
Beneath the surface: intranational institutions and management of the United States–Mexico transboundary Santa Cruz aquifer

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Received 5 June 2009; in revised form 4 January 2010

Abstract. As reliance on groundwater increases, the impact of groundwater-intensive use in internationally shared aquifers threatens not only to create negative environmental and economic externalities, but also to generate tensions between neighboring nations. Through an investigation of the shared Santa Cruz aquifer, located along the United States–Mexico border, we aim to understand factors leading to effective management of transboundary groundwaters. Specifically, we find that purely state-centric approaches provide limited explanatory value, and instead examine how national (domestic) arrangements for water management condition a country's position vis-à-vis its shared groundwaters. Polycentricism in national and subnational institutional regimes leads to gaps and overlaps in authority, limiting binational groundwater management. Concurrently, evolving institutional arrangements lead to ambiguity in decision making, yet crucially also provide opportunities for innovation in binational agenda setting and data sharing, which in turn aid in the alignment of both countries' priorities for the transboundary Santa Cruz aquifer.

Introduction

Currently, groundwater is used to meet 50% of global potable water needs, 20% of water demands for irrigated agriculture, and 40% of the needs of self-supplied industry (UNESCO, 2003; Zektser and Everette, 2006). As rates of groundwater use increase, intensive use of groundwater can lead to higher pumping costs, land subsidence, salt-water intrusion, mobilization of natural or human sources of contamination, and ecosystem deterioration (Llamas and Custodio, 2003). These problems are difficult enough to address within individual countries; with transboundary groundwater resources there is the added challenge of bridging the political and institutional divides that transect the physical boundaries of an aquifer.

Transboundary aquifers are more prevalent than transboundary rivers (UNESCO, 2006); however, there is not as robust a history of collaboration over the management of these resources. For example, even though the United States of America and Mexico entered into a treaty⁽¹⁾ over shared surface waters in 1944 (IBWC, 1944), a comprehensive agreement over groundwater remains elusive (Hall, 2004; Hardberger, 2004; Mumme, 2005a). Inventories of formal agreements over transboundary waters (Beach et al, 2000; Burchi and Mechlem, 2005; Hamner and Wolf, 1998; Matsumoto, 2002) indicate the paucity of treaties specifically addressing groundwater. Our research seeks to understand what factors heighten or hinder binational synergy (cooperation as formal; collaboration as informal) over transboundary groundwater. In

⁽¹⁾Treaty between the United States of America and Mexico on the Utilization of Waters of the Colorado and Tijuana Rivers, and the Rio Grande.

particular we examine the impact of national and subnational institutional arrangements on transboundary groundwater management. This approach contrasts to conventional transboundary water constructs (Barrett, 1994; Dombrowsky, 2007; Giordano et al, 2002; Wolf et al, 2003), which were developed based on surface water and center on nation-states as actors.

We expect that the institutional environment within a country will have a more prominent role in the management of transboundary groundwater than that of transboundary surface water due to the very different physical characteristics and governance challenges of groundwater. Specifically, surface water infrastructure is invariably in the public domain (funded and operated by governmental agencies), and is larger in scale (fewness applies) and therefore more subject to management, and, in the transboundary context, to agreements. Additionally, surface water is more apparently subtractable, resulting from identifiable (visible) use point, which raises the need for allocation decisions. By contrast, groundwater is more commonly privately developed, its infrastructure is dispersed and smaller in scale, and it is difficult to physically control (fugitive) and therefore more difficult to regulate, let alone make the subject of international treaties. These differences suggest that national governments may have more difficulty internally regulating and managing their groundwater resources. Furthermore, many countries have only recently begun to develop institutions that enable the government to regulate groundwater use (Burchi, 1999; Shah, 2002). As laws and agencies governing groundwater management within a country are relatively new and evolving, national and subnational institutions may be of greater salience for transboundary groundwater than surface water.

Through an investigation of the management of shared groundwater in the Upper Santa Cruz River Basin (USCRB), we demonstrate how institutions within the US and Mexico mediate each country's approach to their shared groundwater. The USCRB is particularly salient due to its location (figure 1) in a rapidly urbanizing corridor of the border with additional pressure exerted on groundwater by climate change and variability. More specifically, we find that the polycentric⁽²⁾ and evolving nature of the institutional environment within each country shapes its capacity and interest to negotiate and implement formal binational agreements for shared groundwater.

We begin with an analysis of conventional approaches to the study of transboundary water management, then draw from the literatures on international environmental governance and on institutionalism to support our claim regarding the importance of national and subnational institutions. This section is followed by a description of the study region. We next present an institutional analysis, which is based on information garnered from key informant interviews with water managers and large water users on both sides of the border, participant observation in planning and public outreach meetings, and a review of legal documents, mission statements, and agency mandates. For each country we explain the polycentric and evolving nature of the institutional environment and give specific examples of how features of the institutional environment impinge upon collaboration and cooperation. Lastly, we reflect upon the implications of our findings within the USCRB, along the US–Mexico border, and to transboundary aquifers more generally.

⁽²⁾Ostrom et al (1961, page 831) use the term polycentric to refer to “many centers of decision making which are formally independent of each other.”

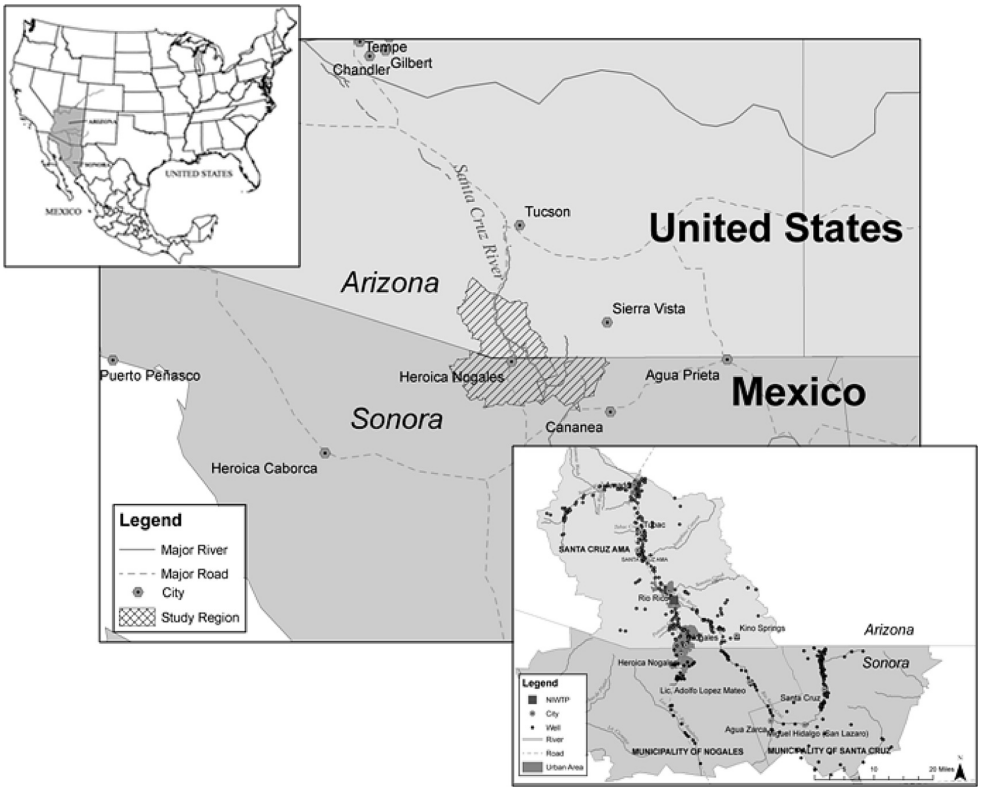


Figure 1. The Upper Santa Cruz River Basin: location and key features.

