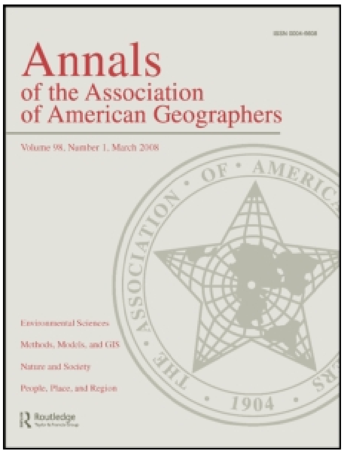

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Adapting Across Boundaries: Climate Change, Social Learning, and Resilience in the U.S.-Mexico Border Region

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Adapting Across Boundaries: Climate Change, Social Learning, and Resilience in the U.S.–Mexico Border Region

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The spatial and human dimensions of climate change are brought into relief at international borders where climate change poses particular challenges. This article explores "double exposure" to climatic and globalization processes for the U.S.–Mexico border region, where rapid urbanization, industrialization, and agricultural intensification result in vulnerability to water scarcity as the primary climate change concern. For portions of the western border within the North American monsoon climate regime, the Intergovernmental Panel on Climate Change projects temperature increases of 2 to 4°C by midcentury and up to 3 to 5°C by 2100, with possible decreases of 5 to 8 percent in precipitation. Like the climate and water drivers themselves, proposed societal responses can also be regionalized across borders. Nevertheless, binational responses are confronted by a complex institutional landscape. The coproduction of science and policy must be situated in the context of competing institutional jurisdictions and legitimacy claims. Adaptation to climate change is conventionally understood as more difficult at international borders, yet regionalizing adaptive responses could also potentially increase resilience. We assess three cases of transboundary collaboration in the Arizona–Sonora region based on specific indicators that contribute importantly to building adaptive capacity. We conclude that three key factors can increase resilience over the long term: shared social learning, the formation of binational "communities of practice" among water managers or disaster-relief planners, and the coproduction of climate knowledge. *Key Words: adaptive capacity, climate change, U.S.–Mexico border, vulnerability, water.*

气候变化的空间和人文尺度被带入在气候变化带来尤其挑战的国际边界的救援。本文探讨美国和墨西哥的边境地区气候和全球化进程的双重影响。在此地区，快速的城市化，工业化和集约化农业导致主要气候变化的担忧，即水短缺的脆弱性。对于北美季风气候内的西部边境部分，政府间气候变化专门委员会预测气温到本世纪中叶将升高 2 至 4°C 和到 2100 年升高 3 至 5°C，同时伴随百分之 5 至 8 的降水下降。如同气候和水驱动因子本身，提出的社会反应也可是跨国界的区域化。尽管如此，两国的反应正面临复杂的体制景观。科学和政策的合拍必须位于司法管辖区的竞争体制和合法索赔的范围内。传统上认为在国际边界适应气候变化比较困难，但区域化适应性反应弹性还有可能增加。基于对建设适应能力作出重要贡献的特定的指标，我们评估了亚利桑那州－索诺拉区域的三个跨界协作案件。我们的结论是长远来讲三个关键因素可以增加弹性：共享的社会学习，水资源管理人员或救灾规划者之间形成的两国"实践社区"，以及气候知识的合拍。*关键词：自适应能力，气候变化，美国和墨西哥边境，脆弱性，水。*

Las dimensiones espaciales y humanas del cambio climático se hacen particularmente relevantes en las fronteras internacionales, lugares donde el cambio climático genera retos especiales. Este artículo explora la "doble exposición" de los procesos climáticos y globalizadores para la región fronteriza EE.UU.–México, donde la rápida urbanización, industrialización e intensificación agrícola resultan en vulnerabilidad por escasez de agua, como la preopcupación primaria por el cambio climático. En porciones de la frontera occidental ubicada dentro del régimen climático del monzón norteamericano, el Panel Intergubernamental de Cambio Climático proyecta incrementos de las temperaturas de 2° a 4°C para mediados de siglo y de hasta 3° a 5°C para el 2100, junto con una posible disminución de la precipitación de 5 al 8 por ciento. De la misma manera que ocurre con lo concerniente a clima y agua, las respuestas sociales que se proponen también pueden regionalizarse a través de las fronteras. Sin embargo, las respuestas binacionales se ven confrontadas con un paisaje institucional complejo. La coproducción de ciencia y políticas debe situarse en el

