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The exigencies of transboundary water security: insights on community resilience

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Societies across the globe strive to achieve water security—that is, assure access to sufficient water of acceptable quality for humans and the environment for changing, sustainable societies and ecosystems. But rapid and significant changes in environmental and social systems complicate attempts to assure water-secure conditions. This challenge is further magnified by transboundary conditions—while landscapes and physical processes disregard political borders, human institutions managing these resources often lack the traditions and capital for ensuring resilient, community-based responses to water shortage and contamination. This review highlights how features of community resilience contribute to enhancing transboundary water security using nine examples from the U.S.–Mexico border region. The cases demonstrate how public participation, adaptivity and flexibility, and social mobilization to promote equity and justice help to nurture and maintain community resilience, to the benefit of transboundary water security.

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Introduction

While many regions of the world face modern water security challenges, in the vast regions that are hyper-arid, arid, and semiarid, water security has always been tenuous [1]. Beginning in the 19th century and accelerating thereafter, modern drivers of change such as industrialization, irrigated agriculture, and urbanization have engendered land-use modifications such as deforestation and desertification; aquifer depletion; and new, less favorable climatic patterns. At the same time, population and concomitant consumption have grown markedly, leading to large increases in demand for water [2]. These transformations have permanently altered long-established notions of water security—which we define as the availability of adequate quantities and qualities of water for societal needs and resilient ecosystems, in the context of current and future global change [e.g. Refs. 3,4].

The water-management literature of the past two decades clearly reflects this new state of affairs. Attention to climate change, arguably the most egregious threat to water security, has helped globalize the problem of what some have called a water crisis. To address these challenges, recent approaches to water management tend to tilt away from 'hard-path, supply-side,' infrastructural solutions to 'soft-path,' demand-side, governance-based ones [5,6]. The soft-path approach to water-resources management seeks to avoid the common, unanticipated consequences of large-scale development ventures and instead emphasizes bottom-up, common-sense, institutionalized problem-solving. Soft-path approaches highlight the role of residents, communities, decisionmakers, water managers, and other stakeholders in achieving water security. In this case, adaptive financial priorities that focus on the social side of the problem (e.g. governance, demand management, monitoring, effective metering) are encouraged over investment on large water infrastructure project that rely on augmenting water supply (e.g. desalination, dams, inter-basin transfers).

Water security as a framing mode

Water security serves as a framing that highlights the importance of governance and advances soft-path approaches. This mode of analysis captures concerns about such issues as quality, quantity, equitable access,

and environmental provisioning of water supplies—all for present and future generations [7•,8••,9]. This understanding of water security also implies its adoption by a diverse set of actors from NGOs (nongovernmental organizations) [10] to UN actors [11–13] to academic researchers [e.g. Refs. 14,3]. Recent studies identified governance factors as key indicators of water security that highlight the robust and effective institutional arrangements needed to manage risk and resilience, share authority, and resolve conflicts, among other interactions between water users [15, e.g. Refs. 16,12,17]. Across all scales of governance, water-security researchers emphasize participatory processes—understood in the broadest sense—as a necessary pathway to achieving water security (as understood in Figure 1) [e.g. Refs. 18,19].

