Transboundary adaptive management to reduce climate-change vulnerability in the western U.S.–Mexico border region

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ABSTRACT

Climate change, variability, shifting demands for freshwater, and allocation of scarce water among multiple human and ecosystem needs comprise a set of interlinked adaptation challenges. This paper addresses how organizations and stakeholders can build adaptive capacity and foster adaptive management in a complex but environmentally significant international transboundary region in order to better confront the impacts of global change. To strengthen adaptive capacity, integrated assessments address coupled natural and human drivers of, and responses to hydroclimatic variability, economic globalization, expanding urbanization, and related global-change pressures. However, such assessments have often presumed a degree of uniformity of institutional arrangements. Two allied aims of the paper are to (1) examine the complexity and heterogeneity of institutions in transboundary regions and (2) illustrate how scientists, managers, and other regional stakeholders use collaboration and integrated assessment to confront climate and water challenges. This paper’s insights are based on a research initiative undertaken over more than a decade. Over this period, a binational, interdisciplinary team has conducted integrated-assessment research and established policy dialogue in the Arizona–Sonora section of the U.S.–Mexico border region. The initiative’s suite of projects addresses multiple aspects of water security and have involved key U.S. and Mexican academic institutions that act as boundary organizations, bringing climate scientists together with public and private-sector stakeholders to strengthen adaptive-water-management capacity across national borders. The analysis demonstrates that transboundary adaptive management is significantly strengthened by: binationality and transborder collaboration; involvement of multiple institutions in both countries; understanding of climate information use by water-resources managers; development of easily accessible, easily understandable tools and information products; expansion of binational communities of practice and effectively addressing challenges to their functioning; and, above all, continuity of effort.

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1. **Introduction: global change in a transboundary setting**

Climate change, variability, shifting demands for freshwater, and allocation of scarce water among multiple human and ecosystem needs comprise a set of interlinked adaptation challenges. Integrated assessments, such as those undertaken by NOAA’s (U.S. National Oceanic and Atmospheric Administration) sectoral applications research program (SARP) and regional integrated sciences and assessments (RISA) program, and by those supported by the Inter-American Institute for Global Change Research (IAI) address coupled natural and human drivers of and responses to, global change. To be most effective, attempts to strengthen adaptive capacity\(^1\) should reach a diversity of agencies and other stakeholders. But this task is delicate and usually place-specific, so such efforts should try to avoid unrealistic presumptions of uniformity of institutional arrangements. The approach and case we present here seek to explicitly acknowledge institutional diversity and heterogeneity. This is all the more necessary because the western North American climate-and-water region we examine, and its institutions of water governance, are bifurcated by the U.S.–Mexico border.

Across the globe, border areas—especially ones that are international—present special challenges for managing social processes and natural resources (Varady and Morehouse, 2003). Accordingly, these permeable, transjurisdictional zones also complicate efforts to adapt to climate change. One special feature of international border areas is the prevalence of incipient or actual conflict (Udall and Varady, 1994). Often, land boundaries or natural resources are contested or were historically subject to contestation—even wars—resulting in a legacy of national sensitivities on both sides. Even ostensibly peaceable borders share many of the same transboundary challenges (Delli Priscoli and Wolf, 2009). These include human migration pressures, cross-border shipments of contraband goods, and most significantly for our paper, management of shared resources by distinct entities working in sometimes disparate institutional frameworks (Megdal and Scott, 2011).

Yet jurisdictions immediately across international borders from each other share common climate regimes and natural resources, including ecosystems, watersheds, groundwater aquifers, mountain ranges and coasts, and wildlife habitat and corridors. Consequently, they face the problem of climate change together. Not only natural areas, but also urban areas may extend across borders, creating transboundary economies, cultural ties, interdependencies, and channels for exchanging ideas. The challenge of integrated assessment in border regions therefore represents a problem of a different order. Borders themselves present an array of potential obstacles to effective public policy, including linguistic and cultural translation, institutional asymmetry, distance from decisionmaking loci, and frequently, a complex geopolitical context (Morehouse, 1995; Ingram et al., 1994).

How can countries and regions build adaptive capacity and foster adaptive management in complex but environmentally significant border regions in order to better confront the impacts of future climate change? To address this central question, our paper examines the complexity and heterogeneity of institutions—at times complementary, at others conflicting—in transboundary regions facing broad and generally uniform climate and water-resource challenges.