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contexto de jurisdicciones institucionales en competencia y reclamos de legitimidad. La adaptación al cambio climático se la entiende convencionalmente como más difícil en fronteras internacionales, pero regionalizar las respuesta adaptativas también puede aumentar potencialmente la resiliencia. Evaluamos tres casos de colaboración transfronteriza en la región Arizona-Sonora, con base en indicadores específicos que contribuyen de modo importante a construir capacidad adaptativa. Nuestra conclusión es que hay tres factores claves que pueden incrementar la resiliencia a largo plazo: aprendizaje social compartido, la formación de "comunidades de práctica" binacionales entre administradores del agua y planificadores de alivio por desastres y la coproducción de conocimiento sobre el clima. *Palabras clave: capacidad adaptativa, cambio climático, frontera EE.UU.–México, vulnerabilidad, agua.*

International borders bring into relief the complex and diverse spatial and human dimensions of climate change. The U.S.–Mexico border region is both emblematic—many countries share transboundary climatic regimes—and exceptional—infrequently does an international border juxtapose neighbors with such differing, highly uneven development, although some other border areas bear important similarities. For countries sharing land borders, the impacts of and adaptation to climate change in the transboundary context pose significant challenges (Pavlakovich-Kochi, Morehouse, and Wastl-Walter 2004). An increasing body of scholarship has emerged on the specter of global insecurity due to unstable and inequitable environmental governance practices. This research calls for a greater awareness of the security challenges—broadly interpreted—associated with managing scarce water and other resources in the context of climate change (Gerlak, Varady, and Haverland 2009; O'Brien, St. Clair, and Kristofferson 2010). Water security, particularly in a transboundary context, must increasingly consider climate change, hydrologic, economic, and institutional dimensions of access to and reliability of supply of water for expanding populations. International fora, referred to as "global water initiatives" by Varady et al. (2008, 1), have been established specifically to address this multidimensionality. Avoiding "hydroschizophrenia" and promoting "hydrosolidarity" among countries competing over contested and increasingly scarce water resources are principal goals of this body of work (Falkenmark 2001; Jarvis et al. 2005). Yet national aspects of these challenges typically remain the focus of policymaking and scholarship. We suggest that explicit attention to transboundary challenges of climate change could yield fresh and beneficial insights.

In the case of the United States and Mexico, developing national adaptive responses to climate change, without reference to political and social regimes across the 2,000-mile border, has often yielded less-than-optimal, even harmful outcomes. For example, when in 2008 the U.S. Department of Homeland Security extended its border wall at Nogales, without consulting Mexican officials, subsequent thunderstorm runoff flowing northward into Arizona became trapped and backed up, flooding numerous stores and homes in Mexico and causing significant property damage. Similar problems have occurred along the border, as when the United States unilaterally limited seepage losses in the All-American Canal, which conveys Colorado River water to San Diego, by lining the channel along the border west of Yuma, Arizona. In response, Mexico filed suit in international court to seek redress for the loss of groundwater recharge (from the canal seepage) that had for many decades served a major irrigation district and sustained critical wetlands habitat. In another example, Mexico's nonpayment of its water debt to the United States, per terms of the 1944 treaty governing sharing the waters of the Rio Grande, erupted in 2002 into a major geopolitical dispute.

In the past, such failures to address transboundary issues cooperatively have often characterized binational relations. Despite this history, recent initiatives in collaborative, transboundary environmental management—particularly for water and wastewater—have become more common, with the emergence of binational institutions such as the Border Environment Cooperation Commission.

This article argues for a transboundary approach to improve the adaptive capacity to climate change, especially for water resources management, in the Arizona–Sonora region. Adaptation to climate change is conventionally understood to be more difficult at international borders. Yet we maintain that regional adaptive responses across borders could increase resilience and decrease vulnerability to climatic changes. Such cross-border approaches can emerge through shared social learning and knowledge, by creating binational communities of practice, such as among water managers or disaster-relief planners, and by addressing inequities resulting from uneven development. We suggest that the strengthening of institutional networks and the coproduction of climate knowledge across borders enhance a binational region's long-term adaptive capacity and resilience.

Theoretical Approach

Although climate change introduces uncertainty and risk for water management, a process-oriented analysis focused on social learning—common understandings of challenges among individuals or institutions—allows a better understanding of this dynamism and uncertainty. Milly et al. (2008) questioned the validity of decision making based on static definitions of the bounds of climatic and hydrologic variability. Within transboundary contexts, adaptive responses to climate change are complicated. Risk and vulnerability, socially constructed concepts, are differentially conceived within cultures and across borders. Our Arizona–Sonora empirical analysis suggests that binational responses to water resources management must consider the context of competing institutional jurisdictions and legitimacy claims.

