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Societal use of freshwater, ecosystems' dependence on water, and hydroclimatic processes interact dynamically. Changes in any of these subsystems can cause unpredictable feedback, resulting in water insecurity for humans and ecosystems. By drawing on resilience theory, we extend current productive–destructive framings of water security to better address societal-ecosystem-hydroclimatic (SEH) interactions, dynamics, and uncertainties that drive insecurity but also offer response opportunities. Strengthening water security in this sense requires strategies that (1) conceptually and practically interlink SEH subsystems; (2) recognize extreme conditions and thresholds; and (3) plan for water security via structured exchanges between researchers and decision makers in ways that account for institutions and governance frameworks. Through scrutiny of case evidence from water-scarce regions in western North America and the Central Andes, we assert that ensuring water security requires adaptive management (interactive planning that accounts for uncertainties, initiates responses, and iteratively assesses outcomes). Researchers and stakeholders from these regions are pursuing a multiyear series of workshops that promote science-based decision making while factoring in the political implications of water planning. This study briefly reviews an emerging water-security initiative for the arid Americas that aims to enhance understanding of adaptive approaches to strengthen water security. Finally, by synthesizing efforts in the arid Americas, we offer insights for other water-insecure regions. *Key Words:* adaptive management, arid Americas, science-policy networks, social-ecological resilience, water security.

Increasingly, hydrological variability that results from climate change is threatening societies and ecosystems via their dependence on fresh water. Simultaneously, global change (including expansion of irrigated food production, growing urban populations with lifestyles that heighten water demand, intensifying use of water for power generation, and regional integration into global economies) is altering hydrological processes. Stark examples of these changes include water rationing in New Delhi and the Aral Sea dust flats. The planet is confronting peak water (Gleick and Palaniappan 2010) and ensuing uncertainties around an insecure water future. Conversely, water in extreme excess can cause interlinked societal and ecosystem vulnerabilities (e.g., Hurricane Katrina's destruction of communities and wetlands along the U.S. Gulf Coast; Wilbanks and Kates 2010).

By addressing complex social and biophysical interdependencies on water, our article contributes to human–environment geography's interdisciplinarity and grand-challenge scope (Skole 2004; current *Annals* special issue series on climate change, health, water, etc.). We aim to demonstrate conceptually the dynamic nature of water security and illustrate its application using case examples. Our point of departure is the understanding of water as simultaneously productive and destructive, perhaps best expressed by Grey and Sadoff's (2007, 547–48) definition of water security: “the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies.” The expanding water-security literature (e.g., Vörösmarty et al. 2010; Norman, Bakker, and Dunn 2011; Bakker 2012; Bogardi