‘Intra’ in ‘Inter’-national groundwater management

Transboundary water management occurs at a variety of scales and formalities, including global resolutions, multilateral or bilateral agreements, regional or local program-specific agreements, and informal collaboration. Formal transboundary groundwater agreements should not be conflated with instances of collaboration (information sharing, consultation, or joint problem solving) that are the product of historical antecedent and, in some cases, personal relationships. Operational arrangements for transboundary collaboration may not be durable in their own right; however, the fact that they recur and evolve is evidence that distinct institutional cultures can permit informal rules of engagement. Research on transboundary waters, which consists primarily of studies of international river basins, provides insights into the causes and outcomes of both formal and informal interactions over shared waters.⁽³⁾ Existing research does not seek to explain the paucity of agreements (formal or informal) over shared groundwater, nor does it investigate how intranational⁽⁴⁾ institutions mediate such processes. Specifically, the central question we aim to address is how polycentric and

⁽³⁾ These studies identify factors leading to conflict or cooperation (Espy and Towfique, 2004; Giordano et al, 2002; Song and Whittington, 2004), analyze bargaining choices (Barrett, 1994; Frisvold and Caswell, 2000), and evaluate regime effectiveness (Bernauer, 2002; Dombrowsky, 2007; Milich and Varady, 1998).

⁽⁴⁾ We use the term ‘intranational institutions’ to refer to the combination of national-level (federal, or central government) and subnational (state, regional, or local) institutions governing groundwater.

evolving institutional arrangements produce (or inhibit) competence, compatibility, and capacity to manage transboundary groundwater.

Research on transboundary waters commonly fails to acknowledge the role of intranational institutions because it adopts the individual country, acting as a monolithic unit, as the unit of analysis.⁽⁵⁾ However, it is the institutions within a country that enable it to enact, implement, and enforce transboundary water management. Within most countries, responsibility for the management of groundwater lies across multiple institutional scales, and, thus, in addressing the transboundary aspects of water management, national institutions must contend with subnational institutions and vice versa. Interplay⁽⁶⁾ within the intranational institutional regime for water management can lead to both synergy and conflict (Gehring and Oberthur, 2008). These interactions, between and within national and subnational levels, highlight the importance of avoiding the ‘territorial trap’⁽⁷⁾ that leads to conceptualization of international groundwater management as occurring exclusively at the national scale.

To better understand the influence that intranational institutional arrangements for groundwater management exert on formal and informal interactions, it is illustrative to consider the important theoretical advances and empirical evidence of institutional dimensions of global environmental change (Young et al, 2008). Particularly relevant are factors related to what Young (2002, pages 98–100) terms “competence, compatibility, and capacity” and their relation to institutional interplay both within and across scales. The first of the three Cs, competence, refers to the political and legal authority within a country that allows it to implement international commitments (jurisdiction). Compatibility refers to the fit between national arrangements and institutions and the international commitment (concordance among mechanisms, procedures, and practices). Capacity relates to the ability of a country to make good on its commitment, which includes that an entity within the country must take on responsibility for implementation (human, social, environmental, fiscal capital). With respect to aquifers, these three Cs determine to what extent groundwater can be regulated and by whom. The institutional arrangements regulating groundwater within a country define that country’s competence, compatibility, and capacity, as those institutions determine the ability of that country to control its internal water management activities (eg abstractions, recharge), and thus the impacts of those activities across the border. Institutional arrangements within a country also determine the ability of each country to engage with its co-‘aquiferian’ to address externalities from water use.

⁽⁵⁾ Wolf (2007, page 253) addresses the limitations of treating countries as “homogenous monoliths” in research on transboundary waters. Nevertheless, this approach is adopted in large-*n*, multiple country empirical studies (Hensel et al, 2006; Spector, 2000; Yoffe et al, 2004), game theoretic analyses (Eleftheriadou and Mylopoulos, 2008; Fernandez, 2002; Just and Netanyahu, 2004; Netanyahu et al, 1998; Roger, 1969), optimization models (Fisher et al, 2002; Küçükmehtemoglu and Guldmann, 2004; Whittington et al, 2005), and multicriteria decision models (Ganoulis et al, 1996). Analyses of Pareto-optimal solutions and sharing the gains from cooperation similarly treat countries as monolithic actors (Giordano and Wolf, 2003; Grey and Sadoff, 2003; Jagerskog and Lundqvist, 2006; Klaphake and Voils, 2006; Sadoff and Grey, 2005; UNDP, 2006; Wolf, 1997; 2007).

⁽⁶⁾ On the basis of Young’s (2002) definition of interplay as the horizontal and vertical interactions that occur among institutions as a result of political and functional linkages, the interactions of specific interest for our analysis arise due to the connectedness of substantive issues (shared groundwater) and the resulting relationships forged among institutions.

⁽⁷⁾ Agnew (1994) uses ‘territorial trap’ to describe three common, yet often fallacious, assumptions of the state as actor: (i) sovereign states have complete control over the territorial space they cover, (ii) domestic and foreign policies occur in isolation and can be viewed independently, and (iii) the premise of the state as existing prior to and containing society.

In the context of water scarcity, ‘anarchic’ or ‘chaotic’ arrangements tend to aggravate competitive groundwater development and use (Shah, 2009); nonetheless, owing primarily to asymmetries inherent in transboundary institutional systems, coordinated management does not necessarily follow from cooperative binational arrangements.

Our research in the USCRB indicates that the polycentric and evolving nature of the institutional environment within both the US and Mexico constrains these three Cs. By polycentric, we specifically refer to the distribution of authority for policy and decision making, implementation, and enforcement to multiple entities at different scales of government.⁽⁸⁾ Although the redundancies and duplication of authority caused by polycentrism are thought to be useful in building resilience (Folke et al, 2005; Tang, 1991), polycentricity also leads to increased transaction costs, inconsistencies, and contested authority (Huitema et al, 2009; McGinnis, 2005). The impact of polycentrism on the management of transboundary resources, and, in particular, the impact of overlapping jurisdictions and the coordination problems that arise from polycentrism, has not been addressed. Research on integrated water resources management demonstrates implementation of water management at the basin scale is impeded by polycentric decision-making arrangements and boundary mismatches (Blomquist and Schlager, 2005) including disaggregated decision authority and institutional turf wars (Biswas, 2008). Even at a subbasin scale, organizational complexity and the high transaction costs associated with coordination across multiple institutions have been shown to hinder implementation of water management activities (Blomquist et al, 2001). Not only does polycentricity lead to overlapping authority and transaction costs, it can also create gaps in jurisdiction when, owing to the fragmented nature of authority, some aspects of water management do not fall under the purview of any water management agency. Given the multidimensional nature of groundwater referred to above, we expect overlaps and gaps in authority to be especially pronounced, as different entities govern water resource use, quality, legal rights, etc.

Polycentric water resource management systems are inherently evolving; new entities, laws, and regulations are formed while existing responsibilities and jurisdictions are modified to address emerging challenges (McGinnis, 2005). Rapid evolution leads to ambiguity (ill-defined roles), which result from institutional design flaws at the formal level or contested authority at the informal, operational level.⁽⁹⁾ Rodríguez-Pose and Gill (2003) demonstrate that tensions between tiers of government are inherent as authority is devolved. As we will show in our case study, this in turn leads to legitimacy claims that can result in overlapping mandates and program implementation working at cross purposes.

⁽⁸⁾ Though the term ‘polycentricism’ has recently been adopted to denote a flexible governance system, wherein citizens select among the level or combinations of levels of government that best combine to meet their needs through the development of special districts, or governing bodies (Andersson and Ostrom, 2008; Ross and Martínez-Santos, 2008), we use the original usage of the term, as in footnote 2, which simply refer to the distribution of decision-making authority across multiple entities (Ostrom et al, 1961).