In seeking the key to the creation of sustainable policy informed by the best science, some scholars emphasize the process of knowledge transmission (Cash et al. 2003), whereas others focus on the creation of scientist–stakeholder networks (Lemos and Morehouse 2005; Pelling et al. 2008). Cash et al. (2003) argued that three criteria are key to mobilizing science and technology to achieve sustainability: the salience, or relevance of scientific information to decision makers; the credibility, or scientific adequacy of the information; and the legitimacy of the information or degree to which it reflects diverse stakeholder values and beliefs and is seen as unbiased. Cash et al. (2003) identified, in turn, three "functions" that lead to effective linkages between scientific knowledge and the production of sustainable policy, including the effectiveness of the communication of knowledge to policymakers, the translation (literal and figurative) of the knowledge in the scientist–decision maker interaction, and the mediation of conflicts to ensure transparency and rule enforcement. Lemos and Morehouse (2005) emphasized that the effective coproduction of scientific knowledge and the potential for developing meaningful policy relies on a synergistic relationship among stakeholders and researchers. In their interactions, these networks ideally move beyond discussion to adapt and transform processes (Lemos and Morehouse 2005, 61). Sustained and dynamic interactions among these networks can create "usable science" and effective policy.

Following Pelling et al. (2008), we ask how institutions shape capacity to build adaptive organizations within the Arizona–Sonora border region. We understand adaptive capacity to be a dynamic process based on social learning between and within institutions, rather than a static condition or set of attributes and outcomes (Pahl-Wostl 2007; Pelling et al. 2008). Shared social learning in a transboundary setting refers to the development of common conceptual understandings of climate challenges and regional vulnerability integrated over multiple institutional scales, from individuals and local agencies to state, federal, and binational actors and authorities. In their analysis of the processes associated with effective knowledge sharing between experts and decision makers, Cash et al. (2003) illuminated key aspects of the social learning process that are referenced in the following individual cases. Social learning can take place by individuals operating within a formal institution or collectively by institutions. Within professional communities (such as water managers, disaster-relief planners), informal communities of practice develop based on trust over sustained, iterative interactions and collaborative, peer-to-peer learning (Pelling et al. 2008). A sustained, dynamic, social learning process can stimulate adaptive capacity in regional water management institutions. Adaptive management itself is constructed—or very strongly conditioned—institutionally. By its very nature as an evolutionary, interactive ("learning"-based), and assimilative process, adaptation depends on how challenges are defined and desired outcomes set. Resilience refers to the capacity of socio-ecological systems to self-organize and to build capacity to learn and adapt, to undergo change while retaining the same functions and structures (Folke, Hahn, and Olsson 2005; Resilience Alliance, http://www.resalliance.org, last accessed 4 March 2010).

Communities are associations based on shared identity in which common values and practices are reinforced (Wenger 1999). *Networks* are informal constellations that cross boundaries of community identity and create new vehicles for information flow within or between organizations. Together, communities and networks can form communities of practice (Wenger 1999) that connect due to bridging ties of social capital (e.g., boundary people who bring different communities together into networks, and boundary objects, meetings or documents that join communities into a linked network). Communities of practice can develop adaptive pathways—new institutional priorities or ways of carrying out activities—within and among organizations.

One such pathway would be created if an organization changes its management structure or practices to accommodate different strategies needed to address climate change.

We first examine the challenges of vulnerability in the Arizona–Sonora region, targeting the area's diverse institutional composition and the problems posed for developing adaptive capacity. Second, we consider cases of innovation in regionalized practices that attempt to bridge the transboundary divide. Many of these are nascent in this region, responding to an evolving understanding of shared cross-border climate and water challenges. As a result, we address potential outcomes and emerging results, as all three cases presented are in early stages of development. Among the authors, one or more of us has been involved in these different collaborations or in researching them; thus, this assessment of adaptive potential also serves to illuminate the more (and less) adaptive aspects of these ongoing collaborative processes and may help to improve them as they develop. This assessment is not intended as a report card on outcomes of any of these processes, but rather, an exploration of the question: what components of binational collaboration are most critical to developing successful adaptation? Because all three cases possess the multiple climate–water–institutions dimensionality referred to earlier, assessment of their adaptive-capacity potential (hereafter, adaptive potential) permits us to apply social learning theory and transboundary analysis as central to science–policy coproduction within each of the three cases and to derive more generic understanding relevant for other cases. Evaluation of adaptive potential considers (1) augmentation strategies (Blackmore and Plant 2008) relying on water transferred from distant sources or using high-cost technologies and infrastructure, (2) information flows and data sharing, and (3) regionalized coproduction of knowledge and policy. Via our process-based understanding of adaptive potential, we employ three indicators, or measures: (1) dynamic, structured opportunities for social learning; (2) emergence of formal and informal networks; and (3) potential for development of adaptive pathways. These indicators permit us to assess the adaptive potential in three regionalized transboundary cases. In conclusion, we consider the implications of these regional strategies in three contexts: (1) coproduction of science and policy across national borders, (2) building of transboundary communities of practice, and (3) development of shared platforms for social learning within institutions.