This paper examines a dozen years of integrated-assessment research and policy dialogue (Scott et al., 2012b) in the Arizona–Sonora section of the U.S.–Mexico border region.\(^2\) The U.S.–Mexico border, as we discuss below, shares the major issues and challenges of many global border regions, particularly those that are in dry, water-short parts of the world (Wilder et al., 2012; Varady and Morehouse, 2004). The research initiative described herein is a suite of projects addressing water security, particularly from the perspectives of adaptation to scarcity and social vulnerability, urbanization, reliance on groundwater, the nexus between water and energy, and ecosystem resilience. These projects have involved key academic institutions (at least one from each side of the border) that act as boundary organizations to bring together climate scientists from multiple disciplines (e.g., atmospheric scientists, hydrologists, ecologists, political scientists, and geographers) with decisionmaker, policymakers, and other resource managers (i.e., stakeholders) to build adaptive capacity with a goal of promoting adaptive water management (defined below) in the border region. Our sustained efforts have catalyzed the formation of a transboundary adaptation community of practice (similarly, defined below).

2. **Concepts and approaches**

In recent years, the terms “integrated assessment” and “adaptive management” have gained wide currency in the scholarly literature on water management and, increasingly, among water policymakers and managers (Garfin et al., 2012, this volume). But until the 1960s, natural-resources management was commonly seen across the world as a struggle between humans and nature, with humans the ultimate victors thanks to the weapons of engineering and technology. Beginning in the early 20th century, and accelerating in the immediate post-World War II period, this view led to such large-scale public works as construction of dams, irrigation networks, tidal barrages, and hydroelectric plants, and to

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\(^1\) 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).

\(^2\) The “policy-dialogues” facet of our work has been entirely deliberate. The work undertaken by our research team has explicitly set out to establish and nourish these dialogues, which have formed the core of a stakeholder-based research approach. The “integrated-assessment research” aspect of the work is more nuanced. Did we set out to engage in integrated assessment? If by that we understand integrated assessment to have been the overarching objective of the suite of projects described below, the answer is no. But if we take integrated assessment to be a carefully thought-out approach (as defined in this paper) to be followed in pursuit of more specific aims—rather than a goal to be sought—then we can situate our research firmly in the integrated-assessment camp.
other manipulations of the environment to meet societal needs. This technology-centered approach to resource management was linear: identify a problem and apply the suitable technology to solve it. Impacts on the environment, society, and the economy—that is, long-term impacts—were deemed irrelevant if they did not relate directly to the short-term solution, if they were considered at all (Varady et al., 2008).

But confidence in this approach began to erode as planners and builders encountered unanticipated obstacles to their ambitions: e.g., insufficient water for making concrete; prohibitive costs and large environmental consequences of obtaining and conveying necessary energy (Scott and Pasqualetti, 2010) and other materials; extremely rugged landscapes; social unrest occasioned by displacements of populations. In addition, linear, technological, “hard path” solutions such as the ones above often yielded poor development outcomes. Many of those outcomes have been unintended, such as displaced communities, downstream impacts, lack of stewardship by local communities, and loss of socioecological resilience resulting from “lock-in” to infrastructure-based solutions.

2.1. Integrated approaches

Alternative approaches like integrated pest management and its holistic analogues in other fields began to replace the single-purpose/single-mode approaches to managing resources. These approaches were fortified by the advent of the idea of sustainability (Brundtland and Khalid, 1987; Tolba, 1987). In the realm of water, sustainability and integrated management were expressed via the paradigm of integrated water resources management, or IWRM. The IWRM template, which was codified by the global water partnership (GWP, 2000), considers jointly many of the multiple aspects of water management: quantity, flow, quality, and access. It also recognizes that not only the water cycle, but environment, society, and policymaking are part of the management equation. But IWRM, though it sets a strong course for integrated practices, does not address the full range of purviews to be considered when assessing or managing water resources.

In this paper, we review the importance of what we see as a more complete spectrum of elements to be integrated within the water-management domain. In our approach, integration cuts across economic sectors; embraces both water management and climate prediction; comprises rural and urban interests; encompasses multiple academic disciplines and knowledge domains in a manner that co-generates and transfers knowledge; traverses political boundaries; and bridges government-civil society gaps, and theorist-practitioner and policy-management divides.

This more comprehensive understanding of integrated assessment emphasizes cultural, social, institutional, economic contexts—and governance. By doing so, it can render knowledge more germane, useful, and usable, thereby stimulating adaptive pathways—new institutional priorities or ways of carrying out activities—that promote more adaptive, “climatic thinking” in operations and planning. Such an approach can help formulate research agendas—and ultimately, if suitably applied, it can influence public policy so as to improve water management.

Integrating multiple elements and perspectives enhances what the U.S. National Science Foundation has aptly termed “decision-making under uncertainty,” a core objective of adaptive management. Early work in ecology by Holling (1973) and others showed that systems could tip into unforeseeable, and often unstable states as the result of external drivers or shocks, such as pest attack or drought. Additionally, ecologists and social scientists came to recognize that human and natural systems interact in adapting to such changes.

