally sustainable because they isolate water from the surroundings (Alexander G. Fernald and Steven J. Guldan, 2004). Cement-lined pipelines are not considered to be as sustainable in the long run as acequias, even though they are deemed to be efficient (Ross, 2022). Balancing agricultural productivity and ecological sustainability in water management, especially in dry regions with prevalent acequias, is difficult. Hence, choosing between traditional and modern methods involves considering immediate agricultural benefits versus long-term environmental impacts.

2.2.2 Strategies for Protecting Acequias Systems

Protecting acequias requires an interdisciplinary approach addressing environmental, social, financial, and technological challenges.

In 2011, a study was conducted surveying acequia members and *parcientes* (acequia irrigators) in Northern New Mexico to (1) Evaluate community views of existing readiness and adaptation capacity to climate change; (2) Recognize major factors that impact the acequia communities' capacity to adapt to changes in climate, population, and community; and (3) Recognize actions and initiatives that can support and develop acequia community preparedness and resilience (Mayagoitia et al., 2012).

The two major stressors perceived to be the greatest vulnerability to communities and families were substantial drought and economic downturn. The survey shed light on important lessons to be drawn from the longevity of acequias and the community's ability to adapt to economic downturns, population growth, increasing development, and droughts. About 79% of the Alcalde-Velarde people surveyed specified the importance of land ownership as a major characteristic to that addressed the above issues (Figure 7).The next major surveyed characteristics were identified as family values and connection to land, water, and community (Mayagoitia et al., 2012).

Mayagoitia and coworkers also described changing the terminology of "climate change" or "climate variability" to other terms such as "drought-coping activities" in their survey questions as the locals expressed undesirable attitudes towards the former.

Figure 7. Key factors influencing the Acequia's capacity to adapt in the Alcalde-Velarde region in New Mexico (Mayagoitia et al., 2012).

A significant social difficulty impacting acequias is dealing with lawbreaking, particularly by new landlords who might need to be made aware of the regulations safeguarding the acequias. Acequia officials usually attempt to settle disputes by speaking with the landowners and documenting their discussions in writing. Members of the community are taught about access points and easements. Conflicts can be avoided by alerting landowners before planned maintenance or infrastructure projects and ensuring workers behave politely. However, if this approach fails, legal action can be taken as interference with acequia easements is a criminal misdemeanor in New Mexico (Romo, O., 2016).

Another solution to maintain the livelihood of acequias is community cohesion. This is essential as it is the driving force behind the survival of acequias during periods of droughts and external threats. Thus, for centuries, communities that owned the water rights of acequias only sold their lands to people from within their communities. That is because their communities knew how to manage and preserve acequias; thus, knowledge of such cannot be purchased or sold (Rango et al., 2013). Modern problems, such as landlords not knowing how to manage acequias, stem from the fact that these community practices are no longer followed which increases risks to acequias.

Climate change influences the effectiveness of acequias as well. In certain seasons, significant precipitation or snowmelt might cause floods instead of refilling the water channels because of their low capacity to store water. Utilizing Snowmelt Runoff Model (SRM) technology to evaluate hydrographic data, such as temperature and precipitation, is one possible way to address this problem. This technology is significant because it can forecast and create weather patterns, giving people the knowledge they need to prepare for changes in the weather. According to