Vulnerability in the U.S.–Mexico Border Region

Vulnerability is conditioned by socioeconomic, institutional, and political as well as environmental factors, including climate (Adger et al. 2006). Assessing vulnerability requires consideration not only of exposure to climate change but also of the risk associated with that exposure and the capacity of an individual, community, or nation to adapt to impacts of climate change (Adger et al. 2006). Vulnerability in the border region's water sector is thus a function of intensified socioeconomic processes—rapid growth, accelerated globalization—and environmental change. Socioeconomic vulnerability is also conditioned by age, ethnicity, gender, or class. For example, elderly people and African Americans in poor neighborhoods were most at risk to the devastation of Hurricane Katrina (Verchick 2008). In the border region, the high concentration of Hispanics, especially in poor U.S. counties and in unplanned Mexican colonias, increases vulnerability for these populations. People might be at higher risk to drought if water becomes scarce and therefore more expensive, if they lack sufficient resources to access or purchase nontraditional water sources. After storms, water trucks (*pipas*) that service marginal neighborhoods might not have access to homes via flooded streets. The region's capacity to respond to these and other high-vulnerabililty water-related challenges depends largely on its water management institutions.

The U.S.–Mexico border region—as a vulnerable area undergoing urbanization, industrialization, and agricultural intensification—is a textbook case of "double exposure" (Leichenko and O'Brien 2008) to climatic and globalization processes (Liverman and Merideth 2002; Ray et al. 2007). The U.S. Southwest and northwest Mexico, where global climate models project severe precipitation decreases and temperature increases, has been called "the front line of ongoing climate change" (Harrison 2009, 1; see Figure 1). Anticipated probable impacts include longer, more extreme droughts, higher water and energy demand, decreased inflows to rivers and streams, and increased urban–agricultural conflict over water (Intergovernmental Panel on Climate Change 2007; Seager et al. 2007).

Since the 1980s, the border region has grown faster than each country's national average. In the United States, an expanding leisure class of retirees, seasonal tourists, and other "amenity seekers" are influencing water management decisions about consumption and

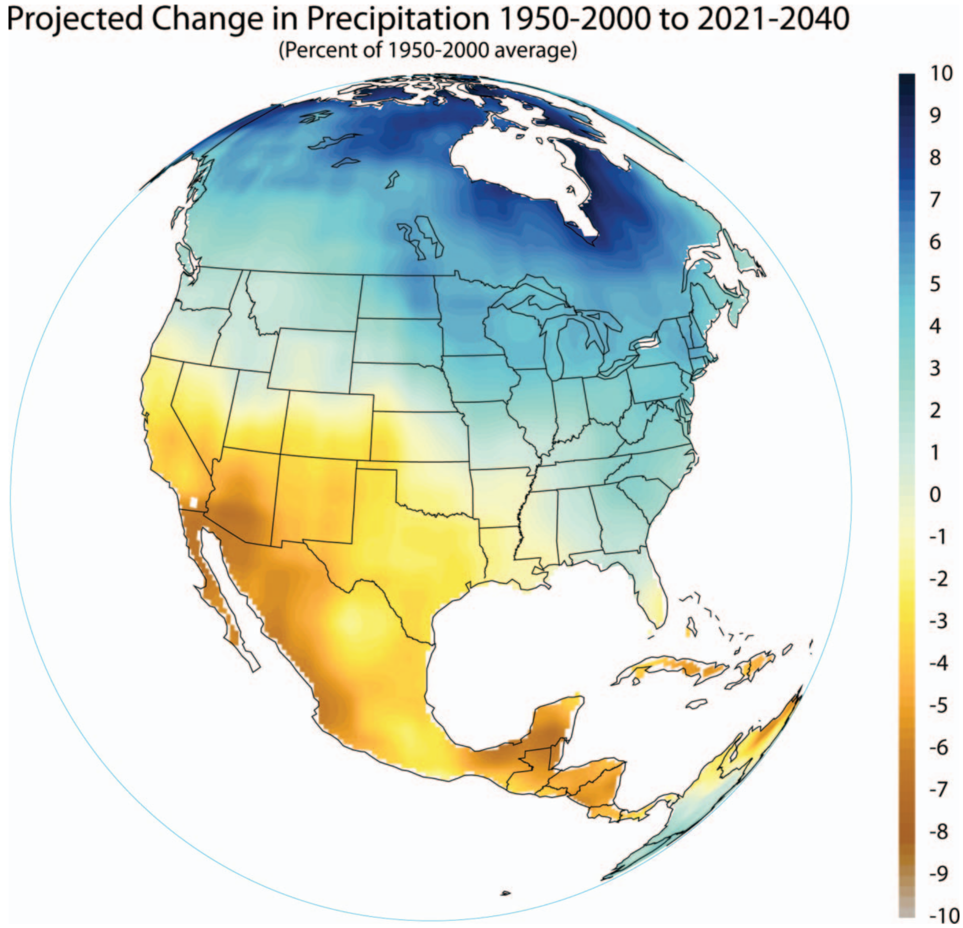

Figure 1. Projected change in precipitation: 1950–2000 to 2021–2040: Projected change in precipitation for the 2021–2040 period minus the average over 1950–2000 as a percentage of the 1950–2000 precipitation. Results are averaged over simulations with nineteen different climate models. *Source:* Figure by Gabriel Vecchi, Geophysical Fluid Dynamics Laboratory, National Oceanic and Atmospheric Administration.