Borders and transboundary communities

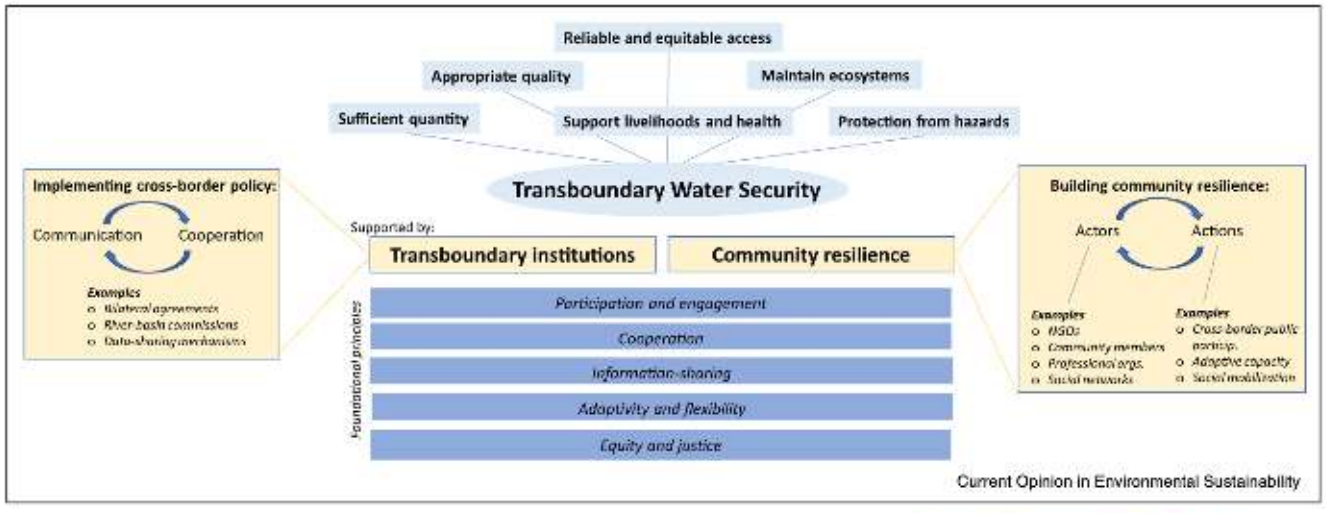
But whether hard-path or soft-path, most interventions are government-led and government-funded. As a result, proposed solutions typically address challenges solely within a single nation. Yet many of the world's outstanding water-security issues transcend national borders. A few examples include transboundary basin-wide hydroclimatic variability in arid regions [3]; overuse of shared aquifers [20]; and, wastewater flowing across borders [21]. These borders are often artificial, heedless of human, wildlife, and vegetative population distributions. Political boundaries also separate cultural norms, legal and administrative practices, and societal institutions—all while being distal from loci of central political influence and power [22]. These differences challenge efforts to adopt cohesive regional approaches to governance—especially governance of water and other environmental resources.

In this context, local communities are often overlooked in resilience planning, though such planning may be easier to accomplish than at larger jurisdictions or at the river basin scale. Yet the ability of such communities to tap cross-border networks makes their role vital. By 'community,' we adapt a definition from the public health scholarship to define community as local places with 'people of diverse characteristics who are linked by social ties, share common perspectives, and reside in geographical proximate locations or settings' [adapted from Ref. 23]. Communities may be urban cities or rural towns, with large or small populations but with social, cultural, and geographic ties.

Transboundary communities are especially vulnerable to the divisive influence of political borders, which can disregard shared histories, cultures, and languages that predate the political border line itself. Even so, close family ties, economies, and social networks can draw transborder communities together [24]. These attributes of local communities are relevant to the beneficial capacities needed for transboundary communities to work together to build resilience, such as long-term relationships and common definitions of vulnerabilities and problems [25,26].

Nevertheless, neighboring communities, even in the same country, can have competing goals and social power differentials, or long-standing conflicts, that may complicate building community resiliency [27•]. Local collaboration can lead to forms of cross-border cooperative governance that are sometimes informal. A few examples include firefighting and other emergency-response efforts in twin cities on the U.S.–Mexico border [28,29•] and on the Estonia–Russia border [29•]; and cooperation on agriculture, environment, health, and other matters along the Ireland–Northern Ireland border [30].

Figure 1



Depiction of a framework for the contribution of community resilience to transboundary water security [3–6,7•,8••,9,15,20,26,34••,37,42,46–50,55,60,63–65,70]. Community resilience is built by diverse actors through a variety of actions. (Figure created by T. R. Albrecht).

The role of resilience

Both scholars and international institutions [e.g. Ref. 31] increasingly focus on the role of local communities (sometimes cast instead as 'cities' or 'urban areas') in building resilience to diverse challenges such as climate change [e.g. Ref. 32•] and disasters and hazards [e.g. Ref. 33]. Although there is no single accepted universal definition of community resilience, some key identifying features of community resilience include such factors as local knowledge, community networks and relationships, and effective communication [34••]. We see 'community resilience' broadly as the processes linking the capacities of communities to adapt and continue their functions despite shocks and stressors that may alter their access to sufficient quantities of good-quality water [4]—is a critical element for water security, especially in transboundary settings. Accordingly, the role of community resilience in transboundary settings is especially crucial for achieving water security.