⁽⁹⁾ Ambiguity has been shown to both aid and thwart international cooperation. When incorporated deliberately into an agreement, ambiguity allows for flexibility so that treaties do not need to be renegotiated (Fischhendler, 2008a). Yet ambiguity can also be quite detrimental, especially when disagreement arises (Fischhendler, 2008b). In this paper we refer to ambiguity in the mandates, jurisdiction, and authority of national and subnational water management institutions. More specific to water management along the US–Mexico border, Frisvold and Caswell (2000) indicate how ambiguity leaves open the question of whether the International Boundary and Water Commission (IBWC), the US Environmental Protection Agency (EPA), or state environment agencies are responsible for water quality.

The Upper Santa Cruz River Basin

We employ a synchronous theory empirical approach in the paper, and, having outlined our conceptual approach above, turn to the case example in order to further our understanding, and return at the end to summarize the implications for transboundary groundwater more generally. The USCRB was selected as a case study because the US and Mexico have a strong history of formal cooperation over shared surface waters, yet, with the exception of one agreement to limit groundwater pumping in a specific location,⁽¹⁰⁾ there are no formal agreements between the two countries regarding their many⁽¹¹⁾ shared aquifers (Mumme, 2005a). Uncoordinated groundwater withdrawals have led to groundwater mining in the majority of shared aquifers, resulting in declining water table levels and reduced water availability. Contamination also threatens to reduce groundwater quality on both sides of the border (Mumme, 2000). Cooperation via agreements on the timing and quantity of abstractions, aquifer protection, or recharge activities could benefit both countries.⁽¹²⁾ The US–Mexico Transboundary Aquifer Assessment Program (TAAP),⁽¹³⁾ which is based on 2006 US federal law, authorized for up to US\$50 million over ten years and initiated in 2007 with input from Mexico, is currently pursuing agreements for binational studies of several of the aquifers that span the border; it is anticipated that this will lead to joint modeling and institutional assessments that will support each country's decision making for its portion of shared aquifers, but not binational management.

The study region is defined by the path of the Santa Cruz river and the aquifer connected to it. On the US side of the border the study region encompasses the area defined as the Santa Cruz Active Management Area (SCAMA). On the Mexican side it encompasses the municipalities of Nogales and Santa Cruz, Sonora. The region, which is part of the Sonoran Desert, is semiarid and susceptible to drought (Morehouse et al, 2000; SAGARPA, 2004). Precipitation is between 280 mm and 440 mm per year (Liverman et al, 1997) and subject to considerable variability under different climate change scenarios (Carter et al, 2000). There is a strong interaction between surface

⁽¹⁰⁾ In 1973 the US and Mexico approved Minute 242 to the 1944 US–Mexico surface water treaty, which stipulates that both countries will inform each other of water development activities that might adversely affect the other, includes an agreement that both countries will limit pumping near San Luis, and suggests a commitment to seek a comprehensive groundwater agreement (IBWC, 1973; Mumme, 2000). Owing to incongruent intranational institutional arrangements—states in the US are wary of federal or international authority over groundwater while Mexican federal and international agencies accord little if any autonomy to intranational agencies—formal negotiations for binational groundwater management have not been enacted.

⁽¹¹⁾ The actual number of aquifers crossing the US–Mexico border is unknown. Mumme (2000) identifies eighteen; the International Groundwater Assessment Center (IGRAC, 2009) identifies ten; the United National Educational, Scientific and Cultural Organization and Internationally Shared Aquifer Resources Management's program (UNESCO and ISARM, 2004) cites eighteen, eight, and nine all in the same document; and the Good Neighbor Environmental Board (2005) claims there are between eighteen and twenty. This incongruence in expert opinions is identified by Todd Jarvis on <http://www.internationalwaterlaw.org/blog/?p=10>.

⁽¹²⁾ For example, in the Hueco Bolson aquifer located between El Paso and Ciudad Juarez, groundwater mining on both sides of the international border reduced each city's ability to meet its water needs (Chavez, 2000). A memorandum of understanding between the two cities is now helping them to coordinate activities and extend the life of the aquifer (UNESCO and ISARM, 2004).

⁽¹³⁾ The nascent US–Mexico TAAP has been successful in reaching agreement on data sharing and aquifer assessment (a step of binational management) under IBWC–CILA (Comisión Internacional de Límites y Agra) auspices via the Joint Report of the Principal Engineers Regarding the Joint Cooperative Process United States–Mexico for TAAP, signed 19 August 2009.

and groundwater, and the majority of water used in the region is withdrawn from wells located in the river valley.⁽¹⁴⁾

Both sides of the border are concerned with meeting water supply needs in the face of population and economic growth. The SCAMA is predominantly rural; the small city of Nogales, Arizona is surrounded by cattle ranging, retiree communities, exurban development, and wilderness. The total population in the SCAMA is approximately 30 000. Within Arizona the prevailing discourse is about achieving growth in balance with the environment; the official water management goals of the SCAMA include maintaining safe yield and preventing local water tables from experiencing long-term decline (ADWR, 1997).

In contrast, Nogales, Sonora is more urban. It has a burgeoning population due to growth in the maquila industry post the North American Free Trade Agreement (NAFTA) and the associated induced migration. Official statistics cite a population of approximately 200 000 (INEGI, 2005), but city officials estimate the true population is closer to 350 000 when counting the extensive 'guest' (ie undocumented immigrant) population. Within Mexico the primary objective is to improve and extend existing water services. Nogales, Sonora expects it will need to more than double its current water endowment in order to meet water needs (Milman, 2009).⁽¹⁵⁾

With respect to managing the transboundary aspects of the aquifer, in the SCAMA the concern is the impact that additional groundwater pumping in Mexico will have on base flow in the Santa Cruz river and underflow into Arizona. Base flow is important both for sustaining the riparian environment and for recharging the younger alluvium between flood events (ADWR, 1995). The connection between pumping in Mexico and underflow into Arizona is poorly understood as there is much uncertainty regarding the hydrogeology of the aquifer as it crosses the border (Milman, 2009). Water use in the SCAMA likely has a smaller impact on Mexico, due to the presence of micro-basins near the border (Halpenny and Halpenny, 1991). Nonetheless, the cross-border connection is important to both countries, as there may be synergy in conducting coordinated aquifer recharge activities.

Both the US and Mexico are considering plans to conduct Santa Cruz aquifer recharging using treated wastewater in order to augment the availability of water. Wastewater from both sides of the border is treated jointly at the Nogales International Wastewater Treatment Plant (NIWTP), located in Arizona. The quantity of effluent discharged from the plant is substantial; the portion of the effluent that originates in Mexico is equivalent to 58% of anthropogenic water demands in the SCAMA (ADWR, 1999). If treated wastewater is used to recharge the aquifer in the southern end of the SCAMA, some portion of the recovered water could be piped across the border to Mexico (Morehouse et al, 2000; Sprouse, 2005). Currently, Arizona state regulations do not permit SCAMA to count effluent of Mexican origin

⁽¹⁴⁾ Wells in the Santa Cruz River Basin provide 40% of the water supply for the city of Nogales, Sonora (COAPAES, 2005). Other resources of water for Nogales, Sonora include wells in the Los Alisos River Basin, located to the southwest of the city, and several lower yield wells located in the Nogales Wash, a tributary to the Santa Cruz that runs through the center of town.