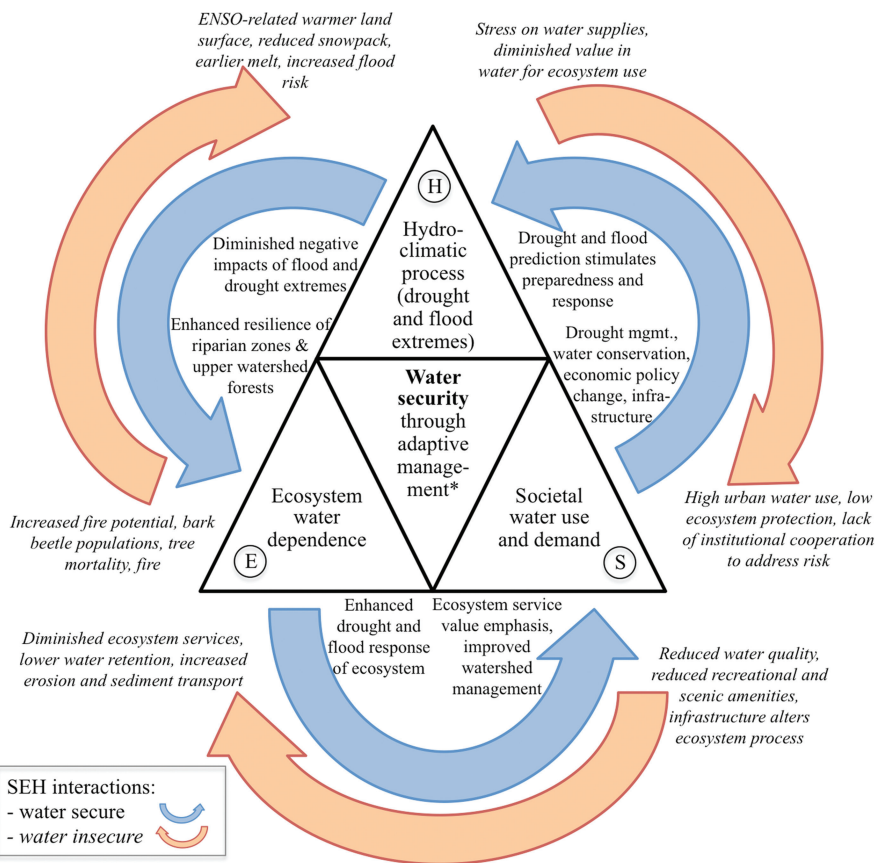


Figure 1. Water security based on the stability of societal-ecosystem-hydroclimatic (SEH) interactions. Note: ENSO = El Niño-Southern Oscillation. (Color figure available online.)

*Adaptive management addresses uncertainty of SEH interactions and outcomes, maintaining interactions within conditions of water security and shifting water-insecure interactions towards conditions of water security

et al. 2012) adds much nuance and refined understanding, especially of governance challenges (Zeitoun 2011; Cook and Bakker 2012). We build on these framings by shedding light on the dynamic nature of societal-ecosystem-hydroclimatic (SEH) interactions that characterize insecurity and uncertainty. In turn, we advance dialogue-based, inclusive responses to water insecurity.

As shown in Figure 1, we conceptualize three-way SEH interactions that push against resilience thresholds (Gunderson, Allen, and Holling 2010) through dynamics that originate in one or more subsystems but that are highly uncertain in magnitude, duration, impact, and mutual feedbacks.

It is increasingly apparent in multiple locations, as described later, that interconnected systems, once destabilized, can rapidly threaten societal and ecosystem uses of water. We thus propose a unifying definition: Water security constitutes the sustainable availability of adequate quantities and qualities of water for resilient societies and ecosystems in the face of uncertain global change. Our definition introduces the resilience dimension as necessary, because more static conceptu-

alizations of water security inadequately address mutually interactive coupled human–natural dynamics and therefore, might overlook possibilities for recovery from water insecurity. This in turn leads to our assertion that adaptation—both in terms of societal and ecosystem management—is a corollary to defining and pursuing water security.

Adaptive management, which first emerged from ecosystems theory and practice (Holling 1978), rapidly gained appeal in the analysis of social-ecological systems (Berkes and Folke 1998) and coupled human–natural resilience (Nelson, Adger, and Brown 2007). Adaptive water management accounts for uncertainty through flexible planning, knowledge sharing—especially between scientists and decision makers—and enhanced capacity to respond reflexively to multiple and uncertain processes of change (Pahl-Wostl et al. 2007). Although the concept of adaptive management has been lauded in water-policy circles, two critiques center on (1) assumptions by proponents that key decisions over water allocation, infrastructure, and outcomes are apolitical (Voß and Bornemann 2011); and (2) ambiguity

over the end goal of adaptive management (Pahl-Wostl et al. 2007).

We argue first that the science-policy interactive process cannot be blind to the political nature of decision making (this is discussed in further detail in the next section). Second, our framing of water security in SEH terms requires a clearer end goal to guide science-policy discussions. Based on our experience working with stakeholders, we consider it fundamental to align the definition of adaptive management with water security as an outcome goal, albeit one that must be understood in dynamic and reflexive terms. Our definition follows: Adaptive water management is the science-policy process to plan interactively for societal, ecosystem, and hydroclimatic uncertainties, initiate responsive action, and iteratively assess water-security outcomes in societal and ecosystem resilience terms.

In this article, we meld water security and adaptive management to account for dynamism and uncertainty in SEH interactions, while providing feasible and politically practicable opportunities to respond to real problems and challenges. We contextualize our conceptual approach by presenting and assessing case evidence from an evolving science-policy initiative across the Americas. This effort confronts threats to water security and adaptively responds to recover SEH stability. The article is organized as follows: This introductory section on key concepts is followed by a review of current understanding of security (including water security), its shortcomings, and our alternative dynamic and reflexive approach. We then consider case examples from western North America and the Central Andes to uncover common water-security challenges and generic lessons. Next we elucidate the arid-Americas challenge for the emerging AQUASEC initiative. We conclude by assessing the utility of linking adaptive management and water security and by posing future directions for geographical scholarship.

Security, Water, and Science-Policy Networks

The term *security* has historically been used to refer narrowly to national security in terms of military or intelligence threats. Since the Cold War, the term has been expanded to include other threats to human well-being (Ullman 1983), including natural disasters, resource conflicts, and environmental degradation. Some transboundary water and environmental threats might exhibit state-security dimensions (Mustafa 2010).