We begin by discussing the distinctive complications transboundary conditions impose on water security. Then, we draw from social-ecological resilience theory to highlight the role of community participation in water-related decisions. We aim to better understand how the notion of resilience can help identify situations with strong promise of coping with transboundary complications and how resilient institutions and community involvement may contribute to enhancing transboundary water security. We examine nine distinct cases from the U.S.–Mexico border region to examine how features of community resilience contribute to enhancing transboundary water security. We conclude with some observations about the connection between resilience and transboundary water security.

The transboundary environment

Transboundary waters are prevalent worldwide—more than half of the world's land area lies within a river basin where hydrologically connected water-resource systems traverse human-drawn, political borders [35]. In total, some 310 transboundary river basins (and 600 groundwater systems) connect nearly three billion people via their access to water [35,36••,37,38].[8] The importance of transboundary water resources—surface and groundwater—is increasingly noted by scholars and water managers. Their significance is attributable to both their global prevalence [36••,39,40][9], and to the growing pressures on water availability imposed by such drivers as climate change, development, and globalization [41,42].

Addressing these mounting forces requires effective water management, which in transboundary contexts is accompanied and complicated by institutional, sociopolitical, and economic obstacles. Water governance and management tasks—including the emplacement of robust institutions, realistic assessment, integrated planning and implementation—are generally far easier to conduct within a single jurisdiction than across multiple jurisdictions [15,20,43]. National governments typically have dealt with internationally shared water by favoring their own national interests. As a result, cooperation takes place principally to securitize water resources at the nation-state level [7•,44]. When cooperation is in the mutual interest of neighboring countries, the most common instruments adopted are treaties, conventions, accords, river-basin organizations, and occasionally, localized arrangements.

The cross-border nature of shared water resources makes effective resource management more complex in multiple ways such as uneven economic development and incongruous legal systems [45,46]; a history of political contention or conflict [45,46]; or a lack of functional and adaptive institutional capacity at local, national or basin-scales [47••,48]. Water governance and management tasks such as policymaking, planning, financing, assessing, and implementing typically are distributed among actors across multiple governance levels. Because of this diffuseness, building institutional capacity at local, national, and international levels is a challenge for transboundary water management [47••,49,50].

While much research has focused on transboundary cooperation and the role of river-basin institutions in transboundary water management with an emphasis on nation-states as the key actors [7•,44,47••,48,49], we examine the less well-understood role of local communities in transboundary contexts. Participation at the local level is particularly crucial for effective implementation of water management practices that are sustainable, equitable, and resilient over time. In the U.S.-Mexico border region, for example, strong transboundary institutions, such as the Treaty of 1944 that allocates the waters of the Tijuana, Colorado, and Rio Grande rivers, and the International Boundary and Water Commission (IBWC, known as CILA in Spanish), are an important factor in sustaining water security both regionally and for local communities in the border region [51]. These robust structures are a foundation that, despite uneven institutions and asymmetric power relations, undergirds water supply and to some extent, water quality considerations in key areas of the border. At the same time, investment represented by transboundary programs such as the North American Development Bank (and formerly, the Border Environment Cooperation Commission), has meant a substantial upgrade in wastewater treatment capacity in border communities and an enhancement of public participation in

[8] 'These basins are shared by 150 countries and disputed areas, cover 47.1% of the Earth's land surface and include 52% of the world's population' [36••].

[9] Of 35 largest river basins in the world, only 6 are not transboundary; those basins cover 154 countries, an average of 4.3 countries/basin [39].

some decision-making processes [52]. Thus, overall transboundary institutions have helped enhance water security for local border communities. Nevertheless, local municipalities alone are responsible for managing many water services, such as provision of drinking water and the development of some sanitation infrastructure.

Resilience in a water-security framing

Achieving water security within a community or society, as suggested above, is laden with difficulties—all the more so when international or jurisdictional borders are part of the landscape. As stated previously, communities—including ones that are transborder—may offer the most hospitable scale for confronting water insecurity (i.e., the absence of water security). Their role is at the forefront of socio-ecological resilience theory [53••].