2.2. Adaptive management and communities of practice

Thus, adaptive management describes the process by which decision makers address uncertain outcomes of major external forces. Managers have always been confronted by uncertainty, leading some to critique the adaptive management concept and approach. However, we attempt to demonstrate here that new, hybrid knowledge systems developed and applied by communities of practice3 are more robust than conventional, deterministic management systems, particularly in the face of major challenges like climate change and variability. For water resources, in particular, Milly et al. (2008) showed that managers need to account for the predictions of climatic and hydrological models, which may indeed show widening bounds of predicted water availability and seasonality due to the inadequacy of past statistical distributions as predictors of the future. Additionally, the spatial and temporal patterns of water use resulting from highly uncertain human demands as well as inflexible institutional arrangements and rigid, state-centered decision-making have become recognized as critical societal factors influencing water management (Pahl-Wostl, 2007).

2.3. Human–climate interactions

Our approach seeks to expand the insights derived from prior examples of integrated climate assessment (Rotmans, 2006; Brasseur et al., 2007; IE, 2012a,b) and IWRM frameworks (GWP, 2000). Following on the work of Eakin and Lemos (2010) among others, we take a broad nature-society approach that considers physical processes of climate change and variability in relation to human vulnerability and adaptive capacity.

Droughts, cyclones, floods, habubs (sand storms), and other climate extremes—as well as incremental, pervasive, and insidious changes to climate—are seen in terms of the reflexive responses they produce in human systems and institutions. These responses, as manifested in management and adaptive processes, can in turn influence hydrological, ecosystem, and other physical dynamics. Extreme events, then, are more than statistical distributions; we seek to

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3 Building on Lave and Wenger (1991), Wenger (1999) considers shared understanding and commitment to joint learning as essential features of “communities of practice”, which can operate at multiple institutional levels, from individuals to communities to organizations. For us, the organizational level is key, although elements of individual and community “practice” are important. Interconnected organizations committed to learning can prove most effective, e.g., for the case presented in this paper, in addressing climate and water adaptation in the U.S.–Mexico border region.
understand the human dimensions of their impacts as well as the critical influence they exercise on societal, institutional, and managerial conceptualization of climate systems.

2.4. Interdisciplinarity and collaborative development of science and policy

In the field of water-resources research, as in related natural-resources studies, scholars increasingly have recognized since the 1970s that establishing and maintaining interdisciplinarity among social and physical sciences is essential to improving understanding of environmental issues. In a broader sense, interdisciplinarity also has been shown as an effective mode to address complex problems (Jasanoff and Wynne, 1998; Gibbons, 2000; Wolgar, 2000).

Functional interdisciplinarity is not easily achieved, for collaboration across intellectual divides requires relatively high levels of commitment, capacity, and resources. Indeed, analyses of what interdisciplinarity is, how it works, and what its effects are (or may be) reveal a series of complex demands and expectations. In fully interdisciplinary efforts, collaboration must be maintained throughout the research process, beginning with identification of problems and who/what is impacted by and thus has a stake in these problems. This process may require developing familiarity with languages and terminologies distant from one’s area of specialization, as well as agreement on what constitutes “acceptable” research methods, modes of analysis, and evidence.

Such basic foundations are essential for proceeding with development of research projects (Lemos and Morehouse, 2005). One critical building block is an articulate theorization and analysis of the problem at hand. Another is the development of germane research questions and the concomitant selection of appropriate investigative methods. And not least in an environment driven by the need for research funds, the actual writing of proposals is essential. Along the way, the researchers must also build relationships with stakeholders whose support for and inclusion in the project is often crucial.

The nature and extent of existing environmental concerns, however, indicates that the kind of scholarly interdisciplinarity described above may not be sufficient. Rather, a more complex form of cooperation, called collaborative production of both science and policy, may be required. Beyond the requirements of interdisciplinarity, co-production, when fully developed, involves ongoing involvement of all parties—including stakeholders—throughout the entire process of building and carrying out a research project (Lemos and Morehouse, 2005; see also Eden et al., 2006, for a study of scientists working for NGOs). Benefits of such collaboration may include development of sustainable relationships between scientists, stakeholders, and the public more generally; better fit between solutions developed and their application on the ground; enhanced public acceptance of the changes emerging from the collaborative research; and greater societal and ecological resilience resulting from flexibility in planning.