⁽¹⁵⁾ In 2005 the municipal-run water utility of Nogales, Sonora [Organismo Operador Municipal de Agua Potable, Alcantarillado, y Saneamiento (OOMAPAS)] had a pumping capacity of 800 lps. It projects it will need 1400 lps to provide daily, although not 24-hour water, service to its residents through the year 2025 (personal communication, Leonardo Sandoval, Director, OOMAPAS, 14 July 2005). In 2007 only 87% of the population had piped water connection to the home and only 5% received piped water service 24 hours per day (personal communication, Martin Navarro, OOMAPAS, 4 October 2007). The city is growing at a rate of 4.3% per year and expects to build 30 000 new houses during the next 5–10 years (personal communication, Claudia Gil, Deputy Director for Urban Infrastructure and Public Works, Ayuntamiento de Nogales, 6 October 2007).

towards meeting assured water supply rules. Alternatively, treated wastewater could be used to recharge either Santa Cruz or the Los Alisos aquifers on the Mexican side of the border (Camp Dresser and McKee, 1997). Aquifer recharge in either of these locations may benefit both countries. Owing to the downstream location of the SCAMA, it may be economically more efficient to treat wastewater and conduct aquifer recharge in the US in exchange for funds or the transfer of recovered water supply than to treat and recharge the water in Mexico. Yet conducting aquifer recharge in Mexico could have a hydrologically positive impact on the US, as it would reduce the effects of intensive groundwater use in Mexico. Thus coordinated management could aid in achieving water supply, sustainability, and economic goals.

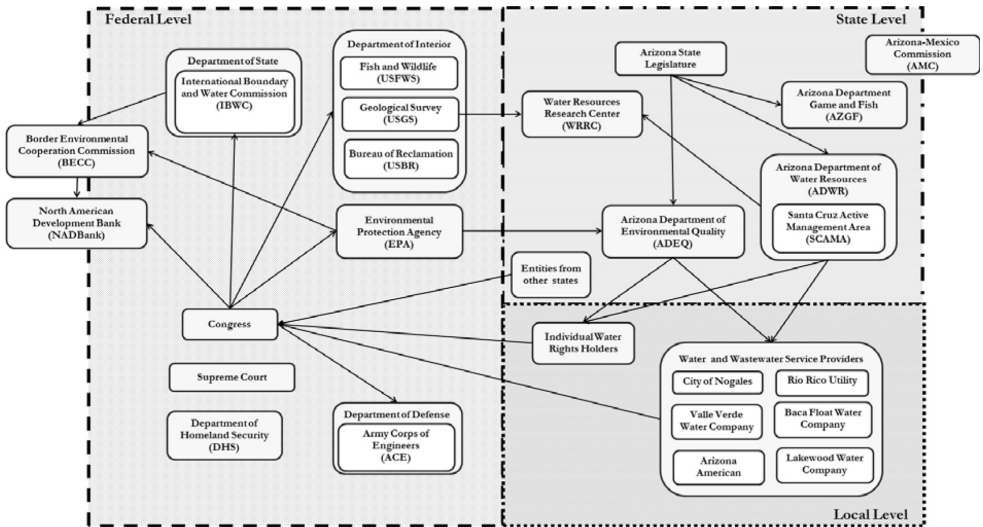
The specific management challenges of the Santa Cruz aquifer requires transboundary coordination involving complex interplay of subnational institutions. Use of the effluent from the NIWTP for aquifer recharge necessitates a binational agreement through the IBWC with Comisión Internacional de Límites y Agra (CILA), yet the binational and subnational decision making and collaborative frameworks required to implement these management activities are unprecedented. A formal agreement requires addressing issues such as agency mandates that confine jurisdiction; capacity limitations and constrain agencies from taking the lead; ambiguity between federal versus state responsibility; and incompatibility between existing regulations, processes and authority with operational policies needed to implement recharge or water transfers (Milman, 2009). We analyze these institutional challenges in more depth, delineating the impact of the institutional environment within both the US and Mexico on the competence and capacity of the two countries to reach an agreement.

Institutional analysis of transboundary groundwater in the USCRB

Within the US

The US system of government has been described as one of “separated institutions sharing powers” (Raustiala, 1997, page 25). This polycentrism extends to land and water resources. Water resources are governed by a policy of federalism; responsibility for the management of water resources is allocated to the states yet the federal government retains authority over international agreements, interstate commerce, the public trust, and the management of public lands (Cox, 1982; Heinmiller, 2007; Sax et al, 2000). As a result, water management occurs through an amalgamation of many diverse actors, activities, and policies designed and enacted at a variety of scales. These entities and regulations evolve over time, as new water management challenges emerge and as frameworks shift regarding the level at which water should be managed. No clear mappings currently exist to delineate these agencies and their relationships. To analyze and illustrate the polycentric nature of the institutional environment for groundwater management, in figure 2 we represent the major US institutions operating in the USCRB. For comparative purposes this should be considered in relation to the asymmetrical institutional environment in Mexico, as shown subsequently in figure 3.

This complex network of authority and decision making reduces the competence, capacity, and compatibility of the US with respect to the transboundary aspects of groundwater management within the USCRB. Competence is limited because (i) certain aspects of water management do not fall under the purview of any existing agency, (ii) allocation of jurisdiction across federal and state agencies results in ambiguity in the scale of responsibility, and (iii) functional linkages between multiple agencies create overlaps in jurisdiction. Incompatibility arises because the institutional arrangements governing water management within the US do not provide for recharge of the aquifer using Mexican-origin effluent. Lastly, capacity is low due to mismatch



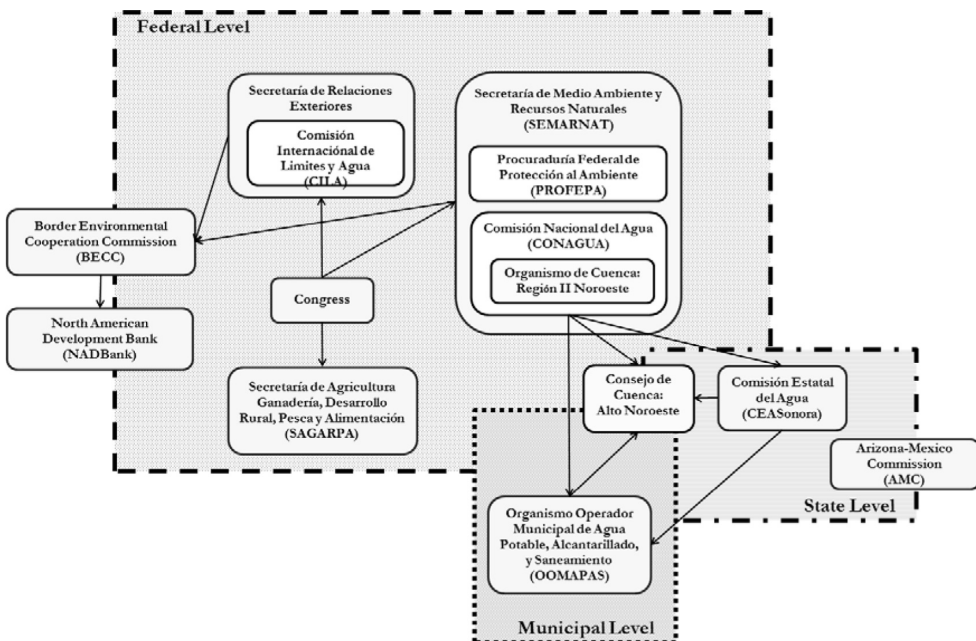
Entity *Synthesis of mandate and functional attributes*

BECC	Certify proposed border region environmental infrastructure and provide technical assistance to local entities.
NADBank	Assist BECC in arranging financing for certified projects through loans and grants.
Department of State	Conduct foreign policy. Grant 'Presidential Permits' for infrastructure crossing the border.
IBWC	Ensure compliance with the 1944 treaty, negotiate treaty amendments, maintain hydrologic monitoring stations, manage joint infrastructure, and communicate information across the border.
EPA	Ensure pollution control by enforcing environmental legislation and develop water quality standards. Promote cross-border environmental planning and finance-related projects under Border 2012 project.
USFWS	Protect endangered species.
USGS	Conduct hydrogeological investigations, monitor surface water flow, maintain water availability data.
USBR	Conduct collaborative (interagency) water supply studies, fund infrastructure development.
ACE	Approve stream crossings (bridges and culverts) and conduct flood studies.
DHS	Monitor border crossing including through drainage culverts.
AMC	Consensus building and information sharing, particularly through AMC Water Committee.
AZGF	Protect endangered species.
ADEQ	Develop, monitor, and ensure compliance with pollution control measures including setting water quality standards, permitting discharge, reuse, and recharge activities.
ADWR	Conduct state-wide water resources planning, administer water rights, undertake hydrologic investigations and monitoring, permit water-related activities, and provide technical assistance to water users.
SCAMA	Develop management plans to achieve Active Management Plan goals, administer groundwater rights, monitor water use, and enforce conservation requirements.
WRRC	Implement the state's component of the Transboundary Aquifer Assessment Program, provide research and policy support for water resources planning and management in general.