In this case, healthy ecosystems that depend on social actions (e.g. preservation from development, conservation of biodiversity, and maintenance) can affect the hydrological cycle and water security. The field of resilience emerged from the work of ecologists in the 1970s studying the interaction of species and their functional responses to external disturbances in relation to ecological stability theory [54–57]. In these early studies, resilience was used as a measure of the ability of ecological systems to absorb external shocks without altering the existing relationships between species populations across temporal and spatial scales [54]. From these studies, resilience began to be applied at a larger scale and to nonlinear and complex trajectories of coupled natural-human systems. This expansion of the term's use implied a need to learn to manage while acknowledging change, a concept that became codified in the new logic of adaptive management [55,58]. The resulting approach to managing natural resources in uncertain contexts draws on theories about the co-evolutionary nature of human and natural systems, shifting towards an emphasis on the need for socio-ecological resilience [59,60]. Today, socio-ecological resilience is a rapidly expanding concept for both academics and practitioners, especially in consideration of aspects of community resilience.

When applied in the context of communities, social groups take the place of ecological features such as species and populations, as outlined in Adger's [61] widely used description of 'the ability of groups or communities to cope with external stresses and disturbances as a result of social, political, and environmental change.' Norris *et al.* [62] further sharpen our understanding of the social aspects of resilience through the lens of 'community resilience,' which they define as a 'process linking a set of adaptive capacities to a positive trajectory of functioning and adaptation after a disturbance.'

In the field of water resources, approaches to resilience are varied and inconsistent [63]. Some approaches focus on engineered resilience achieved through built infrastructure, adaptive institutional frameworks for water governance, the role of ecosystem services in mediating water resources availability and quality, or community resilience [64]. While these approaches can be applied at multiple scales, in transboundary contexts, studies tend to focus on resilience in transboundary institutions and mechanisms for cooperation [e.g. Ref. 65] as opposed to the local communities and social networks that span political borders.

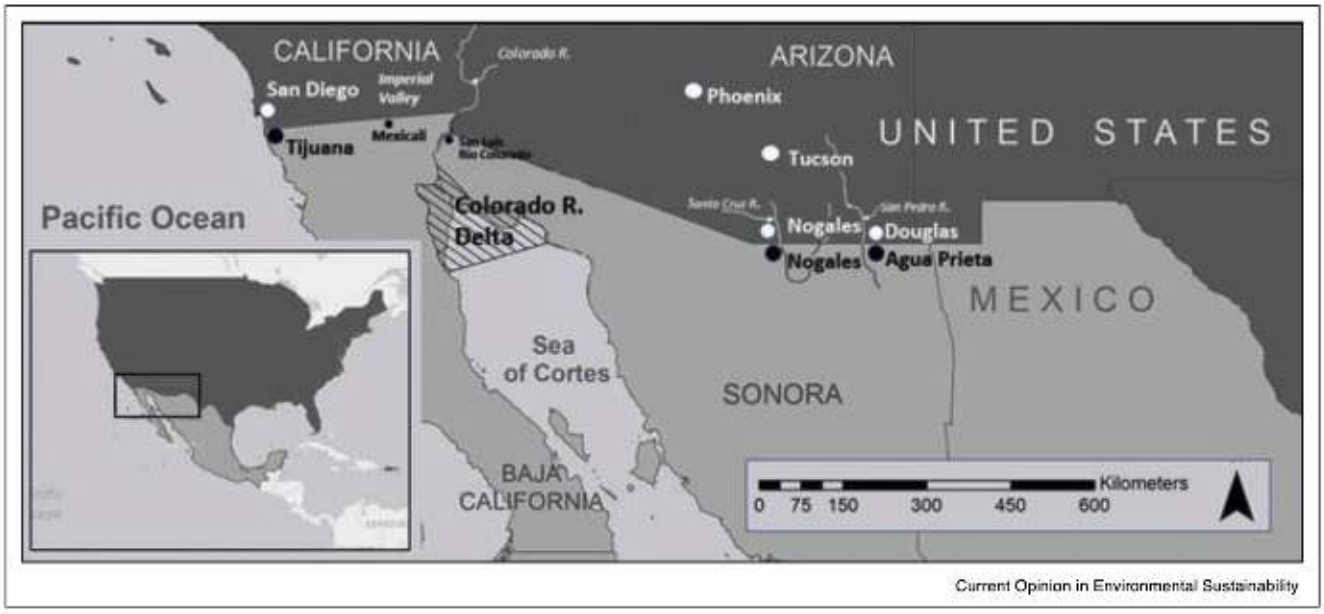
The capacity of social systems to be resilient involves active social networks that exhibit aspects of social cohesion, interconnectedness, and experience in community engagement [66,67••,68,69]. These characteristics allow various social groups to work together across scale, temporalities, and borders to mitigate and adapt to change [70]. Enhancing social resilience also relies on the presence of healthy ecosystems, strong and robust institutions, and adaptive financial priorities [71]. This means that communities that work together, even across forbidding political boundaries, are more likely to withstand problems associated with water insecurity.