Liverman (1999) argued, however, for the need to move beyond apocalyptic constructions, and instead consider environmental security as a cause and goal for cooperation—a call echoed for water resources by Wolf (2007) and others. An expanded understanding of security has been applied to vital sectors such as food, energy, and water (Gleick 1993; Falkenmark 2001). In this context, geography plays multiple bridging roles, especially between physical and social sciences, and between critical theory and policy perspectives.

There is growing recognition of the importance of institutions and water governance, especially to address trade-offs inherent in water security. Researchers and policymakers have been called on to collaborate in science-policy networks that produce usable science and effective, research-based policy (Lemos and Morehouse 2005; Jacobs et al. 2010; Wilder et al. 2010). The goal of these networks is to generate scientific knowledge oriented toward stakeholders' needs while exerting influence before and during policy formulation (Scott et al. 2012).

In an ideal world, science-policy networks are symmetrical, balanced, and equally endowed with resources and influence, with participants who are altruistic, incorruptible, scientifically literate, and able to communicate perfectly with each other in the pursuit of closely aligned outcomes. National interests, regional loyalties, political preferences, and disciplinary differences are absent. Rationality, efficiency, and attention to public welfare prevail. Clearly, scientists, policymakers, resource managers, or any of the other stakeholders who might participate in science-policy networks or their constituent dialogues live in such a world. National interests, domestic politics, economic imperatives, communication gaps, varying perspectives and values, and personality differences can and do emerge during such dialogues (Ingram 2011; Gerlak and Wilder 2012).

But, as our case studies indicate, the decade-and-a-half experiences of our research team have shown that even in the sometimes turbulent crucible of the U.S.–Mexico border region, common water-management objectives can trump dissimilar interests. The scientists, decision makers, officials, and others—from both sides of the border—have generally demonstrated that they can overcome cultural, legal, administrative, and infrastructural disparities. At their most successful, such sessions have yielded agreement on the need for binational cooperation, more and better data and information, harmonized scientific protocols, collaborative research, and mutually acceptable priorities for confronting water insecurity resulting from

drought and flood extremes, ecosystem change, and rising human demand for water. Facilitated by team members, the dialogues were extended to Argentine and Chilean scientists and officials who met with community members and agreed to work to reduce threats to Andean water security—by alleviating drought damage and addressing social inequity in the agricultural sector—even as glaciers continue to recede at alarming rates.

Over the course of 2010 through 2012, facilitated by a vibrant network of researchers funded by the Inter-American Institute for Global Change Research (IAI), our team has developed and launched AQUASEC,¹ the Center of Excellence for Water Security. The regional emphasis is on arid and semiarid regions of the Americas (the U.S.–Mexico border region, northern Chile and Argentina, northeastern Brazil, parts of the Andes in Bolivia and Peru, and inland western Canada). AQUASEC aims to promote water security through

governance and management approaches that are innovative and adaptive, and that identify and take advantage of policy windows, opportunities presented by natural or human events that provide openings or renewed impetus for interactive planning.

Arid Americas Context and the Water Security Challenge

In the arid Americas, water scarcity shapes the landscape, constrains socioeconomic development, and determines ecosystem function. Our focus on western North America (U.S.–Mexico border) and the Central Andes (Chile and Argentina)—see Figure 2—illustrates fundamental water-security challenges. Each region considered individually represents a rich laboratory where SEH interactions in a global-change context can be observed and lessons learned.