conservation. In Mexico, rapid urban growth, driven by availability of jobs created by hundreds of foreign-owned *maquiladoras*, has shifted water-use priorities away from the past farming and ranching economy. Although agriculture remains the largest user of water in Arizona (70 percent of total demand; Arizona Department of Water Resources 2009) and Sonora (86 percent of consumptive use; Comisión Nacional del Agua 2008), growth patterns are driving a shift of water to urban areas. In Mexico's northwest, one quarter of aquifers are severely overdrafted. In Sonora 95 percent of the population has potable water supply and 84 percent has sewerage service (Comisión Nacional del Agua 2008). Many households that have hookups experience daily interruptions to water service, however, and tap water is generally not of drinking quality.

Complex Binational Institutional Landscape

Water management in the border region is fragmented and complex with disparate characteristics in the two countries. The geopolitical relationship between the United States and Mexico complicates cooperation and agreement on water management. For example, U.S. immigration control or drug-trafficking policies often are made with little consultation with Mexico and exacerbate the geopolitical context within which binational water resources issues are considered.

Even otherwise uncomplicated tasks such as constructing a regional database are more difficult in this region, which lacks comparable data and a history of sharing such information (Comrie 2003). Over the past century, the two national governments have established several joint institutions for managing transboundary waters—such as the International Boundary and Water Commission (IBWC) and its Mexican counterpart, CILA; the La Paz Treaty of 1983; and the post-NAFTA Border Environment Cooperation Commission—but these institutions have only a narrow range of responsibility, much of it involving infrastructure construction (Varady and Ward 2009).

In Mexico, water management remains highly centralized in the National Water Commission,

Table 1. Indicators for assessment of potential adaptive capacity building in regionalized transboundary initiatives

Transboundary regionalized initiatives	Social learning	Formal networks	Informal networks	Potential to develop adaptive pathways within institutions	Overall assessment of potential adaptive capacity
Augmentation strategies: Desalination proposals	Low	Low	None	Low	Low
Data sharing and improved information flows: TAAP	High	High	Low	Medium	Medium
Coproduction of science and policy: *Binational Climate Summary* and urban/coastal vulnerability assessments and planning	High	High	High	Medium	High

Note: TAAP = U.S.–Mexico Transboundary Aquifer Assessment Program.

headquartered in the capital (Scott and Banister 2008; Varady and Ward 2009). Despite more than a decade of transferring water management formally to local municipalities and water user associations in irrigation districts, the impact of decentralization has been uneven and limited by lack of revenue-generating authority (Pineda 2002; Wilder and Romero-Lankao 2006; Wilder 2010). In spite of regional variations in water and climatic conditions, the federal government imposes a uniform administrative and management structure. Urban water managers have very limited access to the climate information necessary to plan more adaptively for climate change (Browning-Aiken et al. 2007). Although many rigorous environmental laws exist, their enforcement is uneven. Most seriously, in a weak economy, lack of funding constrains all levels of resource management. Short municipal terms, limited to three years, and lack of a civil service cause high personnel turnover, making sustained planning difficult to achieve over a multiyear horizon (Pineda 2002).

On the U.S. side, most water management institutions are decentralized, with multiple instances of overlapping missions and jurisdiction among various federal, state, and local agencies. Emblematically, dam and reservoir management and allocation is shared by the Army Corps of Engineers, Bureau of Reclamation, Federal Energy Regulatory Commission, federal power marketing agencies, state and local water management entities, public utilities, and irrigation districts (U.S. Climate Change Science Program 2009).

Given the challenges of socioeconomic and climatic vulnerability—increasing water demand, greater competition among users for a shrinking supply, and increasing economic intensification—water managers in the Arizona–Sonora border region are seeking ways both to augment and conserve water sources to ensure that supply can meet projected demand.

Next, we examine three cases of regionalized adaptation to transboundary water management (ranging in adaptive potential from low to high) based on the indicators we have identified—dynamic, structured opportunities for social learning; existence of formal and informal networks; and potential for developing adaptive pathways. The assessments are summarized in Table 1.