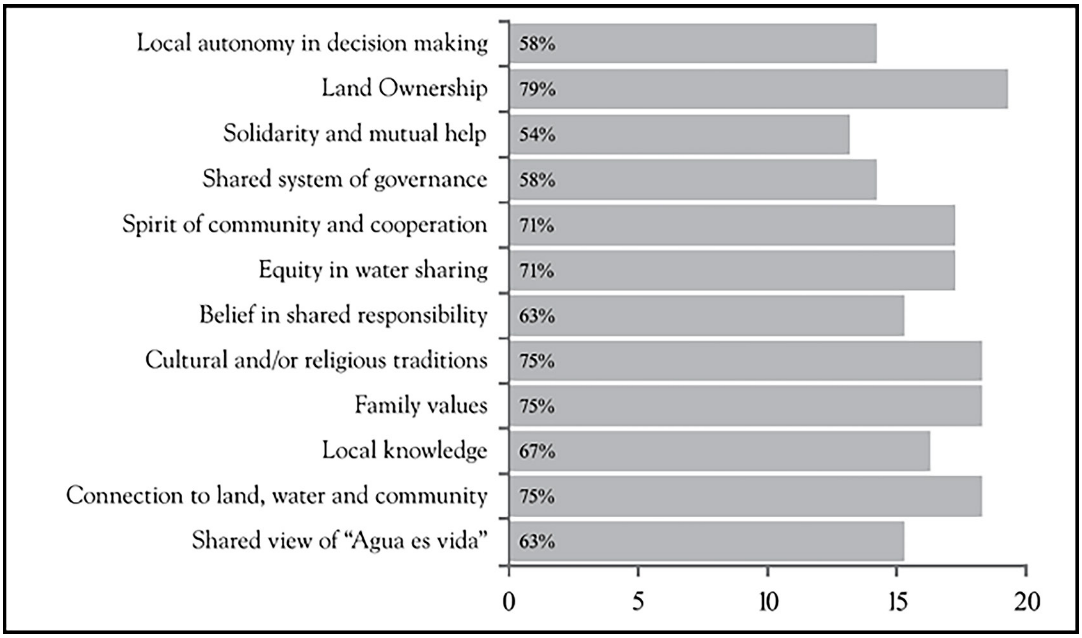

Figure 7: Key factors influencing the Acequia's capacity to adapt in the Alcalde-Velarde region in New Mexico (Mayagoitia et al., 2012).

surveys, Acequia organizations are keen to experiment with new technologies to gain a deeper understanding of how their particular acequias will be impacted by climate change. Thus, SRM technology could be used and taught to New Mexico's communities to help them better protect their Acequias (Rango et al., 2013).

Today, acequia associations organize educational programs, cultural events and religious activities, publish newsletters, provide technical workshops, and hold the annual *Congreso de las Acequias* through the New Mexico Acequia Association (NMAA)- a community-based initiative. Acequias in New Mexico are recognized under New Mexico law as political subdivisions of the state. In Colorado, the state-wide acequias association, *Sangre de Cristo Acequia Association*, protects water rights and acequia governance (Hicks and Peña, 2003). These programs are growing and dedicated to promoting better laws and educating the next generation about the importance of acequias for the environment and culture.

The associations possess the power of eminent domain and are authorized to procure funds and develop contracts for maintenance and improvements. Acequias associations do not possess the power to tax, therefore, maintenance and development expenses are the responsibility of the individuals administered by the irrigation system (OSE, 2022). The Office of the State Engineer (OSE) has an Acequia Liaison dedicated to assisting acequias and *parciantes* with water rights adjudications. Beyond settlements, the Liaison addresses water allocation and governance questions, collaborating with the Interstate Stream Commission (ISC), the Water Resources Allocation Program, the New Mexico Acequia Commission, and the OSE's Native American Liaison on acequia and Pueblo issues (Buynak et al., 2013; OSE, 2022)

Acequia projects receive substantial funding from the federal Water Resources Development Act of 1986. Acknowledging the cultural and historical importance of acequias, Congress empowered the Secretary of the Army to allocate approximately $40 million for diversion structures. State and local entities often match these federal funds, with the Irrigation Works Construction Fund (IWCF) frequently serving as a source for covering non-federal cost shares (Buynak et al., 2013).

Acequias offer a sustainable model for water management, but their survival hinges on addressing the challenges posed by climate change and ensuring continued community and governmental support, in terms of policy as well as funding.

2.3 Qochas in Peru

In the Quechuan language, 'qocha' denotes a natural or artificial body of water, encompassing lakes, pools, or ponds. Qochas are abundant in the Andean highlands of Peru and Bolivia, particularly near Lake Titicaca, at an average altitude of 4000 meters. Some of these qochas date back to the Incan era, such as the one found in Cuzco, Peru (Sparavigna, 2011). Ancient agricultural techniques that revolve around the use of qochas, which are strategically located at the intersections of canal networks, have existed for centuries.

Figure 8: A Qocha in Cuzco, Peru (Gobierno Regional La Libertad, 2019).

Qochas, whether naturally occurring or man-made, serve as depressions on the ground that can be flooded to support agriculture and when linked together create an intricate hydraulic system. They are typically arranged in geometric shapes such as squares and circles, with the most common being circular structure with diameters ranging from 30 to 200 meters (Figure 9). The ponds collect rainwater within their radial or circular structures to reduce the effects of the sun and wind currents, decreasing the rate of evaporation (Mollard and Walter, 2008; Sparavigna, 2011). The reservoirs collect rainwater, mitigate runoff and soil erosion, while also replenishing groundwater. Some research suggests that farmers would use the circular shapes as markers which, coupled with observations of the sunrise and sunset, could be used to determine seasonal planting times (Sparavigna, 2011).

Figure 9: Structure of some circular qochas (top and bottom left) and an image of wet canals (bottom right) (Sparavigna, 2011).