Figure 2. US institutional environment for transboundary groundwater management in the Upper Santa Cruz River Basin.

between agency mandates and resources (financial, human, and material). We discuss the factors influencing each of these three Cs and summarize our points in table 1, which also provides comparison with Mexico as described in the following section.

In the United States competence is limited because no entity is solely responsible for ensuring that transboundary aspects of groundwater management are addressed. Although the IBWC has become the de facto governmental entity responsible for resolving water and boundary-related disputes and conducting activities and agreements



Entity Synthesis of mandate and functional attributes

CILA	Ensure compliance with the 1944 treaty, negotiate amendments, maintain hydrologic monitoring stations, manage joint infrastructure, and communicate information across the border.
PROFEPA	Ensure pollution control and prevention by enforcing environmental (and water) quality standards.
CONAGUA	Administer and safeguard the nation's waters by establishing national water policies, develop standards and regulatory requirements, encourage water use efficiency, and support municipalities in the provision of water and wastewater services.
Organismo de Cuenca Región II Noroeste	Develop regional water plans, determine water availability, administer water concessions and discharge permits, and coordinate public and private activities.
Consejo de Cuenca	Serve as the water resources coordination platform among government entities, water users, and other interests.
SAGARPA	Coordinate water use policies and activities related to agriculture and rural development.
CEASonora	Coordinate water-related programs and resources transferred to the state from the federal government, establish planning standards and regulations regarding the use and supply of water, conduct studies, assess, assist and provide technical and financial support to municipal water, sewerage, sanitation providers and provide those services in conjunction with municipalities when requested.
OOMAPAS	Provide water, sewerage and wastewater treatment services within the municipality, conduct long-range planning activities, construct and operate infrastructure, and regulate connections to services.

Figure 3. Mexican institutional environment for transboundary groundwater management in the Upper Santa Cruz River Basin.

related to water along the US–Mexico border (Hardberger, 2004; Mumme, 2005b), it does not hold exclusive responsibility for the transboundary aspects of the Santa Cruz aquifer. The IBWC was designed to protect sovereign claims over water resources through diplomacy, not to function as a policy entrepreneur seeking solutions to emerging challenges (Mumme and Moore, 1999). Its authority is restricted to carrying out treaty functions (which, as we have noted, do not explicitly cover groundwater), so as to ensure its jurisdiction does not overlap or conflict with other US agencies (Glaeser, 1946). There is some flexibility in interpretation of the IBWC's mandate, especially in light of provisions stemming from NAFTA and its ties to the Border

Table 1. Institutional competence, compatibility, and capacity in the binational Upper Santa Cruz River Basin.

United States	Mexico
<p><i>Competence</i></p> <p>No entity is solely responsible for ensuring that transboundary aspects of groundwater management are addressed.</p> <ul style="list-style-type: none"> • The mandates of existing entities, including the International Boundary and Water Commission and Arizona Department of Water Resources, constrain the scope of their jurisdiction. <p>Federalism leads to overlapping responsibility of federal, state, and the local agencies.</p> <ul style="list-style-type: none"> • Multiple agencies (eg Environmental Protection Agency, US Forest Service, Arizona Department of Environmental Quality) hold jurisdiction over environmental protection and thus share regulatory authority. <p>Water rights holders determine their own usage, consistent with their allocations.</p>	<p>Agencies located within different federal ministries hold partial domain over aspects of transboundary groundwater management.</p> <ul style="list-style-type: none"> • Comisión Internacional de Limites y Agua (CILA) holds transboundary authority, whereas the Comisión Nacional del Agua (CONAGUA) has jurisdiction over water resources administration. <p>Decentralization has led to authority over water distributed over multiple levels of government.</p> <ul style="list-style-type: none"> • Organismo Operador Municipal de Agua Portable, Acantarillado, y Saneamiento (OOMAPAS) charged with planning and implementation yet dependent on CONAGUA for concessions, permits, and financial and technical assistance. • The Comisión Estatal de Agua (CEASonora) provides limited state funding for local water utilities (eg OOMAPAS) but is dependent on CONAGUA for water policy. • Regionalization within CONAGUA results in unclear division of responsibilities between regional and Mexico City offices.
<p><i>Compatibility</i></p> <p>Several institutional provisions required for aquifer recharge are absent.</p> <ul style="list-style-type: none"> • Criteria for attainment of the Santa Cruz Active Management Area (SCAMA) management goals are not fully defined. • No entry has authority to implement a lease to retain effluent for recharge. • Provisions for selling recharge credits outside of the Active Management Area are lacking. • No certified recharge facilities exist within SCAMA. 	<p>Several institutional provisions required for aquifer recharge are absent.</p> <ul style="list-style-type: none"> • Water quality standards for aquifer recharge have not been published. • Provisions for recharge credits have not been established. <p>OOMAPAS operational role for wastewater collection (and thus its ability to conduct aquifer recharge) is incompatible with CONAGUA's statutory role of administering this as 'national waters'.</p>
<p><i>Capacity</i></p> <p>SCAMA has only three employees, tasked with a number of wells, surface rights, well drilling permits, designating or certifying assured water supply, etc, and not empowered to work on extending the agency mandate. The 2009 state budget crisis exacerbated this mismatch.</p>	<p>OOMAPAS experiences high staff turnover and is independent on other governmental agencies (CONAGUA, CEASonora) for financial resources and technical assistance.</p> <p>CONAGUA, OOMAPAS defer to CILA with respect to the border. Yet CILA defers to CONAGUA with respect to water within and up to the border.</p>

Environmental Cooperation Commission, yet the IBWC has been known to interpret its directive narrowly (Mumme, 2005b; Mumme and Moore, 1999). Overstepping its mandate is politically unthinkable due to interorganizational dependence: the IBWC relies on cooperation and compliance of state and local entities in implementing or conducting water management activities and is subject to congressional approval (Mumme, 2005b; Mumme and Moore, 1999).

Involvement of the IBWC in managing transboundary groundwaters is particularly controversial, as groundwater has historically fallen under the purview of the respective state government within the US. To date, Minute 242 is the only addendum of the 1944 treaty that addresses groundwater, yet it lacks specificity and was viewed as infringing upon state jurisdiction (Mumme, 2005a). As shown in figure 2, a number of other federally sponsored agencies also influence activities directed at managing the transboundary aspects of the Santa Cruz aquifer, such as the use of Mexican-origin effluent for aquifer recharge or the possible transfer of reclaimed water across the border. These agencies include the Water Resources Research Center (Arizona's federally designated water resources institute), the Arizona office of the United States Geological Survey, the Bureau of Reclamation, and the EPA. In addition, the Department of Homeland Security and the Army Corps of Engineers oversee border security issues related to water.