Case 1: Desalination as a Water Augmentation Strategy (Low Adaptive Potential)

Desalination of seawater has attracted both attention and financing by those who see it as a failproof source of water in the study region (Kohlhoff and Roberts 2007). As the cost of desalination has decreased, its appeal for augmentation has risen. Nevertheless, desalination does not rank high in our measures of adaptive potential. Although desalination, as a technological innovation, could meet increasing demand, it is unlikely to prompt sustainable change in water users' behaviors under climate change. In fact, desalination, if not coupled with conservation measures, enables a business-as-usual water culture—averse to social learning—and discourages sustainable water use. The region's major urban areas would become dependent on both desalination technology and good relations between U.S. and Mexican authorities—each of which could prove unreliable.

In the study region, desalination has important transboundary implications. For example, the municipality of Puerto Peñasco, a booming coastal resort town, plans to construct a desalination plant (Figure 2). There are twenty resorts in Puerto Peñasco, with approved permits for eighty-six more (Interview with desalination project coordinator, 10 November 2008). With limited access to surface water and exhausted aquifers, Puerto Peñasco must turn to desalination to sustain itself and enable growth.

The U.S. Trade and Development Agency financed a feasibility study for the desalination project, in part

Figure 2. Arizona–Sonora region of the U.S.–Mexico border. *Credit:* Rolando Diaz Caravantes.

due to the economic promise the $35 million plant has for U.S. consultants and contractors. States in the Southwestern United States are interested in more than feasibility studies, however; they favor transboundary arrangements offering access to the desalinated water. Arizona and Sonora have partnered to commission a study of a binational desalination plant, also in Puerto Peñasco, as a part of both states' future water augmentation strategies (HDR 2009). Nevada water augmentation plans speak of a similar strategy (Southern Nevada Water Authority 2009). The plans variously offer to pay for desalination plants in Mexico in exchange for shares of Mexico's Colorado River allocations or to convey water to points of use in Sonora and across the border in the United States (Glennon and Pearce 2007; Kohlhoff and Roberts 2007).

Many consequences of the proposed desalination—including the effects of brine "reject" discharge—are not known, and the results of an environmental impact study scheduled for completion in December 2008 have not been released. No existing federal law regulates how a desalination plant operates in Mexico (López-Pérez 2009). Although developing new sources of fresh water to augment existing groundwater sources would protect aquifers and potentially allow them to recover to nearer equilibrium levels, perceived limitless supplies of water likely would encourage urban growth. There could be additional impacts on the fragile estuaries and fisheries of the Gulf of California and potential disruption of significant ecosystems where the proposed aqueduct would traverse the desert. Moreover, because Arizona and Nevada would continue to use their full allotments plus desalinated supply—without reducing current use—no net gains to the aquifers or to Colorado River allocations likely would be realized.

Overall, then, we assess the augmentation strategies of desalination to be of low adaptive potential. Assessed against the identified indicators, the desalination proposals do not involve structured opportunities for social learning or changes in institutional culture or policy priorities. Data sharing would be in the context of formal contract-based exchanges, rather than more permeable, fluid, relational kinds of knowledge exchanges such as those identified by Cash et al. (2003). New communities of practice are not anticipated to emerge from desalination strategies and binational relationships will be straitjacketed within a bounded legal framework. The desalination strategies are not only unlikely to add to adaptive capacity, but they could lead to more of the entrenched, legalistic relations that have sometimes hampered cooperative, binational water management in the past. Absent a conservation strategy, these strategies enable a status quo water culture that views desalinated seawater as a limitless substitute for fresh water. Ironically, increased interdependence will ensue under the proposed desalination strategies, requiring improved cooperation between the United States and Mexico, yet these strategies do little to foster better communication and enhanced collaboration, and therefore could actually increase vulnerability.

Case 2: Data Sharing and Improved Information Flows (Medium Adaptive Potential)

Within the border region, lack of data comparability and data sharing have long been challenges that hinder transboundary cooperation. Scientific knowledge about groundwater aquifers is particularly sparse. The U.S.–Mexico surface water treaty of 1944 and the commission structure to enforce it created institutions for water quantity allocation and water-quality monitoring. Transboundary groundwater, by contrast, has proved more difficult to govern (Feitelson 2006).

An emerging initiative, the U.S.–Mexico Transboundary Aquifer Assessment Program (TAAP), seeks to overcome these institutional and water-resource challenges through binational collaboration. Authorized by U.S. federal law and funded by annual budget appropriations, TAAP is implemented by the U.S. Geological Survey and the state water resources research institutes of Arizona, New Mexico, and Texas, with collaboration from Mexican federal, state, and local counterparts as well as IBWC and CILA. Three essential steps characterize TAAP: (1) building shared vision through joint setting of objectives and prioritized outcomes, a process based on learning among boundary people; (2) scientific assessment of groundwater resources; and (3) dual adaptive-management strategies that conform to each country's institutional environment while expanding binational information flows and data exchange.