Qochas allow for proper soil management and improve land fertility; they moderate the surrounding microclimate, generating moisture and enhancing the growth of native plants (Carrasco-Torrontegui et al., 2021). Moreover, qocha contributes to landscape rejuvenation, strengthens food security, and ensures sustenance for small animals and livestock during dry spells. The choice of qocha design is determined by the characteristics of the soil. Qochas intended for sowing are ideally constructed on porous soil and cracked rocks to promote rapid water infiltration. Conversely, qochas designated for harvesting benefit from clay soil, which has a higher capacity to retain water over an extended period (Guerra, 2019).

2.3.1 Confronting Challenges, Embracing Solutions

Due to their geometric structures, Qochas are susceptible to geologic changes. Some research suggests salinization to be a major cause for the deterioration of qochas. Other research attributed the deterioration of qochas to be largely due to anthropogenic reasons related to the mechanized flattening or leveling of the earth for enhanced agriculture (Craig et al., 2011).

In 2008, the Swiss Agency for Development and Cooperation (SDC)'s Global Program on Climate Change (GPCC) partnered with the Peruvian government and launched the Climate Change Adaptation Program (PACC) in Peru. The program's goal was to identify climate change impacts in the Cuzco, Andean, and the Apurimac regions of Peru as well as implement a series of adaptation measures in order to mitigate said effects.

The PACC operated on a four-year cycle for each phase and consisted of two phases (PACC 1 and PACC 2). The first phase involved a baseline study as well as coordinated actions, both regionally and locally. The second phase built on the previous work of the first PACC phase to bring about systemic improvements in climate adaptation methods. The program focused primarily on disaster risk reduction, water resource management, and food security. The foundation for the development of the adaptation measures was formed by the collaboration between research institutions in both Peru and Switzerland. The partnership enhanced knowledge and expertise in climate change adaptation in a developing country but also enabled the integration of climate change concerns into Switzerland's developmental efforts in Peru (Huggel et al., 2008).

Having witnessed the effects of climate change, some Peruvian villages were already reintroducing ancient agricultural techniques such as the qochas and this effort was inspired by PACC (Álvarez, 2017). As part of a community-based initiative, PACC supported the construction and reinforcement of two types of qochas.

The first qocha supported by the PACC program was established in Quillihuara, in the district of Checca, Cusco, in early 2011. Initially, it faced challenges, and the idea was met with backlash as, for many in the community, the benefits of the qocha were not clear. Seven hectares of eroded land with sparse grass were cordoned off and a dam was constructed in a natural hollow to harvest rainfall. Most of the villagers participated in this effort. The triumph in Quillihuara qocha set the course: there was a clear need for more of these water bodies. To address this, PACC arranged qocha competitions amongst the villagers and farmers to inspire further contributions. The outcome surpassed expectations: within two years, 146 reservoirs were erected in the Huacrahuacho watershed —135 for family usage and 11 for communal use. They consisted of diverse sizes and capacities, some temporary and others permanent— along with 48 more in the Mollebamba watershed, all intended for family use (al Cambio Climático, 2014).

The second qocha supported by the program was the Moroccacca qocha, which emerged high in the mountains. It served 150 families from the peasant community of Pucacancha, situated several hundred meters above the town center. This communal lake spanned approximately two and a half football fields and had the capacity of five Olympic pools. A leader chosen by PACC in his community of Pucacancha vocalized the success of the qochas development program, mentioning that other communities have made requests to the respective authorities to facilitate the development of similar projects, as there had been conflicts over water in the area (Guerra, 2019).

The PACC's promotion of Qochas provided significant benefits to local communities; the program's social effects were considered positive and significant (Mamani and Quispe, 2021). It surpassed traditional water storage methods in terms of cost-effectiveness and impact. A total of 146 micro-reservoirs were established with an investment of 250,000 soles (65,311 USD), collectively storing 83,177 cubic meters of water. This transformed local agriculture by enabling families to diversify their crops and improve irrigation fields. The increase in agro-pastoral incomes served as evidence of the positive effects of this agricultural boost, offering a solid defense against the impacts of climate change. Qochas became a central element of PACC's strategy, showcasing how targeted interventions can enhance community adaptability to climate change (Perez et al., 2017).

A study on the impact and successes of PACC 1 and PACC 2 on a local and regional level can help to identify lessons learned that can be replicated to further support traditional knowledge initiatives.

PACC 1:

- Contributed to national policy instruments, including Nationally Determined Contributions (NDCs) and the National Strategy on Climate Change.

- Helped Cusco and Apurímac become model regions for formulating regional climate change strategies.