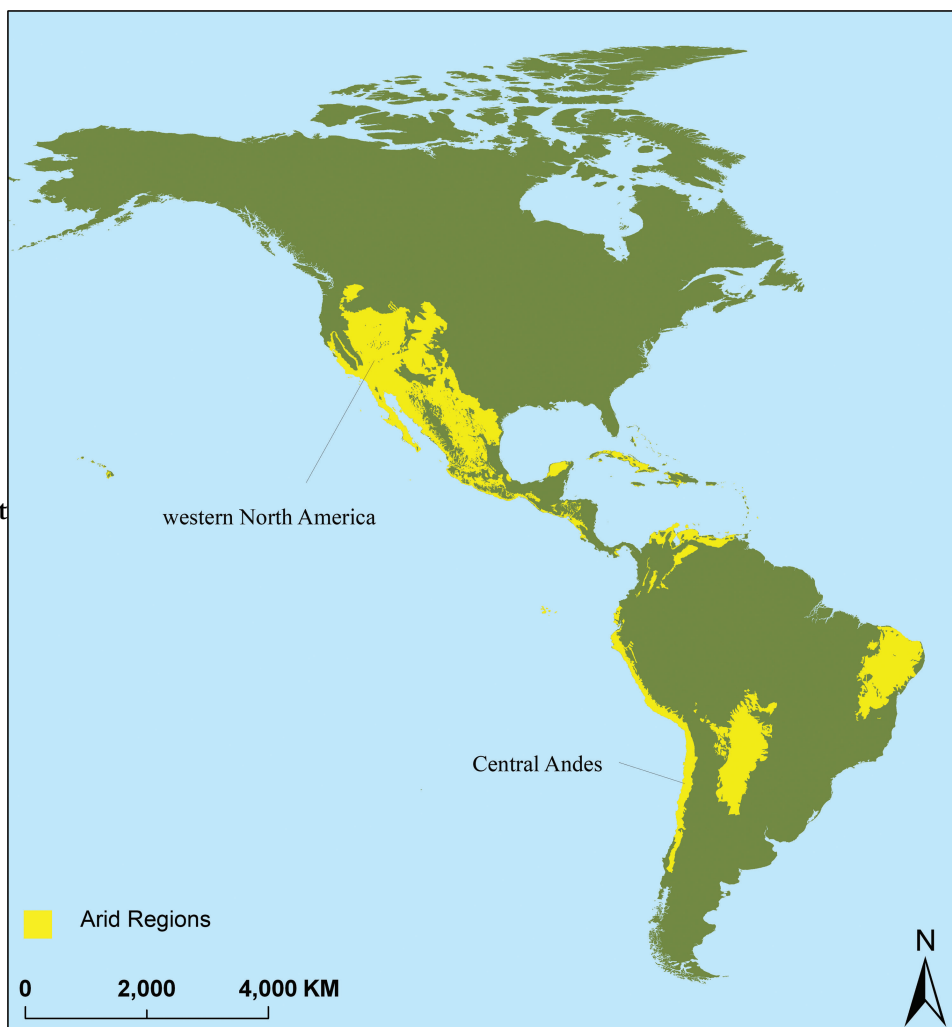


Figure 2. Arid Americas showing case study locations. (Color figure available online.)

Together, they constitute the foundation for an operational approach to water security that seeks to enhance the resilience of ecosystems and societies. Climate change, resource exploitation, and land-use change combined with water governance structures, institutional arrangements, societal values, and development pathways can threaten water security. Here we characterize the dynamics of these drivers and the reflexive science-policy approach that is emerging to link water security and adaptive management to global change.

SEH dynamics include increased water use across the arid Americas resulting from global economic integration, which is driven by neoliberal transition that has accelerated growth and urbanization in this region. The Intergovernmental Panel on Climate Change (IPCC) projects drier conditions in 60 percent of Latin America and desertification of 50 percent of its agricultural lands (Bates et al. 2008). The El Niño-Southern Oscillation (ENSO) is the most profound hydroclimatic driver in the arid Americas. El Niño episodes bring warm and wet winter conditions to North America's deserts and much of South America's west coast but dry conditions to northeast Brazil; La Niña produces the opposite effects. These episodes affect snowpack and stream flow as indicated in Figure 1, with La Niña reducing annual stream flow and decreasing water-supply reliability in the two regions we consider. The IPCC notes that the Americas currently lack adequate adaptive capacity to meet projected future water demands. Adaptive capacity—the relative ability of communities or institutions to anticipate and respond to stresses in ways that lead to desirable outcomes (including water security)—is key to adaptive management and effective governance more generally. Decision makers will increasingly have to come to terms with growth-driven urban, agricultural, and power-generation water requirements, added to ecosystem needs, all under rising hydroclimatic variability.

Case Examples of Scientist–Stakeholder Collaborations Toward Adaptive Water Management

Adaptive water management is challenging to carry out in complex, real-world contexts. One important component of the AQUASEC initiative is the interaction among scientists and stakeholders, who might be water or land managers, water-rights holders (e.g., irrigators, indigenous groups), civil society members (neighborhoods, nongovernmental organizations), and decision makers (agency directors, elected officials,

community leaders). Case examples from our experiences in building institutional adaptive capacity of diverse stakeholders illustrate the benefits and challenges of collaborative approaches.

The U.S.–Mexico border region has exhibited a history of transboundary collaboration on shared water and environmental resources (Fischhendler and Feitelson 2003) as well as legal frameworks that support such collaboration (La Paz Agreement of 1983; Minute 306 addition to 1944 U.S.–Mexico water treaty, in 2000). Avoidable water-insecurity risk has resulted, however, when the United States or Mexico opted not to collaborate; this represents a societal threshold potentially crossed (Figure 1). An example is the 2008 impoundment of floodwaters causing damage in Mexico when the United States extended the border fence without adequate consideration of local hydrology.