Over TAAP's brief lifetime, mutually defined priorities for Arizona's and Sonora's common Santa Cruz and San Pedro aquifers have been identified as vehicles for water for growth, adaptation to climate change, local aquifer-recharge programs, and institutional assessment of groundwater management asymmetries. These priorities reflect fulfillment of two of the effective knowledge transmission criteria identified by Cash et al. (2003), as both salience (relevance of information shared) and credibility (scientific adequacy of the information) appear to be fully satisfied by TAAP processes for data sharing. It is explicitly recognized that binational aquifer assessment will support each nation's management of its share of transboundary aquifers. One implication is that water quality has received diminished attention, given that, upstream, Mexico considered it disadvantageous to identify sources of groundwater pollution. Additionally, TAAP takes a regional approach by emphasizing aquifer-level priority setting and assessment that account for differences between participating states on the U.S. side. However, the principal boundary object in this case (the physical aquifer spanning the border) is not subject to a shared learning approach to management as a result of contrasting laws and regulations for groundwater in the United States and Mexico.

Sharing of information—both as inputs to the scientific assessments and outputs from binational activities—is a critical social-learning feature of TAAP that confers it adaptive potential; however, much has yet to be realized. A negotiation process is underway within the IBWC/CILA umbrella, leading to a binational agreement to identify aquifers for assessment, permit exchange of information, initiate assessment activities, and disseminate results. In the United States, where groundwater is managed and regulated by state and local entities, a flexible mechanism was sought for direct cross-border collaboration with homologue entities. In Mexico, by contrast, federal authority regulates groundwater, and as a result of this asymmetry, agreement was sought within the IBWC/CILA framework. Operating within this institutional arrangement will present challenges for some TAAP stakeholders who are accustomed to pursuing water resources and institutional analyses unfettered by a commission structure and the need to review results prior to dissemination. Nevertheless, TAAP is already generating successful, binational examples of exchange of transboundary aquifer information; for Santa Cruz, a bilingual database of existing studies and reports has been created, and a similar one is in development for San Pedro. To date, users have been other stakeholders directly engaged in the TAAP process; a version for public, Web-based release is planned for the near future.

Such data sharing and improved information flow strategies rank in our assessment as of medium adaptive potential. For TAAP, they require substantial social learning and involve sustained interactions among primarily formal organizations. In this sense, the interactions among professional communities for the express purpose of data sharing take place within a more passive and bounded framework of interaction, with little emphasis on organic, informal network formation or a shared platform of ongoing social learning—hence our assessment that TAAP has medium, albeit very positive, adaptive potential. TAAP could lead to important improvements in sharing of climate and groundwater information across national boundaries and could potentially develop more systematic incorporation of new information sources into organizations' planning practices.

Case 3: Coproduction of Science and Policy with Binational Stakeholders (High Adaptive Potential)

The U.S.–Mexico border region is a fruitful place for collaboration among stakeholders and scientists who share a common interest in developing adaptive capacity to respond to climate change in the water sector. We focus this analysis on just two of several important stakeholder-based science initiatives within the binational Arizona–Sonora region that potentially can contribute in new ways to building adaptive capacity in the water sector.

The first is the development of a binational and bilingual climate outlook newsletter and Web site, called the *Border Climate Summary/Resumen del Clima de la Frontera* (henceforth *BCS*).[1] The *BCS* is based on the *Southwest Climate Outlook,* produced by the Climate Assessment of the Southwest program for over seven years (Jacobs, Garfin, and Lenart 2005). The *BCS* is being developed as part of collaborative research between climate and social scientists in Arizona and Sonora, in consultation with border-region stakeholders. Currently in its fifth quarterly edition, the *BCS* has three goals: (1) to give scientists a tangible foundation from which they can engage stakeholders in dialogues about hydroclimate data and information needs for decision making; (2) to integrate, in one place, value-added hydroclimate information from disparate sources in the United States and Mexico; and (3) to convey new science findings on topics germane to the interests of regional stakeholders.

The binational research team engages urban water managers and disaster-relief planners in a series of workshops that elicit stakeholders' feedback and suggestions to test and refine the *BCS* and to learn about other region-specific data, information, and research needs, such as a comprehensive hydroclimate information portal for the border region. Participants in a 2008 Sonoran workshop noted that they are keen to understand more about North American Monsoon dynamics, tropical cyclone prediction, groundwater resources, and other information that can be provided through *BCS* feature articles (Coles, Scott, and Garfin 2009). At the workshops, stakeholders iteratively provide feedback to the researchers, to inform and help create the science products and delineate the specific information they need to plan more adaptively for climate challenges. Workshop themes have focused on urban issues, national perspectives, and coastal vulnerabilities.