Community resilience for transboundary water security: the rich case of the U.S.–Mexico border region

In a number of transboundary settings across the world, community resilience and bottom-up approaches at the local level are critical elements for assuring water security. Such efforts complement transboundary institutional capacity at the basin level, and both contribute to bolstering many elements of transboundary water security, as demonstrated in Figure 1. Both are built on shared principles of participation and engagement [e.g. Refs. 34••,45]; cooperation [e.g. Refs. 46,49]; information-sharing [e.g. Refs. 34••,45]; adaptivity and flexibility [e.g. Refs. 26,50]; and, equity and justice [e.g. Refs. 5,15]. The framework in Figure 1 guides our case study analysis in this section.

In the U.S.–Mexico border region, cross-border interactions offer a variety of particularly germane examples of long-lasting cross-border community collaboration. A key reason the U.S.–Mexico borderlands region (Figure 2) is such a rich laboratory for local resilient actions is a tradition of building social capacity and environmental resilience in communities. For instance, nearly two decades ago Lemos *et al.* [28] found that policymaking and water-service delivery in this region can occur in underserved communities when nonprofit organizations step in to support and work with the community to provide water and wastewater infrastructure. Part of the success of this type of program was its ability to adapt and respond to emergent situations—in other words, to tap resilience at the community level. In cases such as this, community engagement and adaptivity become determining factors

Figure 2



Map of U.S.–Mexico border region.

for water security (see Figure 1). Building community resilience in transboundary contexts also can involve social networks among cross-border actors including environmental NGOs, broad adaptive capacity including financial priorities, or social mobilization.

Below, we feature a suite of specific U.S.–Mexico cross-border collaborations underway in which communities and local institutions are taking the lead to make communities healthier and cleaner, and working to improve quality of life. These cases are displayed in four groupings that reflect diverse issue areas, including *urban water management, environment and conservation, transboundary flows and delta rehabilitation, and public health and water contamination*. In selecting these cases, we draw from *well-publicized activities or programs* in the border region that we have encountered in our long-standing research and engagement in the U.S.–Mexico border region. We rely on *publicly available* websites, reports, and academic scholarship in presenting these cases. They illustrate situations in which community action helped strengthen resilience—even in the face of the many previously mentioned obstacles of working across the border and the complications that poses.

Case 1: urban water management in border communities

Transboundary effluent use

Wastewater treatment in the twin border cities of Nogales, Sonora, and Nogales, Arizona (AZ) illustrates the complexity of transboundary resource management at the urban scale [72]. Topography dictates a south–north flow of water from the Mexico to the U.S. Binational cooperation was thus needed to treat wastewater from both cities. Because of the land gradient, an international treatment is 9 miles north of the border. In the U.S., effluent discharged into the Santa Cruz River has resulted in beneficial ecosystem services. But in Nogales, Sonora, the paving of natural drainage systems intensifies flash-floods [73], which are further increased by a border wall that inhibits natural runoff [74]. In Nogales, AZ, the poorly maintained infrastructure that conveys binational sewage to the treatment plant causes frequent sewage spills, posing serious health risk. After decades facing these challenges, the two communities have created networks of local administrations, government agencies, NGOs, and academics. For example, U.S.-based watershed modeling identified locations for flood-reducing berms in Sonora, while in Nogales, Sonora, academics collaborating with local government developed a comprehensive urban-planning project to address flooding [75]. That plan led to local greening efforts (e.g. schools) to decrease sediment and erosion and increase social awareness [76].

Urban greenspace justice

In Tucson, Arizona, 45% of the population identifies as Hispanic/Latino. In the southern part of the city, the proportion is considerably higher. There, students at a high school have been working since 2018 on an urban greenspace justice project called *Tucson Verde para Todos*, Green Tucson for All. Led by University of Arizona

researchers and local nonprofit, Watershed Management Group, the effort seeks to increase urban green infrastructure and enhance resilience through the use of appropriate technologies. The project helps control floods, and reduces heat by providing shade, and overall it addresses the problem of urban heat stress in low-income, marginalized communities in a part of the city that is vulnerable to floods and extreme heat [77].