At the state level, the Arizona Revised Statutes designate the Arizona Department of Water Resources (ADWR) as responsible for administering Arizona water law and ensuring long-term adequate supplies for the state (ADWR, 2002; Arizona State Legislature, no date). Although ADWR's mission is to ensure "an adequate quantity of water of adequate quality for Arizona's future" (ADWR, 2002), in practice ADWR's water resources planning and management activities are restricted by the tools and jurisdiction granted to it. ADWR's main functions are to administer and enforce the Arizona groundwater code and surface water rights laws; new laws must be passed by the Arizona legislature or through the governor's office. ADWR can conduct technical studies and develop water plans; however, its policy-making activities are constrained to developing incentive systems (such as fees and subsidies) and developing and enforcing regulations. ADWR does not directly enact activities such as abstraction, recharge, or recovery and it is not authorized to move water or seek to augment supply. Rather, those activities are undertaken by local-level entities such as the municipal service providers, local governments, and individual water rights holders as shown in figure 2, lower right.⁽¹⁶⁾ Moreover, ADWR does not have the authority to address transfers of water out of or into the state, nor to conduct international agreements, although it cochairs with the Sonora State Water Commission (CEASonora) the water committee of the Arizona–Mexico Commission, a consensus-building mechanism initially predicated on strengthening commercial ties between Arizona and Sonora.

Not only is there no entity mandated to address the impacts of Mexico's use of groundwater on the SCAMA, there is also ambiguity regarding which level of government should be charged with addressing this issue. Interviews with key informants in Arizona indicate that at the local level there is the sentiment that, because addressing

⁽¹⁶⁾ ADWR regulates the direct use of groundwater by individual entities through a system of water rights, which are subject to reasonable and beneficial use (ADWR, 2001). The 1980 Groundwater Management Code restricts groundwater use in Active Management Areas (AMAs), where groundwater users must either possess a grandfathered water right, a service provider right, or a withdrawal permit (ADWR, 2001). Up to 10 acre-feet per annum for domestic or stock use may also be extracted from 'exempt wells'—that is, wells with a pumping capacity of less than 35 gallons per minute (gpm), without a permit. See <http://www.azwater.gov/dwr/WaterManagement/Content/AMAs/default.htm>.

water challenges in the region requires international cooperation, the US federal government should adopt a proactive stance towards water management throughout the basin, especially as it relates to ensuring continued flow of water from Mexico (eg wastewater to be treated and used for recharge of the aquifer, underflow, and stream flow across the border). However, concurrently, federal governmental employees view management of groundwater in Santa Cruz aquifer as primarily the responsibility of state and local entities, with federal assistance in negotiating and ensuring compliance with desired activities once local planning has occurred. This ambiguity between state or local and federal responsibility stems in part from what Norman and Bakker (2005; 2009) call “scalar mismatch”—that is, a problem or challenge occurs at the local level but the solution necessarily involves a higher level of government, as the authority to enact international agreements lies at the federal level. In the specific case of transboundary groundwater, this mismatch is compounded by weak capacities to enforce actual groundwater use, related as we observe above to its ‘invisibility’.

Owing to functional linkages, multiple agencies must interact in order for activities designed to address the transboundary aspects of the aquifer to occur. In the SCAMA one issue of concern is maintaining critical habitat for endangered species such as the gila top minnow and the southwestern fly catcher.⁽¹⁷⁾ The EPA, through its enforcement of the Endangered Species Act,⁽¹⁸⁾ and the Arizona Department of Fish and Game, through its Project Evaluation Program,⁽¹⁹⁾ hold responsibility for ensuring federal or state authorized projects do not negatively impact critical habitat. Additionally, the Arizona Department of Environmental Quality regulates water quality—for example, NIWTP discharge to Santa Cruz river.

In addition to competence, compatibility is impacted by the intranational institutional environment as existing procedures and mechanisms for water management within the United States do not include provisions for using Mexican-origin effluent to conduct aquifer recharge in Arizona. The SCAMA was formed as an independent water management district in 1994 (ADWR, 1997; Arizona State Legislature, no date).⁽²⁰⁾ The management objectives of the SCAMA (maintaining safe yield and preventing local drawdown) are still being operationalized. The lack of formal definitions of drawdown and safe yield present a barrier to using effluent for recharge, as regulations over the abstraction and recovery of recharged water remain unclear and mechanisms for transferring recharge credits within or outside of the AMA have yet to be developed. Not only are regulatory procedures lacking, but there are also no certified groundwater storage facilities that could be used as the site of recharge activities.⁽²¹⁾ Lastly, no entity in the SCAMA has the jurisdiction to enter into a formal

⁽¹⁷⁾ Personal communication, Doug Dunham, United States Fish and Wildlife Service, 12 October 2007; and Sherry Sass, Friends of the Santa Cruz River, 29 May 2006.

⁽¹⁸⁾ See <http://www.epa.gov/lawsregs/laws/esa.html>

⁽¹⁹⁾ See http://www.azgfd.gov/w_c/project_evaluation.shtml

⁽²⁰⁾ Arizona Senate Bill 1380, which became Arizona Revised Statute 45-411.04, created the SCAMA, separating it from the Tucson AMA. This change was enacted in recognition of the distinct water management needs of the region, including challenges arising from the unique hydrogeology and the need for binational coordination of water resources within what is now the SCAMA (ADWR, 1997).

⁽²¹⁾ Chapter 3 of Title 45 of the Arizona Revised Statutes (Arizona State Legislature, no date) allows for underground storage and replenishment in certified facilities (ADWR, no date; Colby and Jacobs, 2007). No such facilities have been permitted within the SCAMA and the suitability of such facilities, including the use of the Santa Cruz as a managed (in-channel) facility, has not been evaluated (ADWR, 1997).

forbearance lease that would formalize jurisdiction over the effluent of Mexican origin, granting legal authority for it to be used by entities within the SCAMA.⁽²²⁾

Within the US there exists little capacity to undertake transboundary groundwater management activities in the USCRB because, as addressing transboundary groundwater is not specifically in the mandate of existing agencies, they do not have the personnel, funding, or jurisdiction to take the lead in promoting and enacting transboundary groundwater management. For example, the SCAMA office of ADWR is staffed only by two technical and one administrative employees, who are tasked with regulating and supervising water rights, including the usage of water abstracted from the more than 2000 wells located throughout the US portion of the USCRB. This small staff has inadequate capacity to undertake additional coordination, planning, or regulatory activities. As it is, the current budget crisis threatens their ability to carry out existing responsibilities.

In summary, within the SCAMA, competence is undermined by ill-defined legal and political authority arising from the lack of a singular entity charged with addressing the transboundary aspects of the aquifer, overlap in the jurisdictional mandates of governmental agencies, and ambiguity in the roles of federal versus local actors. Incompatibility occurs because existing institutional arrangements do not provide the mechanisms or regulations needed to enact proposed transboundary management activities. Lastly, capacity to take action is limited due to the lack of a lead agency and insufficient resources.

Within Mexico

Since the 1980s Mexico has been undergoing a process of decentralization, particularly in the water resources realm ([Castro, 1995](#); [Donnell, 2003](#); [Gonzales-Villarreal and Garduño, 1994](#); [Hearne, 2004](#); [Rodríguez-Pose and Gill, 2003](#)). Certain aspects of water management, described in more detail later, have been devolved to state and local institutions and private sector participation has been encouraged.⁽²³⁾ Decentralization efforts were initiated through neoliberal reforms and structural readjustment policies ([Donnell, 2003](#); [Hearne, 2004](#)); however, their logic today is reinforced by growing regional and local legitimacy. As a result the many changes to the water sector that have ensued have concurrently strengthened different aspects of the authority of the federal (over financial resources and water allocation) and local governments (over municipal and agricultural water use).⁽²⁴⁾ Consequently, decentralization efforts have

⁽²²⁾ In 2002 Arizona Senate Bill 1410 was proposed, which would create a Water Management and Importation Authority (WMIA) in the SCAMA. The WMIA would have the authority to construct and operate water augmentation projects (including underground storage and recovery), to acquire and exchange water, water rights, and water credits; to enter into agreements with governmental agencies; and to raise funds to pay for its activities (Arizona State Senate, 2002). However, the bill was not passed, primarily due to concerns that it might have unintended impacts on other AMAs and it might negatively impact ADWR activities and funding sources (Arizona Municipal Water Users Association, 2002).