A hallmark of recent AQUASEC efforts has been the emergence of science-policy networks that address water security planning in an adaptive process. Since 2007, scientist–policymaker networks involving climate scientists, water managers, and disaster relief planners have conducted five binational workshops with nearly 400 total participants (Scott et al. 2012). The workshop series aimed to create new adaptive capacity through interactive feedback on regional climate and water resource forecasts, an online bilingual newsletter, and webinars (Wilder et al. 2010). Adaptive management requires such sustained, iterative approaches to contribute effectively to water security.

One of the most successful examples of building scientist–decision maker collaboration to effect policy change leading to water-secure SEH outcomes is found in the Colorado River delta. There, binational collaboration among scientists, policymakers, and nongovernmental environmental organizations promotes and secures ecological flows vital to sustaining critical wetlands and species habitat (Zamora-Arroyo and Flessa 2009). The first phase of a joint scientific process to monitor impacts of a desalination plant on the wetlands showed no harm to the wetlands (i.e., ecological thresholds had not, for the time being, been violated). Infrastructure can be an adaptive tool—in this case to meet environmental water-quality objectives—but taken to extremes, it can threaten water security (e.g., unplanned brine disposal from desalination). The delta case usefully illustrates the role researchers can have in informing a policy process that seeks adaptive water-management solutions. In so doing, this exemplifies how a sustained and iterative multistakeholder negotiation process addressed the

three vertices of the SEH triangle (Figure 1) to find solutions that meet both societal (cities and irrigators) and ecosystem (wetlands) demands for water under difficult hydroclimatic conditions.

Also in this region, the U.S.–Mexico Transboundary Aquifer Assessment Program (TAAP) represents a sustained effort to bring together federal, state, and local government agencies from the two nations, key border universities, and the International Boundary and Water Commission. They share data on transboundary aquifers and improve scientific knowledge about groundwater resources (Scott 2011). Scientists and decision makers from both countries have strengthened networks to address knowledge asymmetries through a tightly scripted formal process for binational data exchange, and in the process, they have promoted cooperation on groundwater security.

Some SEH dynamics in the region require adaptive responses but offer few direct opportunities to influence underlying causes. Emblematic examples are wildfires (O'Connor et al. 2011) and massive tree mortality (van Mantgem et al. 2009) that have resulted from the combination of increasing temperatures, severe sustained drought, and bark-beetle life cycles (together, an example of hydroclimatic drivers resulting in ecosystem thresholds being crossed). As response measures, forest- and watershed-management practices and zoning of human settlements represent only indirect means to reestablish SEH stability and strengthen water security.

Although drought and water scarcity, as already described, are the principal drivers of water insecurity in arid regions, rainfall can also represent a hazard. During the warm season, from July to September and December to February in the northern and southern hemispheres, respectively, rainfall tends to occur over large areas of complex terrain. This American monsoon system (Vera et al. 2006) can cause flooding even in hyperarid regions. In North America, tropical cyclones that develop in the western Atlantic or eastern Pacific Oceans provide significant moisture and convection to the coastal areas, which can lead to flooding and landslides. Storm-track information from the U.S. National Hurricane Center, rainfall data from Mexico's National Meteorological Service, and disaster indicators from the EM-DAT database (Centre for Research on the Epidemiology of Disasters 2011) reveal that during the last forty years the events with the greatest impact on northwestern Mexico's population and environment occurred under a combination of intense cyclones at landfall, high population density, and high rainfall rates (Farfán, Alfaro, and Cavazos forthcoming).

Rainfall amount, which is the best indicator of flooding impact in this context, is also the region's water-supply lifeline. What can be a short-term, localized hazard is simultaneously a resource when considered over longer time frames and at larger spatial scales.

The Central Andes present challenges that are distinct regionally but share similarities with western North America. The latitudinal gradient from the Atacama, the planet's most arid desert, to a temperate-humid climate with abundant vegetation leaves central Chile's transitional ecosystem subject to threshold shifts from Mediterranean to semiarid, particularly as climate change increases pressure on water resources. Climate-change models project a marked warming tendency (particularly at higher elevations) and a reduction in precipitation of up to 30 percent. Rivers already exhibit changes, not only in total flow but also in the timing of discharge (Rubio-Alvarez and McPhee 2010), especially the ones with snowmelt regimes (Vicuña, Garreaud, and McPhee 2011). Storage infrastructure partly addresses these SEH interactions, even though its construction simultaneously increases sediment loads and water treatment needs downstream. Water-security impacts in the agricultural sector (Meza, Silva, and Vigil 2008) and the potential for urban–rural water conflicts are especially pronounced (Meza et al. 2012).