We acknowledge that interdisciplinarity and collaborative development of science and policy, as described above, may be difficult to achieve and maintain (Lemos and Morehouse, 2005; Vogel et al., 2007). However, we also recognize that in the context of seemingly intractable problems—such as assuring water of sufficient quantity and quality to meet multidimensional demands—strategies such as these currently hold great promise. When sensitively applied, they can effect the changes needed to sustain our complex and intertwined social and ecological systems (Gunderson and Holling, 2002).

2.5. Information flows

In order to succeed, collaborative development of science and policy relies on free flowing and easily accessed information. As a result, our approach stresses efforts aimed at improving the availability, usefulness, and usability of climate information and of the climate diagnostic assessments that underlie the information publicly provided (see, e.g., Buizer et al., 2010; Varady et al., 2009). Collaborative production of knowledge in this context includes assessment not only of climatic factors but also how such factors manifest differently with regard to societal and environmental impacts. In a transboundary setting, the process also requires active, bilingual or multilingual dissemination of current climate information, availability of new tools, and forecasts of likely scenarios (IE, 2012c).

Water-resources management is one of the key areas across the globe and across boundaries of all kinds where critical and interlinked climatic and societal issues regularly emerge. Crucial to understanding such complex processes is the development of insights into social and environmental vulnerabilities (e.g., Vásquez-León, 2009; Romero Lankao, 2010) and into how the workings of institutional rules, practices, and discourses contribute to the nature and different types/levels of vulnerability experienced across the region in question (Wild et al., 2010).

Suitable understanding and assessment of such vulnerabilities entails gathering information on basic demographic, economic, and sociopolitical factors. It also requires an appreciation of the governance structures and practices that may directly or indirectly affect relative vulnerability to climate adaptive capacities of institutions, such as water management. Societal norms and behaviors also are important factors to be understood (Lach et al., 2005). The papers in the present Environmental Science and Policy special issue highlight not only the various ways in which these elements play into the types and relative levels of vulnerability present in any given context, but also illuminate possible avenues for addressing barriers to effecting the changes needed.

Adaptive approaches to account for variability and uncertainty have advanced our understanding of integration as conventionally understood by IWRM and its offshoot, integrated river-basin management. These conceptual models essentially focus on simultaneous consideration of surface water and groundwater. River basins and aquifers are subsets of larger water-resources systems that interact physically with the climate system; they also can be used and managed in mutually deleterious ways if human drivers are not accounted for or if human and ecosystem impacts of alternative water management plans are not well understood. Through our ability to manipulate water flows, human demands for freshwater have in many cases become the dominant influence on water balances in regions of highly variable hydrological and climatic processes. This process has continued, especially as politically influential and financially well-endowed cities impose their...
“hydraulic reach” over an expanding rural landscape (Scott and Pineda Pablos, 2011).

In this sense, “doing interdisciplinarity” and opening up information flows in a transboundary region has a particular translational or interpretive nature that makes the approach essentially distinctive. In a bilingual area, literal translation is required, of course; but as importantly, so are cultural and institutional translation needed. The essence of such a strategy is that “translation” work is accomplished by binational and bicultural teams. This is a distinguishing feature of our approach that sets it apart from comparable work in a single country context.

3. Integrated assessment and adaptive capacity in the western U.S.–Mexico border region

The locus of our initiative is the region of northwest Mexico and the southwest U.S. that lies astride the international border separating the two countries. The entire border is one of the world’s longest, but the efforts we report on here (hereafter, the border region) lie within the part of the border to the west of Las Cruces, New Mexico (see Fig. 1). Most of this landscape is sparsely populated, with major exceptions in the twin cities of Nogales, Arizona-Nogales, Sonora; Calexico, California-Mexicali, Baja California; and of course, San Diego, California-Tijuana, Baja California. When the border zone is defined, as it commonly is, as extending about 100 km to either side of the boundary, the cities Tucson, Arizona, and Hermosillo, Sonora, can be considered border cities.

In this portion of the border zone, just as in many arid and semiarid regions globally, water is the lens that brings climatic processes into sharp societal relief. Precipitation is generally below 500 mm per year, and in most places, below 300 mm; some hyperarid stretches in the desert zone near Yuma, Arizona, receive no more than 75 mm annually. In such a setting, our notion of water-and-climate assessments—which includes interdisciplinarity, effective information flows, multisectoral perspectives, and integrated resources management—allows for a thorough, broad-gauged approach.