⁽²³⁾ Although not active in the study region, *Consejos de Cuenca* (watershed councils) and *Comités Técnicos de Aguas Subterráneas* (groundwater technical committees) have been developed in other regions in Mexico to increase coordination among governmental agencies, water users, the private sector, academia, and other sectoral representatives ([Scott and Banister, 2008](#); [Tortajada and Contreras-Moreno, 2005](#); [Wester et al, 2009](#)).

⁽²⁴⁾ The 1989 reform, which created the *Comisión Nacional del Agua* (CONAGUA), served to first concentrate authority over water resources in the federal government, this was to be a preliminary step towards decentralization of water services ([Castro, 1995](#)). Later reforms, including the 1992 Law of the Nation's Waters and the 1997 movement to regional offices of CONAGUA, were not designed to reduce the authority of the federal government, but rather to distribute jobs and patronage ([Hearne, 2004](#)). Lastly, the most recent water law reform of 2004 created basin organizations and aimed to promote local and participatory decision making ([Hearne, 2004](#); [Martinez-Lagunes and Rodriguez-Tirado, 1998](#)).

led to ambiguity in authority and have been accompanied by only partial devolution of power and resources (Scott and Banister, 2008), including information. The broader federal mandate in Mexico is reflected in figure 3.

This evolution of institutional arrangements within Mexico has resulted in the allocation of responsibility for water resources both across distinct agencies and among nested governmental agencies. Consequently, intranational competence is limited because (i) agencies located within different federal ministries hold partial domain over aspects of transboundary groundwater management and (ii) functional linkages between nested agencies lead to ambiguous and overlapping jurisdiction. Incompatibility arises from discordance in the institutional mandates of nested institutions and from missing institutional provisions for aquifer recharge. Lastly, capacity is low due to a mismatch between agency mandates and resources (financial, human, material, and authoritative) arising from the decentralization process.

In Mexico, as with the US, competence is limited because no entity is solely responsible for ensuring that transboundary aspects of groundwater management are addressed (see figure 3). The executive branch, primarily via CONAGUA, is responsible for all activities related to the use, management, and protection of 'national water'.⁽²⁵⁾ CILA's jurisdiction overlaps with CONAGUA's for the transboundary component of the Santa Cruz aquifer. CILA is charged with conducting diplomatic negotiations, yet it strictly adheres to Mexico's position within those negotiations as determined by the Secretaría de Relaciones Exteriores (SRE). Nor does CILA implement water management activities, with the exception of operating and maintaining infrastructure (dams, wastewater treatment plants) specifically designated in a formal agreement between the two countries. The result of this separation of power, with CILA holding transboundary authority and CONAGUA holding authority over water resources administration, is that the competence of Mexico to address transboundary aspects of groundwater management is dependent on coordination across these agencies.

Competence is also impacted by the decentralization processes, which has led to ambiguity of authority among nested agencies. As CONAGUA regulates national waters, states in Mexico have limited jurisdiction over water resources management. In Sonora, CEASonora is responsible for administering water-supply-related programs and funding transferred to them from the federal government and for assisting municipalities in providing water and sanitation services. CEASonora, along with ADWR, cochairs the Arizona–Mexico Commission water committee as shown in figure 3. Since 1989 CONAGUA has promoted the municipalization of water services—that is, the transfer of state-run utilities to municipalities, usually in the form of parastatal or private entities (Pineda Pablos, 2002). In the USCRB ownership and operational responsibility for the Nogales, Sonora municipal-run water utility (OOMAPAS) was devolved to the municipality from the state in June 2005. Thus the municipality is currently responsible for providing water, sewerage, and wastewater treatment and disposal services to its residents.

OOMAPAS is charged with planning and implementing water and sanitation services for the municipality; this includes determining the quantity of water needed, the sources of that water, and how that water will be treated and discharged (or used for recharge). Yet OOMAPAS does not have adequate information on the aquifer nor the authority over water allocation. Rather, CONAGUA remains responsible for

⁽²⁵⁾ CONAGUA must coordinate with other executive agencies including SRE for matters related to transboundary waters, the Procuraduría Federal de Protección al Ambiente for safeguarding water quality, and Secretaría de Agricultura Ganadería, Desarrollo Rural, Pesca y Alimentación on matters related to agriculture and rural development (Comisión Nacional del Agua and Salmon, 2008).

conducting studies to determine water availability and for administering permits for water abstractions, diversions, and discharge.⁽²⁶⁾ The result is ambiguity in authority and jurisdiction, as OOMAPAS is normally responsible for operational provision of water and sanitation services yet it cannot do so without support from CONAGUA. The dependence of OOMAPAS on CONAGUA was expressed during interviews with OOMAPAS employees, who indicated they felt OOMAPAS was only beginning to have authority to make decisions independent of CONAGUA.

The evolving nature of the water management institutions within Mexico has created ambiguity not only across, but also within, levels of government. In 1997 the organizational structure of CONAGUA was changed and state offices were replaced by thirteen regional offices of CONAGUA, designated based on hydrographic criteria (Martinez-Lagunes and Rodriguez-Tirado, 1998). The 2004 revisions to the Law of the Nation's Waters required the conversion of these offices to Organismos de Cuenca (basin organizations), a primary difference being that basin organizations are charged with incorporating civil society interests (Garduño, 2005; Gonzalez and Magana, 2006; Hearne, 2004; Scott and Banister, 2008). Responsibility for determining groundwater availability and issuing of permits is being transferred from the central offices to the newly formed basin organizations (Wester et al, 2009). Interviews with key personnel in the USCRB indicate that decentralization is very much still in process, as transfer of data, resources, and responsibilities remains incomplete. This detail is important; ambiguity even within a single agency is problematic as, culturally, Mexican officials can be very conscientious about following set bureaucratic protocols and are cautious not to overstep boundaries.

Lastly, decentralization within Mexico has led to capacity gaps, particularly at the municipal level, due to a mismatch between agency mandates and resources. Pineda Pablos (2002), in his analysis of the evolution of urban water provision in Mexico, finds that insufficient organizational and technical abilities and the transitory nature of municipal administrations, which are subject to reelection every three years, have impeded the effectiveness of decentralization. OOMAPAS is no exception. The devolution of responsibility for planning to OOMAPAS was not accompanied by the concurrent devolution of data⁽²⁷⁾ or planning standards.⁽²⁸⁾ This capacity gap is exacerbated by low human capital due to high staff turnover, particularly in the

⁽²⁶⁾ Water use was regulated by concessions granted by CONAGUA. Groundwaters, according to stipulations in the constitution, may be freely brought to the surface and used so long as such use is in the public interest. Where groundwater withdrawal may impact public utility, CONAGUA has the authority to regulate abstractions by declaring a 'zona de veda' or restriction zone. If a restriction zone has been declared, groundwater users ostensibly may not obtain new concessions from CONAGUA; where there are no restrictions, users may apply for time-bound, volumetric concession titles in order to make use of the water (Farias, 1993; Manzanilla et al, 1991; Zamora et al, 2004). Water discharge is also regulated, and permits must be obtained from CONAGUA.

⁽²⁷⁾ Water availability studies and information on diversions and abstractions is under the purview of CONAGUA, and not directly provided to OOMAPAS (personal communication, Martin Navarro, OOMAPAS, 21 September 2007). Furthermore, water abstraction data are incomplete, as not all water users have registered (Martinez-Lagunes and Rodriguez-Tirado, 1998; Scott et al, 2010; Shah, 2002). In 2007 a number of well owners on the Mexican side of the border that supply water to water trucks had not registered or paid their water concession fees (personal communication, Eduardo Robles, CONAGUA, 7 October 2007).