Studies in the Maipo, Limarí, and Maule river basins in Chile serve as long-term experiments for collaborative modeling of SEH interactions and identification of adaptation strategies. In all three basins, the adaptive-management conceptual framework is used, emphasizing interactions among hydroclimatic processes, ecosystems, and societal water use (Figure 1) to communicate impacts and evaluate options with stakeholders. The Maipo study analyzes climate change, vegetation and land-use change, and fluctuating availability of water that could push urban and agricultural water users into conflict. Because water is allocated based on use rights, the study assesses the ability of rights-based water allocation to address water insecurity. Researchers, farmers, and the main utility company have collaboratively evaluated the validity of the results. The Limarí study analyzes the effects of climate change on the seasonality and magnitude of river discharges, and assesses the reservoir system's performance in reducing water insecurity of the irrigation association and agricultural communities while meeting riparian ecological flows. Finally, the Maule study addresses the impacts of climate change for hydropower generation and the conflicts between irrigation communities as a consequence of a changing climate. All three examples

provide valuable knowledge to understand the complex SEH dimensions of water security in the Andes.

Although limited water availability threatens water security, the combination of economic stressors and social vulnerability has synergistic effects—a clear example of SEH interactions. This entails focusing decision-making efforts on SEH processes. Lack of early-warning systems and inadequate institutional support constrain adaptive capacity to deal with drought and flood causes of water insecurity. Coping with crisis requires the active collaboration of scientific and sociopolitical institutions and ongoing participation of stakeholders. The creation of permanent working groups with the participation of different stakeholders is a fundamental task. These groups meet regularly to discuss new findings, provide feedback on simulations, and assess the validity of assumptions. Collaborative work with Chile's National Irrigation Commission, the General Directorate of Water, the Ministry of Environment, utility companies, and farmer associations constitutes interactive planning and adaptive management to address water security.

Work in the Maipo, Limarí, and Maule basins has broader implications in Chile. For example, the Second National Communication to IPCC, which members of our team are involved in, produced a synthesis report on climate change impacts, adaptation, vulnerability, and total emissions. The report has caught the attention of the private sector and the general public. This represents a policy window to pursue integrated assessments on the water-security themes we outline in this article, specifically, the societal vulnerabilities and sectoral impacts of water insecurity.

Building on the Chilean and North American experiences, AQUASEC is currently extending the adaptive management approach to a multicountry set of Andean basins experiencing water insecurity—Mendoza (Argentina), Choquecota (Bolivia), and Elqui (Chile)—where social and ecological resilience is under threat and development is potentially constrained. For stakeholders to better cope with emerging challenges, AQUASEC is providing training, exchange visits, and other capacity-building opportunities.

Conclusions

Conceptually, water security integrates SEH processes. Water insecurity can result from instabilities generated within one or more SEH subsystems (e.g., the U.S.–Mexico border wall that exacerbated flood-

ing). Adaptive management based on science-policy processes permits proactive efforts to maintain systems within water-security thresholds. As observed with the binational workshop series, this requires sustained effort.

Further work by geographers, allied scholars, and practitioners is needed on two conceptual questions: (1) how SEH thresholds are defined and operationalized, and (2) the relative effectiveness in water-security terms of adaptive responses that directly or indirectly address causes. Additionally, the case examples raise three conundrums. First, water is both a resource and a hazard, as reflected in the American monsoon example. Second, infrastructure simultaneously represents an adaptation tool and a threat to water security; this was identified in the Colorado delta desalination and Chile reservoir examples. Third, the urgency of many global-change challenges militates against the drawn-out planning time frame needed for broad-based science-policy processes, as identified with reference to Andean glacial melt. These challenges can only be resolved by facilitating adaptive management over multiple and often overlapping sectoral domains (e.g., the coupling of water and energy infrastructure in the Maule, Chile example) and over extended time frames and broad spatial scales. The challenge of responding to crises through often protracted and deliberate collaborative processes can be aided by policy windows resulting from institutional thresholds such as public attention to wildfire in North America or glacial melt in the Andes. Finally, the regional water-security mandate of AQUASEC builds on local initiatives, institutional processes, and emerging science-policy results to develop and sustain new forms of adaptive management to strengthen water security across the Americas. Initiating adaptive management without posing water security as an outcome goal would not have had the galvanizing effect evident in the western North America and Central Andes cases presented. The shared learning approach to collectively develop responses to water-security threats across the arid Americas also has broader relevance for other regions—sub-Saharan Africa, the Middle East, and South Asia, among others—with disparate institutions for decision making but analogous water-security challenges.