As is common in dry regions, in our study area, the availability, adequacy, quality, spatial distribution, and timing of water resources are critical elements of their management. These define patterns of human settlement, and economic development, as well as the sectoral uses of water in agriculture, cities, and increasingly human-dominated ecosystems. Yet management itself is conditioned, differently, in the transboundary context. Thus, centralized vs. decentralized modes of vulnerability assessment, adaptation, and priority-setting respond to institutional complexity and heterogeneity. In some contexts, a more articulated process of adaptive management may come into play. Adaptive management involves ongoing iterative experimentation, often beyond the scope of individual funded projects, with both science and policy in an effort to improve outcomes. Adaptive management efforts addressing climate impacts on the Colorado River, especially the Delta, in the U.S.–Mexico border region provide a good example of such efforts (Pulwarty, 2001).

Because major infrastructure projects on both sides of the border have paved the way for expanding development and thus shielded humans—at least partially—from climate extremes, infrastructure typically receives priority in development planning. In our view, this tendency overlooks, or can even undermine, the adaptive possibilities of “software” approaches such as risk mitigation through demand management, insurance and derivatives (Pollard et al., 2008), and intersectoral transfers of water, among others.

In western North America, the modern history of water-resources use and development is typified by large infrastructure projects, e.g., dams on the Colorado River and rio Grande River, the California state water carrier, the Central Arizona Project, and the unfolding Sonora Sistema Integral. Until now

![Fig. 1 - Western U.S.–Mexico border region study area.](image-url)
the water sector has overtly emphasized supply side water management. In both the United States and Mexico, there is little doubt that supply-side policies emphasizing infrastructure will continue to play a central role in mediating social access and impacts of water. But the integrated approach we describe tends to favor demand management, which we see as a promising policy tool for adaptation to climate change.

Adaptive water management as we understand it, places emphasis on information flows among scientists and stakeholders, social and institutional learning (to account for variabilities and uncertainties as outlined above), and above all seeks to have not just material, water-resources modifications (e.g., more sustainable water balances), but enhanced societal outcomes and ecosystem services. In the water arena, and particularly in the western U.S.–Mexico border region, which is characterized by water scarcity, the water-resource implications of climate change constitute an ongoing challenge for adaptive management.

The projects we have developed address these needs from perspectives that are both multi-sectoral (climate, drought, disaster management, water availability, agriculture, industry, urban/rural issues, environment, demographics, infrastructure) and multi-stakeholder (elected officials, agencies, non-governmental organizations, scientists, civil society, and the public, all interacting in a loosely knit community of practice).

The adaption community of practice in the U.S.–Mexico border region (Wilder et al., 2010) has been formed and strengthened via a continuing set of workshops, field visits, webinars, and other forms of collaborative assessment and diagnostic planning (Scott et al., 2012b). Through this process and in consultation with other stakeholders, participants deepen the linkages between water and society by addressing climate-induced water-resources uncertainties including drought, acute water scarcity, flooding (as caused by hurricanes), social vulnerability, and their implications for a range of human uses of water. Chief in our region are agriculture, industry, urban water supply (Wilder et al., 2012; Scott et al., 2012a), and expanding energy needs. Taken together with continued demographic and economic growth in the region, existing large infrastructure projects or new infrastructure, the implications for water security are serious. Water for the environment has thus far been the clear loser.

Our views of integrated assessment are informed by drawing on the authors’ experience in the course of participating in a decade-long suite of projects on water and climate adaptation in the western U.S.–Mexico border region (see Table 1). Building

<table>
<thead>
<tr>
<th>Sponsor</th>
<th>Project/initiative</th>
<th>Partners</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inter-American Institute for Global Change Research (IAI)</td>
<td>Adaptive water mgt. under climatic uncertainty</td>
<td>U.S. &amp; Mex. water mgt. agencies, researchers, stakeholders.</td>
<td>2007–2011</td>
</tr>
<tr>
<td>Arizona Water Institute</td>
<td>Water &amp; energy sustainability in border region</td>
<td>Water &amp; elec. utilities, state &amp; federal agencies</td>
<td>2008–2009</td>
</tr>
<tr>
<td>Water Reuse Foundation</td>
<td>Water reuse to offset scarcity</td>
<td>Water &amp; wastewater utilities</td>
<td>2009–2011</td>
</tr>
<tr>
<td>National Science Foundation</td>
<td>Strengthening riparian resilience</td>
<td>Researchers, water mgt. agencies, utilities</td>
<td>2010–2015</td>
</tr>
<tr>
<td></td>
<td>Global groundwater governance &amp; policy</td>
<td>UN officials, int’l. researchers, stakeholders.</td>
<td>2011–2013</td>
</tr>
</tbody>
</table>
on IWRM principles, we are concerned with the integration of multiple water sources (surface-water, groundwater, wastewater, and rainwater harvesting). Furthermore, ecosystem needs for water are increasingly identified, at least in planning. However, translating these needs into actual allocations of water of acceptable quality for ecosystem processes requires significant additional effort. The U.S.—Mexico border region community of practice has, over the course of the past decade, been refining the science-policy approach to these challenges. Accordingly, the initiative is centered on:

- Interdisciplinarity of investigators (social and physical sciences, with emphasis on former; Scott et al., 2012b)
- Participation of scientists, managers, decision-makers, and civil society in a transboundary adaptation community of practice
- Vulnerability and institutional analyses bring together climate diagnostic assessment with understanding of demographic, economic, and sociopolitical factors, and governance which, in turn, frame the adaptive capacity of institutions (e.g., water management) in the region

The identification of climate-related vulnerabilities and an assessment of climate information flows and uses are two important first steps in order to understand how and where to build adaptive capacity in the Arizona–Sonora section of the U.S.—Mexico border region. Climate-related vulnerability is spatially uneven in the border region and is defined and experienced in distinct ways given the economic asymmetry present there.

Vulnerability can be defined in two distinct but related ways (Wilder et al., in press). One framework centers on the underlying political, economic, social, institutional, and biophysical structures that drive vulnerability, including asymmetries in power and resource distribution (e.g., Sánchez-Rodríguez and Mumme, 2010; Lahsen et al., 2010; Eakin and Luers, 2006; Adger, 2006). Reducing vulnerability is closely linked with poverty alleviation and development strategies in developing countries with persistent inequalities (Seto et al., 2010). A second approach centers on developing systematic measures of climate-related risk in a system, calibrated by exposure and sensitivity (of actors at multiple scales, including household and neighborhoods to cities, states or countries) to a climate-related risk and the coping (or adaptive) capacity to deal with it (Jacobs et al., 2010; Yohe and Tol, 2002; Moss, 2011).

It is noteworthy that not all social groups exposed to a climate-related risk (e.g., hurricanes, floods, and drought) are equally vulnerable to suffering harm from it. Risk embodies the likelihood plus the consequences. Thus, the consequences of a harm occurring are embedded within the concept of vulnerability. Vulnerability to a climate-related risk is mediated by sensitivity, exposure, and capacity to cope or to adapt (Wilder et al., in press).

Adaptive capacity is also embodied within the concept of vulnerability. The projects in our suite (Table 1) have developed baseline vulnerability studies in four major urban areas in the Arizona–Sonora region. Based on surveys, interviews, focus groups, and stakeholder workshops (attended by about 400 decisionmakers in the region), we identified major urban climate-related vulnerabilities, including: over-reliance on single source of supply (especially the Colorado River); severely-overdrafted groundwater aquifers; water insecurity (i.e., insecure access to water and sewerage in informal colonias); rapidity of and insufficient planning for sustainable growth (see Table 2; Wilder et al., 2012; Pineda-Pablos et al., 2012).

In the face of these constraints, the use of climate information (e.g., projected changes in patterns of minimum

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### Table 2 – Comparative assessment of urban vulnerabilities and adaptive responses.

<table>
<thead>
<tr>
<th>Research sites</th>
<th>Priority vulnerability themes identified</th>
<th>Adaptation activities (initiated, ongoing, or planned)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambos Nogales, Ariz./Son.</td>
<td>Fragmented, complex transboundary water mgmt. across Ambos Nogales; Inadequate access to drinking water &amp; sanit. in poor Nogales, Sonora neighborhoods; and staggered water service (tando) across municipality</td>
<td>Collaboration on wastewater treatment &amp; groundwater assessment via IBWC/CILA &amp; state/local water mgmt. orgs. Systematic research on water vulnerability at neighborhood level; community mobilize on key vulnerabilities in water access; alternative strategies being tested (e.g., compost toilets)</td>
</tr>
<tr>
<td>Puerto Peñasco, Son.</td>
<td>Aquifers exhausted &amp; cannot support projected future growth of tourism/hotel industry; Fragile estuaries in Upper Gulf of California with endangered species need protection from both over-fishing &amp; tourism expansion</td>
<td>Municipal desal. plant in feasibility study to serve Puerto Peñasco &amp; tourism industry</td>
</tr>
<tr>
<td>Tucson, Ariz.</td>
<td>Reliance on supply from over-allocated &amp; water-stressed Colorado River; Drought-prone &amp; high-growth area</td>
<td>Active NGO (Ctr. for Protection of Deserts &amp; Oceans, CEDO) working with local fishermen &amp; businesses to put protections in place</td>
</tr>
<tr>
<td>Hermosillo, Son.</td>
<td>Water rationing (tando) across Hermosillo due to low water supply, use patterns &amp; infrastructure losses; Regional &amp; urban-rural competition for water</td>
<td>Arizona–Sonora have joint binational planning underway for new desal. plant in Puerto Peñasco; Sonora Integrated System (“Sonora SI”) plans major water transfers from commercial irrig. districts in south of Sonora to Hermosillo &amp; other cities</td>
</tr>
</tbody>
</table>


Summary table of climate-related vulnerabilities and adaptation activities in the border region study sites.
or maximum temperature or precipitation, seasonal or long-term forecasts) represents a significant element of the adaptation formula. Thus, an assessment of the availability, accessibility, and appropriateness of climate information to vital water-management institutions—referred to earlier in this paper as a diagnostic—is key to understanding the adaptation potential in the border region.