Empowering women and community gardens

Since 2003 a women's cooperative, DouglaPrieta Works, involves women from the binational communities of Douglas, AZ, and Agua Prieta, Sonora. The cooperative engages in aquaculture, runs a community garden to help sustain their families' food security, and operates a sewing cooperative to help provide household incomes. The cooperative operates a permaculture demonstration site designed to teach families sustainable food-production techniques, including gardening, aquaculture, and small livestock raising.

Case 2: environment and conservation[10]

Education

Pronatura Noroeste and the Universidad Autónoma de Baja California (UABC) train local women in the Colorado Delta region to participate in monitoring and educating about bird populations in the Pacific Migratory Flyway. In spring 2019, they set up an educational tent on the beach, designed to teach visitors about the site's shorebirds, and their relationship with the fish on whose eggs they depend. Teresita Félix, one of local stewards, said of the project 'We're educating ourselves about the birds and cultivating a respect for them, getting to know their life cycle and spreading the word about what they come to this site to do.' Short exit surveys of visitors indicated a new ability to recognize the migratory shorebirds and an intention to help conserve them.

Citizen science

The Sky Island Alliance works in a cluster of global biodiversity hotspot in northwestern Mexico and the southwestern U.S. This ecoregion features isolated 'sky-island' mountains, ranging from 915 to 3300 m (3000–10 000+ feet). The Alliance's goals—accomplished thanks to over 400 volunteers from the two countries contributing over 12 000 hours annually—are to protect open space, restore land and water, maintain wildlife corridors, and advance science. Two projects are particularly related to water sustainability. As part of its citizen-science programs, five time per year, volunteer groups monitor the health of springs in the arid desert. And on restoration field trips, they plant native pollinator vegetation, remove invasive species, build water saving features with natural materials, and construct wildlife ramps for frogs and other small wildlife to reach water.

Advocacy, fundraising, and education

A number of river-basin-protection groups have been active in the region. One, the Friends of Big Bend/Big Bend Conservancy was started in 1995 with a mission to support, promote, and raise funds for two border-region natural areas, Big Bend National Park in Texas and the Rio Grande Wild and Scenic River in partnership with the U.S. National Park Service. The Conservancy has restored some 23 ha (55 acres) of wetlands in the Park and is restoring riparian bird habitat in a disturbed river site in the park. To the west, also on the Arizona–Sonora border, Friends of the San Pedro Rive in Arizona is a mostly volunteer, nonprofit organization dedicated to conservation and restoration of the San Pedro river through advocacy, education, interpretation, and field-work. And a bit further west, Friends of the Santa Cruz River, also in Arizona, has operated since 1991 to protect and enhance the flow and water quality of the Santa Cruz River, as well as the health of the riparian ecosystem that the river supports. The nonprofit, all-volunteer group addresses the perennial-flow portion of the river and works with riverside landowners, government agencies, and other citizens' and community groups to keep the river flowing, its banks clean and green, and its environment bountiful to both wildlife and people.

Coastal cleanup and scientific collaboration

For 40 years, the Intercultural Center for the Study of Deserts and Oceans (CEDO), in Puerto Peñasco, on Mexico's Sea of Cortes/Upper Gulf of California coast, has led the binational Arizona–Sonora region in coastal conservation. CEDO relies on a binational staff of a few paid employees, and young university students and volunteers. Activities include conducting ecological research, educating children about protecting coastal environments through binational and bilingual summer camps, working with local fishing communities to improve fishing practices while protecting livelihoods, hosting frequent beach cleanups, and supporting women's cooperatives.

Case 3: transboundary Colorado River flows and rehabilitating the Delta region

In 2008–2009, unilateral action by the U.S. to line the earthen All-American Canal (AAC) with concrete over objections and court challenges by Mexico resulted in an ineffective outcome, when accounting from a *transboundary* perspective. The AAC is an 80-mile (128-km) aqueduct in southeastern California that conveys Colorado River water west to Imperial California's Valley farms and to nine cities. These court cases were decided in favor of the U.S., which viewed lining as a loss-prevention