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Note

1. See <http://aquasec.org>, <http://www.uc.cl/es/la-universidad/noticias/6042-la-uc-y-la-universidad-de-arizona-lanzan-el-centro-aquasec-sobre-seguridad-hidrica-en-las-americas>, and <http://www.uanews.org/node/47483>.

References

Bakker, K. 2012. Water security: Research challenges and opportunities. *Science* 337:914–15.
 560 Bates, B. C., Z. W. Kundzewicz, S. Wu, and J. P. Palutikof, eds. 2008. *Climate change and water*. Geneva, Switzerland: Intergovernmental Panel on Climate Change Secretariat.
 Berkes, F., and C. Folke. 1998. *Linking social and ecological systems: Management practices and social mechanisms for building resilience*. Cambridge, UK: Cambridge University Press.
 565 Bogardi, J. J., D. Dudgeon, R. Lawford, E. Flinkerbusch, A. Meyn, C. Pahl-Wostl, K. Vielhauer, and C. Vörösmarty. 2012. Water security for a planet under pressure: Interconnected challenges of a changing world call for sustainable solutions. *Current Opinion in Environmental Sustainability* 4:35–43.
 570 Centre for Research on the Epidemiology of Disasters. 2011. EM-DAT: The International Disaster Database. Brussels, Belgium: Université Catholique de Louvain. <http://www.em-dat.net/> (last accessed 30 September 2011).
 575 Cook, C., and K. Bakker. 2012. Water security: Debating an emerging paradigm. *Global Environmental Change* 22 (1): 94–102.
 580 Falkenmark, M. 2001. The greatest water problem: The inability to link environmental security, water security and food security. *International Journal of Water Resources Development* 17 (4): 539–54.
 585 Farfán, L. M., E. J. Alfaro, and T. Cavazos. Forthcoming. Tropical cyclone impact over the population in western Mexico: 1970–2010. *Atmósfera*.
 Q2 Fischhendler, I., and E. Feitelson. 2003. Spatial adjustment as a mechanism for resolving river basin conflicts: The US–Mexico case. *Political Geography* 22:557–83.
 590 Gerlak, A., and M. Wilder. 2012. Exploring the textured landscape of water insecurity and the human right to water. *Environment* 54 (2): 4–17.

Gleick, P. H. 1993. Water and conflict: Fresh water resources and international security. *International Security* 18 (1): 79–112. 595
 Gleick, P. H., and M. Palaniappan. 2010. Peak water limits to freshwater withdrawal and use. *Proceedings of the National Academy of Sciences* 107 (25): 11155–62. 600
 Grey, D., and C. W. Sadoff. 2007. Sink or swim? Water security for growth and development. *Water Policy* 9 (6): 545–71.
 Gunderson, L. H., C. R. Allen, and C. S. Holling, eds. 2010. *Foundations of ecological resilience*. Washington, DC: 605 Island Press.
 Holling, C. S., ed. 1978. *Adaptive environmental assessment and management*. New York: Wiley.
 Ingram, H. M. 2011. Beyond universal remedies for good water governance: A political and contextual approach. 610
 In *Water for food in a changing world*, ed. A. Garrido and H. M. Ingram, 241–61. London and New York: Routledge.
 Jacobs, K., L. Lebel, J. Buizer, L. Addams, P. Matson, E. McCullough, P. Garden, G. Saliba, and T. Finan. 2010. Linking knowledge with action in the 615
 pursuit of sustainable water-resources management. *Proceedings of the National Academy of Sciences*. doi: 10.1073/pnas.0813125107. Q3
 Lemos, M. C., and B. Morehouse. 2005. The co-production of science and policy in integrated climate assessments. 620
Global Environmental Change 15:57–68.
 Liverman, D. M. 1999. Geography and the global environment. *Annals of the Association of American Geographers* 89 (1): 107–20.
 Meza, F. J., D. Silva, and H. Vigil. 2008. Climate change 625
 impacts on irrigated maize in Mediterranean climates. Evaluation of double cropping as an emerging adaptation alternative. *Agricultural Systems* 98:21–30.
 Meza, F. J., D. S. Wilks, L. Gurovich, and N. Bambach. 2012. Impacts of climate change on irrigated agriculture in 630
 the Maipo Basin, Chile: Reliability of water rights and changes in the demand for irrigation. *Journal of Water Resources Planning and Management* 138:421–30.
 Mustafa, D. 2010. Social construction of hydropolitics: The geographical scales of water and security in the Indus 635
 basin. *The Geographical Review* 97 (4): 484–501.
 Nelson, D. R., W. N. Adger, and K. Brown. 2007. Adaptation to environmental change: Contributions of a resilience framework. *Annual Review of Environment and Resources* 32 (1): 395–419. 640
 Norman, E. S., K. Bakker, and G. Dunn. 2011. Recent developments in Canadian water policy: An emerging water security paradigm. *Canadian Water Resources Journal* 36 (1): 53–66.
 O'Connor, C. D., G. M. Garfin, D. A. Falk, and T. W. Swetnam. 2011. Human pyrogeography: A new synergy of 645
 fire, climate and people is reshaping ecosystems across the globe. *Geography Compass* 5 (6): 329–50.
 Pahl-Wostl, C., J. Sendzimir, P. Jeffrey, J. Aerts, G. Berkamp, and K. Cross. 2007. Managing change toward adaptive 650
 water management through social learning. *Society and Ecology* 12 (2): 30. <http://www.ecologyandsociety.org/v0112/iss2/art30/>
 Q4 Rubio-Alvarez, E., and J. McPhee. 2010. Patterns of spatial and temporal variability in streamflow records in south 655
 central Chile in the period 1952–2003. *Water Resources Research* 46:W05514.