Our suite of projects has sought to understand the network of water-governance actors and how they use climate information (or fail to use it) to make operational and planning decisions about water supply. Our team conducted online surveys and group discussions at five regional workshops, as well as focused interviews with water managers in the four study sites shown in Fig. 1 and Table 2. Via these instruments, we facilitated dialogue about the need to incorporate climate information meaningfully into urban water operations and planning.

A more ambitious goal of ours was to foster the development of informal communities of practice, which would adopt new operational pathways integrating climate science into routine agency operations tasks and long-term planning initiatives. Finally, we used these scientist-stakeholder interactions to generate feedback about gaps in climate information, in terms of accessibility and availability. Innovations in providing climate information—including bilingual, interactive webinars—were initiated and a periodic publication, *Border Climate Summary*, was produced in English and Spanish between 2009 and 2010 (IE, 2009/2010) featuring regional climate information for Arizona–Sonora.

Related characteristics of our binational initiative center on:

- Binationality/transborder collaboration, and appreciation of (political, cultural, institutional) crossborder challenges (Varady, 2009).
- Involvement and participation of multiple institutions in both countries, accounting for asymmetries (Megdal and Scott, 2011).
- Attempt to understand climate information flows and information use by water-resources managers, including the use of a binational climate-information periodical, the *Border Climate Summary/Resumen del Clima de la Frontera* (BCS), developed as part of the NOAA-and-IAI-funded work by the research team. The BCS has been employed as a platform upon which dialogue is structured regarding information needs. In early 2012 it was reconstituted as *Transborder Climate/Clima Transfronterizo* (IE, 2012c).

- Development of other easily accessible, easily understandable tools and products, such as factsheets and bilingual Web sites.\(^4\)

\(^4\) For example, “Information Flows and Policy: Use of Climate Diagnostics and Cyclone Prediction for Adaptive Water-Resources Management under Climatic Uncertainty In Western North America” (http://udallcenter.arizona.edu/iai/pdf/ia_factsheet.pdf; and Varady et al., 2009) and “moving forward: adaptation and resilience to climate change, drought and Water Demand in the urbanizing southwestern United States and Northern Mexico” (http://udallcenter.arizona.edu/sarp/pdf/SARP_Fact_Sheet-English.pdf).

- Expansion, nurturing, and fostering of a binational community of practice that develops adaptive pathways within and among relevant institutions. For example, such a pathway would be created if an organization were to change its management structure or practices to accommodate different strategies needed to address climate change. An illustration is NOAA’s longstanding efforts to modify its information content and platforms so as to promote more widespread use by stakeholders.

- Addressing challenges to the effective functioning of communities of practice, including—specifically, disciplinary pigeon-holing, bureaucratic rigidity, insufficient information-sharing.

- Maintaining continuity of effort through persistence, which is an unending challenge given the constantly shifting cast of actors, changing policy environment, and unexpected developments.

4. Synthesis and conclusions

The integrated approach described here addresses the “multiple ways of knowing” (Ingram and Endter-Wada, 2009) that different actors use to frame their knowledge of water and climate in the border region. Engineers, politicians, and environmentalists, for example, define problems differently, and not surprisingly they arrive at quite different solutions. Just as different actors operate from multiple frames of knowledge, they also may seek distinct agendas. Environmentalists may want a specific and rapid policy change; academics, an original and scientifically defensible finding; and water managers and bureaucrats, a cost-effective and politically viable set of procedures. Although the multiple-ways-of-knowing concept may seem obvious, Ingram and Endter argue compellingly that failure to recognize its existence is the root cause of the failure of many water governance arrangements.

Our focus on how collaborative processes work to bridge these divides (Scott et al., 2012b; Wilder et al., 2010; Lemos and Morehouse, 2005; Pelling et al., 2008; Cash et al., 2003) demonstrates how successful integrative collaborations and adaptive-management planning are able to integrate climate science effectively into institutional operations and plans.

Yet there are clearly limits to the effectiveness of, and costs for sustaining integrated assessments that seek to enhance regional adaptation to climate and water variability. Calls for integrated and collaborative processes are widespread, facile, and appealing. But in practice, in spite of this general appeal, there has not been a groundswell of experience of the sort of broad-gauged integration we describe in this paper.