The *BCS* newsletter is a form of coproduction of knowledge that informs policy by increasing access to recent science results (in layperson-friendly language), building capacity for regional stakeholders to use climate information, involving them in the development of the content, and increasing coordination between information providers in both nations.

In related regional research, the binational team is working with regional stakeholders to develop vulnerability assessments for each participating urban area, taking into account the impacts of climate change on future water supply. Although planning toward mid- and long-term horizons (five, ten, or twenty years) is a well-developed practice among the Arizona water managers, very little planning is conducted in equally vulnerable Sonora urban areas due to lack of resources and inaccessibility of appropriate data. By working with stakeholders to jointly develop appropriate climate data (in part via the *BCS*) and understanding of urban vulnerabilities, to future water demand needs—via iterative workshops, surveys, and interviews—researchers hope to develop communities of practice, or informal transboundary networks of water and emergency management professionals. These networks ultimately might rely on common or shared sources of climate data, common understandings of urban vulnerability within the region, and best practices for planning adaptively to meet climate-related challenges.

All of these regionalized, transboundary processes to engage the scientific, stakeholder, and policymaking communities are ongoing, making it difficult to assess the ultimate level of achievement they will attain in yielding more adaptive regional solutions. We assess the *BCS* and the urban vulnerability–stakeholder engagement initiatives to be of high adaptive potential, due to the dynamic and structured social learning opportunities, the development of professional networks, and the coproduction of scientific knowledge (especially in the *BCS*) that could lead to new adaptive pathways within the participating institutions. Both the *BCS* and the urban vulnerability case studies engage iteratively with stakeholders via surveys and workshops that are designed explicitly to develop knowledge-sharing processes and products that meet the standards of salience, credibility, and legitimacy (Cash et al. 2003). The response and participation of stakeholders has been promising. For example, some 130 stakeholders representing twenty-one agencies and management institutions attended workshops held over the last eighteen months. About 1,500 persons receive the *BCS/RCF*. A formal initial evaluation of the *BCS* newsletter indicated that it fills a gap in needs for region-specific information, particularly by making bilingual information more accessible.

Conclusions

The regionalized approaches we have assessed have the potential to stimulate adaptive planning and management over a long term. On the other hand, the border region's convoluted and often divisive institutional arrangements, coupled with the legalistic framework that guides most decision making, can complicate and impede collaboration and cooperation. Although the literature on scientific knowledge transmission for effective policy offers helpful guideposts for evaluating the quality of social learning and knowledge-sharing processes (e.g., Cash et al. 2003; Pelling et al. 2008), it is challenging to identify objective measures of advances in social learning. Loose networks of stakeholders might come together for a time and coalesce around a shared platform of understanding and concepts about vulnerability and adaptation, only to be disrupted by elections that place new individuals in key stakeholder roles, or might be aided by a major occurrence (such as a hurricane) that underscores the vulnerability of communities within the region. Researchers rely on time-limited funding sources, making researcher interactions also part of the fragile fabric of scientist–stakeholder networks. In the transboundary U.S.–Mexico region, adaptations such as binational desalination plans could potentially reduce water supply vulnerability in the Southwestern United States while potentially increasing environmental vulnerability in Mexico. The transboundary nature of developing sustainable solutions is particularly difficult.

Nevertheless, we find that two of the three initiatives discussed hold promising adaptive potential. These strategies, if pursued, could increase social learning among urban water managers, emergency-preparedness planners, and coastal-resources planners. Both formal and informal networks are being advanced through sustained and iterative interactions among different resource managers within the Arizona–Sonora region, facilitated both by boundary people (e.g., the research team and local stakeholders in each site who plan and facilitate meetings) and by boundary objects (e.g., the workshops and the binational climate summary). Working together to produce and refine the binational climate summary with a regional focus on a shared climate regime (e.g., the monsoon) illustrates the coproduction of scientific knowledge that can influence policy within the region and encourage more sustainable planning. In the end, new communities of practice might emerge that institutionalize regional climate science and "climatic thinking" into their current and future water management practices, share institutional data within the community, and are committed to collaboration.

Moving beyond the entrenched patterns of divisive and bounded dealings on water management might increase regional resilience and offer communities more capacity to face looming changes. The obstacles associated with transboundary engagement are steep but the consequences of noncooperation are dire. Transboundary scientist–stakeholder collaboration might hold the key to confronting climate change in vulnerable borderlands.

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Note

1. The *Border Climate Summary* is available in English and in Spanish (*Resumen del Clima de la Frontera*) at http://www.climas.arizona.edu/forecasts/border/summary.html. Links to the *BCS* are found on the Colegio de Sonora (www.colson.edu.mx) and Centro de Investigación Científica y de Educación Superior de Ensenada, Baja California (CICESE) Web sites (http://usuario.cicese.mx/~tcavazos/).

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