- 660 Scott, C. A. 2011. The water-energy-climate nexus: Resources and policy outlook for aquifers in Mexico. *Water Resources Research* 47:W00L04.
- 665 Scott, C. A., R. G. Varady, F. Meza, E. Montaña, G. B. de Raga, B. Luckman, and C. Martius. 2012. Science-policy dialogues for water security: Addressing vulnerability and adaptation to global change in the arid Americas. *Environment* 54 (3): 30–42.
- 670 Skole, D. L. 2004. Geography as a great intellectual melting pot and the preeminent interdisciplinary environmental discipline. *Annals of the Association of American Geographers* 94 (4): 739–43.
- Ullman, R. H. 1983. Redefining security. *International Security* 8 (1): 129–53.
- van Mantgem, P. J., N. L. Stephenson, J. C. Byrne, L. D. Daniels, J. F. Franklin, P. Z. Fulé, M. E. Harmon, A. J. Larson, J. M. Smith, A. H. Taylor, and T. T. Veblen. 2009. Widespread increase of tree mortality rates in the western United States. *Science* 323:521–24.
- 675 Vera, C., W. Higgins, J. Amador, T. Ambrizzi, R. Garreaud, D. Gochis, D. Gutzler, et al. 2006. Toward a unified view of the American monsoon systems. *Journal of Climate* 19 (20): 4977–5000.
- 680 Vicuña, S., R. Garreaud, and J. McPhee. 2011. Climate change impacts on the hydrology of a snowmelt driven basin in semiarid Chile. *Climatic Change* 105 (3–4): 469–88.
- 685 Vörösmarty, C. J., P. B. McIntyre, M. O. Gessner, D. Dudgeon, A. Prusevich, P. Green, S. Glidden, S. E. Bunn, C. A. Sullivan, C. Reidy Liermann, and P. M. Davies. 2010. Global threats to human water security and river biodiversity. *Nature* 467 (7315): 555–62. 690
- Voß, J. P., and B. Bornemanne. 2011. The politics of reflexive governance: Challenges for designing adaptive management and transition management. *Ecology and Society* 16 (2): 9. <http://www.ecologyandsociety.org/v016/iss2/art9> Q5
- Wilbanks, T. J., and R. W. Kates. 2010. Beyond adapting to climate change: Embedding adaptation in responses to multiple threats and stresses. *Annals of the Association of American Geographers* 100 (4): 719–28. 695
- Wilder, M., C. A. Scott, N. Pineda Pablos, R. G. Varady, G. M. Garfin, and J. McEvoy. 2010. Adapting across boundaries: Climate change, social learning, and resilience in the U.S.–Mexico border region. *Annals of the Association of American Geographers* 100 (4): 917–28. 700
- Wolf, A. T. 2007. Shared waters: Conflict and cooperation. *Annual Review of Environment and Resources* 32:241–69. 705
- Zamora-Arroyo, F., and K. W. Flessa. 2009. Nature's fair share: Finding and allocating water for the Colorado River delta. In *Conservation of shared environments: Learning from the U.S. and Mexico*, ed. L. Lopez-Hoffman, E. D. McGovern, R. G. Varady, and K. W. Flessa, 23–38. 710 Tucson: University of Arizona Press.
- Zeitoun, M. 2011. The global web of national water security. *Global Policy* 2 (3): 286–96.

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