PACC 2:

- Focused on advancing initiatives to increase public investment in ecosystem services and biological diversity.
- Worked with national authorities in Peru to promote these initiatives, including the Ministry of Environment and Ministry of Economy and Finance.
- Aimed to enhance Peru's capacity to leverage funds from international finance mechanisms like the Green Climate Fund.
- Emphasized integrating funding into national plans to demonstrate country ownership

The lack of systematic data collection on indicators made it difficult for the evaluation team to validate the program effectiveness and impact metrics offered by PACC 2 (Perez et al., 2017). The accomplishments of PACC 1 were stated clearly as they had a specific focus, whereas PACC 2 took multiple focus routes, which caused misreported data due to lack of proper SMART (specific, measurable, achievable, relevant, and time-bound) goals.

Table 2 below highlights some of the goals and accomplishments of each PACC 1 and PACC 2.

Table 2. Goals and accomplishments of PACC 1 and PACC 2 from 2009 to 2016 (Perez et al., 2017).

The PACC programs significantly contributed to shaping national public policy. They enhanced the capabilities of stakeholders and dialogue platforms to advocate for and disseminate insights from the adaptive measures of high Andean rural communities on the global stage. The programs allowed for the consolidation of research outcomes of PACC with the ancestral wisdom of indigenous communities and their integration into national policies.

Phase	Duration & Budget	Goal	Accomplishments
PACC 1	2009 – 2012 Funds not reported.	• Switzerland started this adaptation as part of its efforts to cooperate internationally. • PACC began as grassroots, local pilot project and effectively connected at the regional and national levels, ultimately contributing significantly to the development of the current Peruvian adaptation policy.	• Over 1,200 families improved their climate change adaptation practices. • In the Huacrahuacho micro-watershed (Cusco region), 745 families, representing 57% of the watershed's total inhabitants, participated in climate adaptation competitions. • In the Mollebamba micro-watershed (Apurimac region), 463 families, accounting for 86% of all families in the area, joined climate adaptation competitions. • 46% of participants in trainings, internships, and farmer contests were women.
PACC 2	2013 – 2016 4.43 Million USD	• Improving the standard of living in Andean villages experiencing moderate to severe poverty. • Reducing the vulnerability of the population in rural high Andean areas to climate change.	• Institutional strengthening. • Strengthening capacities in public investment. • High Andean families with improved technologies. • Strengthening capacities in research and education. • Scaling up and influencing national policies.

3 Towards Policy Options to Support Traditional Knowledge

Traditional knowledge systems related to water resource management such as the Aflaj, Acequias, and Qochas were established to adapt to climate change centuries ago. They have in many instances withstood the test of time and demonstrated their adaptability and role in mitigating contextual climate change impacts. These systems have not only proven to be environmentally sustainable, but their success also relies heavily on social cohesiveness, community participation, and communal stewardship of resources.

Local and international efforts have demonstrated to be largely successful in preserving these systems and utilizing them in a sustainable way. Aflaj systems in Oman benefitted from various conservation and rehabilitation programs largely due to the Omani government's efforts to preserve and maintain these traditional irrigation systems. The Acequias in the U.S. garnered support from the NMAA, the Sangre de Cristo Acequia Association in Colorado, and the local government to support the maintenance and improvement of acequias infrastructure as well as educating the community about the importance of acequias. The qochas in Peru proved to effectively retain water as well as enhance agricultural productivity, hence, offering a robust resistance against climate change impacts in the Andean region. This has been successful recently largely due to the PACC program launched by the international organization, the SDC, and the local Peruvian government. In 2023, UNESCO inscribed on the Representative List of the Intangible Cultural Heritage of Humanity on traditional irrigation knowledge and techniques.

In the case studies in this report, policy interventions from governments that specifically focused on the protection, restoration, reintroduction, and awareness promotion of these traditional practices proved to be effective. The impacts led not only to positive environmental outcomes but had significant societal and in some cases economic benefits as well. These policies included protective regulations and laws, designation of the practice as important (i.e. getting it listed as world heritage), empowering of local knowledge holders (i.e. via local communities and associations), developing and funding infrastructure rehabilitation programs, and community awareness programs.

A symbiotic relationship between modern scientific approaches and traditional knowledge could greatly enhance adaptation and mitigation efforts. Traditional knowledge empowers local communities by providing them with control over their resources as well as provides them with ownership of the management of their local ecosystem and environment. Success of traditional practices lies mainly in the local community, hence, empowering the knowledge holders, preserving traditional knowledge, and educating younger generations is imperative to their success. This is being recognized among researchers and civil society – leading to increased interest by them in this space.

To further its work on the traditional knowledge program area, Earthna will continue to document and further explore traditional knowledge practices, including building databases compiling available information to provide a centralized resource for future research and implementation. Looking ahead, Earthna envisions a broader outreach and engagement strategy that builds on this report. Plans include publishing a series of similar reports that explore other traditional water management practices as well as traditional practices related to land, food and construction.

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