⁽²⁸⁾ Standards for planning of water and sanitation services are set by CONAGUA and CEASonora. These standards include not only engineering and water quality specifications, but also specifications regarding parameters for per capita water consumption and which statistics on population and population growth are to be used for planning purposes. These parameters must be used by the municipality for planning purposes, even if there are indications that they do not well represent the municipality (personal communication, Martin Mexía, CEASonora, 8 October 2007).

upper management of OOMAPAS. Interviews with the three directors who ran OOMAPAS between 2005 and 2008 indicate none of the three had seen copies of previous management plans, nor could they cite the quantity of water concessioned to OOMAPAS.

In summary, within Mexico internal ambiguity is a product of both the incongruence between the strong regulatory and allocation decision-making role of the federal government with a mandate for local water service provision and the evolutionary nature of water institutions undergoing reform. These features serve to reduce competence, as the division of responsibility and authority between various governmental entities remains unclear. They also constrain compatibility, as the powers allocated to the federal government inhibit action by local entities to close regulatory gaps. Lastly, where devolution of authority and responsibility has not been accompanied by devolution of power and resources, the changing institutional structure can result in insufficient capacity of local entities.

Polycentric and evolving institutions in the USCRB

The above analysis demonstrates how the institutional environment governing groundwater within both countries can be characterized as polycentric and evolving, with the emphasis for the US on polycentric and for Mexico on evolving towards increased local (municipal) authority particularly for water service provision. Within each country the distribution of authority over groundwater across multiple entities at different scales of government (polycentrism) leads to gaps, overlaps, and ambiguities in the jurisdiction of water management agencies. The dynamic nature of the institutional environment (evolving) adds to these, as changes in institutional jurisdiction both increase ambiguity and can lead to tensions between tiers of government. For example, within the US the lack of an agency to take the lead in enacting management strategies to preserve underflow and base flow into Arizona is a gap resulting from polycentrism, whereas the multiple agencies with regulatory authority over water management activities which could impact the environment typifies an overlap. In Mexico incomplete decentralization processes are demonstrative of ambiguities in authority.

Our finding of gaps, overlaps, and ambiguities arising from the polycentric and evolving institutional environment in the USCRB are not unexpected; in fact this resonates with the research on polycentrism and integrated water resources management mentioned in the literature review above. Polycentrism has been shown to lead to redundancies, inconsistencies, and coordination problems (Biswas, 2004; McGinnis, 2005). Yet the impact of a polycentric and evolving intranational institutional environment on transboundary groundwater management has not previously been explicitly recognized. The gaps, overlaps, and ambiguities that arise from the polycentric and evolving structure of the institutional environment hinder the ability of the US and Mexico to enact formal cooperation over transboundary aquifers.

Moving forward in the USCRB

Given the constraints of the institutional environment, the greatest movement towards collaboration over the aquifer has been through activities associated with the TAAP, which for Arizona identifies the Santa Cruz aquifer and the San Pedro aquifer to the east for 'priority' assessment. The TAAP is not, and does not aim to be, a formal agreement regarding transboundary groundwater management; rather it is an effort to engender binational cooperation for data and information sharing, including joint studies of the aquifer and comparative analysis of both countries' national and subnational management and policy for transboundary groundwaters. As knowledge of hydrologic processes is essential for effective groundwater management, this effort will support each country in the management of its portion of the shared

groundwater resources. The extent to which TAAP goals will be achieved remains an open question, as the TAAP is still in its nascent stages and currently (2009) has received pilot-scale funding for planning purposes (Scott et al, 2008; submitted).

It is interesting to note that the intranational contexts of decision making are reflected in the diverging perspectives on the form a binational agreement of groundwater, even one focused solely on data sharing and joint research, should take. The US enigmatically seeks a unitary Mexican negotiating partner, yet at the same time assumes that it is feasible, and even desirable, for institutional evolution to occur away from the centralized IBWC–CILA role in binational water agreements to a more polycentric, and local one. Mexico, conversely, seeks to retain authority in the IBWC–CILA framework and has not subscribed to the multiple-table, polycentric decision-making model. This is manifest in Mexico's insistence on a border-wide aquifer data-sharing agreement, whereas the US is attempting to decouple this, and address shared groundwaters on an aquifer-by-aquifer basis.

Conclusions

In this paper we have demonstrated that cooperation over transboundary groundwater is strongly conditioned by factors internal to the co-'aquiferians'. With reference to the USCRB aquifer between the US and Mexico, our analysis identified specific gaps, overlaps, and ambiguities that arise from the polycentric and evolving nature of the intranational institutional environment in both the US and Mexico and explained how these reduce the competence, compatibility, and capacity of each country to address transboundary groundwater management. In highlighting the polycentric and evolving nature of the institutional environment governing groundwater management in both the US and Mexico, we move beyond conceptualization of international groundwater management as occurring exclusively at the national scale, and thus escape Agnew's territorial trap. By explicitly recognizing the polycentric institutions which exist, the interplay between them, and their dynamic nature, we demonstrated how states do not have complete control over the territorial space they cover, how domestic water management can impinge upon foreign policies, and how evolving institutional arrangements can lead to contested authority. The value of our analysis is to stress the importance of extending models typically used to represent transboundary groundwater to consider how intranational institutional arrangements both determine authority and constrain the choice set.

Beyond the Santa Cruz aquifer and the US and Mexico border, there is reason to believe that intranational institutions are key determinants of countries' positions towards their shared aquifers. As countries respond to the relatively recent (post-1950s) surge in the use of groundwater and as paradigms for water governance change, new national and subnational institutional arrangements for water management are being forged (Burchi, 1999; Hodgson, 2006; [Mukherji and Shah, 2005](#)). Within the water sector there has been a movement towards decentralization of management, private sector participation, and allocation of marketable property rights (Easter and Hearne, 1995; Saleth and Dinar, 2000; [Tortajada, 2001](#)).⁽²⁹⁾ Although institutional arrangements within any country will not mirror exactly those of the US or Mexico, it is unlikely that this evolving process will be entirely free of ambiguity, and may instead result in more long-lasting gaps and overlaps in authority.

⁽²⁹⁾ Despite private groundwater development, both the US and Mexico have systems for the regulation of groundwater through permits and concessions. By contrast, this has not been observed in many other regions, most notably South Asia's groundwater 'anarchy' (Shah, 2009).

We can expect subnational institutional regimes to be especially influential in the management of transboundary groundwaters due to their physical and institutional characteristics, including: (a) the local nature of regimes for managing this distributed, 'invisible' resource, (b) the dispersed and informal nature of infrastructure, which makes it difficult for national authorities to physically control its use, (c) methodological and measurement challenges in establishing the status of groundwater, and (d) the 'strategic' value of groundwater for urban growth, particularly relevant to high-growth, water-scarce regions such as the US–Mexico border case we have presented.

Recognition of the role of intranational institutions not only aids in understanding outcomes, it also points to policies that might improve the potential for transboundary groundwater management. For example, Waterbury (1997) asserts cooperation begins at home; this should be extended to include not only the need to efficiently and effectively manage water resources but also the imperative to develop institutions with the authority, capacity, and responsibility for comprehensive planning and for implementing water management activities. This includes taking steps to clarify jurisdiction and providing mechanisms to increase communication, coordination, and collaboration across fragmented institutions. It also suggests that, as countries shift to more decentralized management paradigms, the process should be designed to account for foreseeable scalar-mismatch problems, including for mechanisms that may allow for binational agreements to apply at the local level. Lastly, it implies that countries should begin to address expected or imminent water management challenges as they become apparent, given the gestation period for institutional change required to effectively adapt and respond to new challenges.

Acknowledgements. Support for the research was provided by the United States–Mexico Transboundary Aquifer Assessment Program, the National Science Foundation (Doctoral Dissertation Research Improvement and Graduate Research Fellowship Programs), the Morris K Udall Foundation, the Soroptimist Foundation–Founder's Region, and the University of California Institute for Mexico and the United States. We would like to thank the many persons interviewed as part of this study, along with Professor Isha Ray and the Water Group in the Energy and Resources Group, for their valuable feedback and assistance.

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