[10] For descriptions of the community organizations cited, see the following Web sites (all accessed 26 Nov. 2019): Pronatura Noroeste (http://pronatura-noroeste.org/es/); Sky Island Alliance (https://www.skyislandalliance.org/); Big Bend Conservancy (https://bigbendfriends.org/get-involved/events); CEDO (http://cedo.org/en/home)

measure for water it saw as belonging to the U.S.' allocation. Mexico viewed the lining as essentially a 'taking' of cross-border seepage water that had been utilized by farmers in the Mexicali area for over 60 years [51]. In ignoring Mexico's traditional claims to the seepage water and not involving border communities in the decision, the U.S. satisfied only California's needs without regard to the impact for Mexican farmers in Mexicali [78]. However, on the very heels of this conflict, a 2010 earthquake in Mexicali called forth a humanitarian response on the part of the U.S. Mexico was allowed to store portions of its Colorado River allocation in U.S. reservoirs. This temporary measure led to one of the most striking transboundary collaborations in the history of this border region, resulting in a treaty amendment in which the U.S. and Mexico agreed to provide 'environmental flows' to sustain critical endangered wetlands in the Colorado River Delta, located entirely within Mexico. The amendment—known as Minute 319—was in effect from 2012 to 2017 and allowed the restoration of vast swaths of the wetland areas [81]. Subsequently, Minute 323, which is in effect from 2017 to 2024, institutionalizes some of the ecological measures and provided a pathway for an environmental trust to purchase surplus water rights to continue the restoration effort [79, 80]. The U.S.–Mexico collaboration integrally involved formal institutions such as the joint International Boundary and Water Commission and invoked the amendment mechanisms of the Treaty of 1944, showing the importance of robust institutions. But in addition to these formal binational and national actors, long-standing networks of NGOs, community organizations, and scientists played significant roles in developing Minutes 319 and 323, leading to a healthier and more resilient ecosystem in this biodiverse area of the border. Many of these community-level actors remained engaged in studying both the ecological and social impacts of the environmental flow in the delta region.

Case 4: public health: cross-border response to water contamination

We define water security as access to sufficient amounts of good-quality water for society and resilient ecosystems, for now and for the future. Even when water is available, breaches in quality can arise jeopardizing water security and harming human health. When transboundary transmission of waterborne diseases occurs, identifying the source of contamination can become even more challenging. Lack of collaboration and sharing of information may even result in undetected outbreaks [81]. Trust and collaboration between local communities spanning borders can significantly improve the identification and resolution of these threats. The benefits of these cross-border ties were evidenced in a binational outbreak investigation that took place in Arizona, U.S., and Sonora, MX. In 2011, the state of Sonora identified an unusual number of cases of acute flaccid paralysis in San Luis Río Colorado (MX). At the same time, the Yuma County (AZ) health department identified several cases of Guillain-Barré syndrome. After laboratory testing, *Campylobacter jejuni* was identified as the likely pathogen. A pre-existing binational communication system facilitated the initial exchange of information and a transboundary investigation was launched. The process entailed working cooperatively to conduct a case-control study to identify the source of the outbreak. Investigators assessed drinking water, wastewater systems, and hydrology of the area to determine potential environmental exposures. They collected samples of drinking water from San Luis Río Colorado and tested by the Centers for Disease Control and Prevention. Data were shared between countries on routine water-quality testing conducted in both cities.

Throughout the outbreak, the binational team acted as a single unit and reported investigation progress jointly to the Pan American Health Organization (PAHO). While the source of the outbreak was not absolutely determined, its identification and causal pathogen would not have been possible without cross-border cooperation. Public-health officials stated that the collaborative investigation resulted in higher-quality and more-comprehensive data than would have been collected independently. The local-level collaboration between the health departments and stakeholders, including water providers and community members, had been developed over decades of prior collaboration on other health issues such as providing continuity of care tuberculosis cases and other infectious disease issues. Even in the face of significant political tensions; the outbreak occurred less than a year after a controversial Arizona anti-illegal immigration bill, SB 1070; local-level cooperation and trust allowed the communities to work together as a single unit to address the outbreak.

Discussion and analysis

The above cases demonstrate examples of cross-border public participation, adaptivity and flexibility to respond to changing dynamics, and social mobilization to achieve equitable and just outcomes—features we see as critical to community resilience (see Figure 1). Building community resilience, in turn, is a slow process, triggered by common challenges. It is clear that building such resilience requires time and resources to maintain it, and constant efforts to move it forward.