And if successful instances of this approach remain rare overall, such cases are even less common in transborder, binational, or multinational settings. As noted, those settings present a greater challenge to collaboration and integrated assessment than do relatively homogeneous institutional contexts (as might exist within a single country). The added complications—due to disparate institutional practices, sometime conflicting political agendas, and possibly uneven technical and financial resources—severely constrain attempts to integrate efforts across international frontiers.
The U.S.–Mexico case offers perhaps the best example of these constraints in that it features the world’s only border separating a major industrialized country from a developing country.

For more than a decade a research team based at the University of Arizona’s Udall Center for Studies in Public Policy has undertaken a suite of projects relating to the central theme of water management and its relation to climate in the western portion of the U.S.–Mexico border region. These efforts spring from a tradition of stakeholder-based research that features the role of binationality, public participation, free flows of information, openness, transparency, and sustainability in environmental decision making in the region. Table 1 identifies more than a dozen such projects undertaken since 2003. The tabulation shows the diversity of funding sources and participants in the process, while demonstrating the breadth of related issues: water supply sources, availability, use, conservation, relation to energy, and security; climate information and its use; and notions of vulnerability and adaptation.

In this context, the suite of projects shown in Table 1 has attained some noteworthy achievements. The quasi-regular binational workshops convened over the years have reduced tensions that may be inherent in such processes (van Kerkhoff and Lebel, 2006). They have built trust and lowered the barriers to cross-border cooperation. A good example is the Trans-boundary Aquifer Assessment Program, which though a unilateral, U.S. initiative, has engaged vigorous Mexican participation. Another incipient accomplishment is the interest by Mexico’s national meteorological service, SMN, to establish a regional climate center in Sonora. While that effort remains under planning, to an appreciable degree it was prompted by developments stemming from joint project sessions dating to 2005 that included high SMN officials. A third example, in the Upper San Pedro River basin that crosses the Arizona–Sonora border, is of even longer duration, originating in 1997. There, a concerted set of public-input events, scientific exchanges, behind-the-scenes discussions, and institution-building efforts led to the creation of the upper San Pedro Partnership, a 20-member watershed association on the U.S. side, and to attempts to create an analogous Mexican institution across the border. The Partnership has proven to be a vigorous and effective organization that is now sanctioned by the U.S. government as the responsible agent for assuring sustainable water use in the U.S. part of the basin. A final accomplishment is the inclusion for the first time of a chapter on U.S.–Mexico border climate in the U.S. Global Change Research Program’s 2013 national climate assessment—the lead author and several coauthors are longtime members of the research team discussed in the present paper (Wilder et al., in press).

Notwithstanding these developments, we realize that progress demands intense planning, perseverance, and dedication on the part of the team of researchers. And significantly, as Table 1 illustrates, it also requires financial support by committed sponsors. These sorts of exogenous inputs have facilitated science-policy dialogues and in some instances, led to policy changes. But our research team has been constantly reminded that this process is ongoing and it requires time and resources. Stakeholder engagement and the integration of practitioners and researchers in the community of practice described above have been only partly achieved, particularly on the Mexican side, where civil society is not as robust as in the United States. Within the water-climate nexus in the region, we have made some positive strides to link knowledge with problems. And we have helped evaluate and critique vulnerabilities and their causes. But the process can only be consummated when strong, science-informed programs become self-sustaining. While we think that our suite of projects is headed in this direction, the initiative is sure to be buffeted by political events, financial conditions, personnel turnover, and shifting priorities.

Our work has shown that several conditions are necessary for successful strengthening of adaptive capacity in transborder contexts such as the western U.S.–Mexico border region. The key elements are: binationality, transborder collaboration, and mutual trust; involvement of multiple institutions in both countries; understanding of climate information use by water-resources managers; development of easily accessible, easily understandable tools and information products; expansion of binational communities of practice and effectively addressing challenges to their functioning; and, above all and perhaps most challengingly, maintaining continuity of effort.

We argue that—with suitable strategies, ample trust, and sustained diligence—the binational (or in some cases, multinational) component of collaboration can overcome suboptimal, unilateral planning for transboundary water and climate issues that cross international borders.

In sum, integrated “transitional” approaches such as the one we have described here require added effort. But when skillfully undertaken, they can provide heightened understanding and more durable adaptive responses when compared with bounded, disciplinary frameworks. The experience of our research team in the U.S.–Mexico border region, if cautiously adapted to other regions, holds good potential for achieving cross-border science-practitioner collaboration and enhancing adaptive capacity in the water-climate domain.

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