The cases illustrate both challenges and successes of community resilience in addressing many aspects of transboundary water security, from managing urban wastewater to enhancing environmental flows to support habitat for migratory birds. In the Delta and urban-effluent examples, the active participation of local communities was necessary in order to design strategies and approaches to meet local needs. While at times, border issues may be formally institutionalized in bilateral

agreements, such top-down approaches insufficiently address local disparities of access to water and sanitation and challenges to securing adequate financing for infrastructure projects. Yet, cross-border cooperation on wastewater treatment addressed the lack of treatment capacity in Nogales, Sonora, while also providing a beneficial use for treated wastewater to support riparian ecosystems in Arizona. In addition to utilizing the adaptivity and flexibility of the treaty design, cross-border social networks were a powerful driver of collaboration and facilitated knowledge-sharing and joint planning that enhanced the health of cross-border ecosystems.

The urban water-management and conservation examples demonstrate the importance of community engagement, social mobilization, and learning accomplished through educational programs, community garden projects and citizen science-based monitoring efforts. These programs also address water-access inequality by engaging marginalized populations, such as women and low-income populations. Community participation in river-basin-protection groups demonstrates the influence that such social networking and community engagement can have on fundraising, education, and advocacy—even in cross-border settings. Citizen science, environmental cleanup, and educational efforts increase local awareness of cross-border environmental challenges, as well as the organizations and individuals working to address them in their communities. Networks of NGOs and community members achieved meaningful outcomes for in ecosystem conservation in multiple transboundary rivers in the border region, including the landmark 2014 ecological water-release to the Colorado River Delta. These social networking and engagement activities help to solidify relationships among border actors that persist and grow over time, increasing potential for future collaborative efforts.

The example of water contamination and public health demonstrates the importance of establishing professional networks and information-sharing protocols in advance of an emergency. When urban water was found to be contaminated, community participation and information sharing was immediately initiated and was facilitated by an established cross-border organization. Such binational institutional capacity, prearranged data-sharing procedures and active participation allowed for a rapid and more comprehensive response to an emergent situation that ultimately reduced public exposure to water-related health risks. These examples feature various elements of community resilience that are linked to tangible outcomes that bolster transboundary water security.

Conclusion: resilience and transboundary water security

In this essay, we have employed the broad concept of water security as a framing mode to explore the exigencies and complicating conditions of international borders. Clearly, when natural resources or environmental processes cross constructed borders, they face sociopolitical and economic obstacles to effective governance and management practices. We paired this observation with a question: *How does the notion of resilience help identify situations with strong promise of coping with transboundary complications?* Going further, we asked how resilient institutions and community involvement may contribute to enhancing transboundary water security.

In seeking an answer, we expected to, and did see that diverse pathways would be taken. We also anticipated that each pathway likely would reflect the context of the issues and associated community preferences. In surveying the literature and supplementing that exercise with some regional case studies, we confirmed that this context featured diverse actors—from citizens and scientists to NGOs and government agencies. The collective actions of these stakeholders sometimes are formal, and at other times informal. But those actions have in common the elements of public participation, adaptive capacity, and social mobilization, which taken together are critical components of a slow process we recognize as community resilience. We observe that such community resilience needs to be nurtured and maintained and that the absence of any of the key components can yield insecurities such as water insecurity.

To illustrate our observations, we looked at the U.S.–Mexico border region, one of the world's longest and most important international boundaries. The region surrounding this border exhibits stark political, cultural, economic, and administrative asymmetries. We selected nine very brief cases of transboundary issues in which community resilience played a constructive role in enhancing water security. These examples are displayed in four groupings that reflect diverse issue areas, including *urban water management, environment and conservation, transboundary flows and delta rehabilitation, and public health and water contamination.*

From our look at the relationship between transboundary water security and community resilience, we perceive fruitful avenues for continued probing. We don't know enough about the extent to which these phenomena interact and are mutually supportive. A more nuanced and complete understanding of these relationships will benefit from a multi-method research approach that comprises both temporal and spatial investigations. Such work may include network analysis coupled with qualitative interviews, and surveys and participant observation across multiple scales and issues. We see theoretical benefits to understanding resilience and the role of governance, but also practical, on-the-ground insights that can inform policymaking, investments, institution-strengthening, and capacity-building. Ultimately, the objective of this

pursuit is to better communicate when and where things work, and where the absence of particular components of community resilience produce water insecurities.

Conflict of interest statement

Nothing declared.

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