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Water Resources Research

RESEARCH ARTICLE

10.1029/2019WR026068

Key Points:

- A formal binational agreement over transboundary groundwater resources is desired by 30% of stakeholders interviewed between Mexico and Texas
- Small-scale, informal, nonbinding approaches seem to be more preferable and feasible in the borderland between Mexico and Texas
- The more formality, the greater the impacts but lesser achievability; the less formality, the more achievability but limited systemic impacts

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Groundwater Management in the Borderlands of Mexico and Texas: The Beauty of the Unknown, the Negligence of the Present, and the Way Forward

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Abstract Over the last decade, transboundary aquifers traversing the Mexico-Texas border have generated growing interest of federal institutions on the Mexico side and state and federal institutions on the Texas side. Notwithstanding this, binational efforts to understand, assess, and manage shared groundwater resources remain limited and politically sensitive. On the Mexico side, long-standing centralized groundwater governance structures have created institutional barriers at the local level to the expansion of knowledge and cooperation over these transboundary resources. On the Texas side, property rights related to groundwater resources limit the scope of options available for cooperative management of cross-border aquifers. This paper examines stakeholders' perspectives on the borderland between Mexico and Texas through 44 surveys and personal interviews. Findings show that stakeholders appear to support a binational groundwater agreement as a means for assuring the sound long-term management of transboundary groundwater resources in the border region; however, the majority of stakeholders also suggest that short-term local or regional arrangements may be preferable over binational agreements as local/regional approaches may be more achievable or realistic. Second, participants identified leadership and individual personalities as key factors for success at the local level but noted that such influence had limited sustainability and limited regional-systemic effects. Third, the stakeholders indicated that water quality, rather than water quantity, is the main driver of transboundary cooperation efforts in the region. Fourth, participants suggested that failures and successes in groundwater cooperation efforts are based more on fear and political lobbying than on understanding of scientific facts.

1. Introduction

Recent research has shown that between 50% and 60% of the area overlying the hydrogeological units shared between northeastern Mexico (Chihuahua, Coahuila, Nuevo Leon, and Tamaulipas) and Texas contains good aquifer potential with good water quality conditions (R. Sanchez et al., 2018b). From the approximately 53 domestic and transboundary hydrogeological formations identified in the region (Figure 1), only four have received binational recognition and, therefore, funding and prioritization by both countries: the Mesilla/Conejos-Medanos Aquifer, the Hueco-Bolson/Valle de Juarez Aquifer, the Edwards Aquifer, and the Gulf Coast/BRB (Bajo Rio Bravo) Aquifer. The rest of the area remains largely ignored or not valued for its groundwater potential. Acknowledgment of water flowing underground across both countries is assumed to be somebody else's responsibility or a matter that does not necessarily require the same level of attention as surface water. The conceptualization of groundwater as an unseen and therefore a potentially never-ending resource, coupled with limited data and research, as well as other pressing border priorities (security and immigration) capturing the attention of the citizenry and governments, has resulted in an unsustainable situation for the region's transboundary groundwater resources.

With the exhaustion of surface water as an option for future water demand, particularly in the Rio Grande basin, as well as climate change trends that have challenged the highly surface water-dependent agricultural sector on both sides of the border, over the last decade, transboundary aquifers traversing the Mexico-Texas border have generated growing interest of federal institutions on the Mexico side and state and federal institutions on the Texas side. This condition is also true for the rest of the border between Mexico and the United States where some cooperation in terms of transboundary groundwater management have also been reported under the framework of the Transboundary Aquifer Assessment Program (TAAP) (Megdal &

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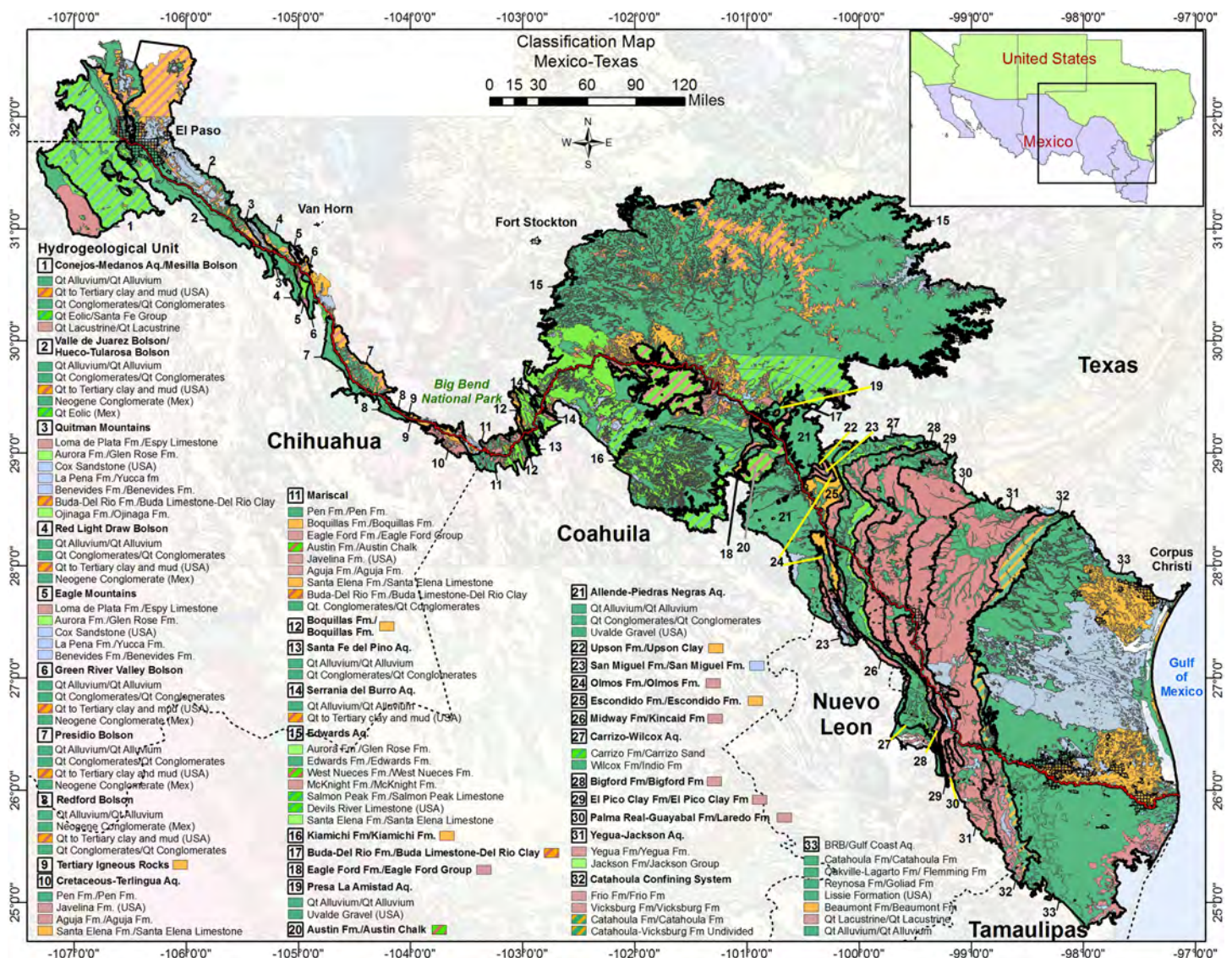


Figure 1. Hydrogeological units (HGUs) between Texas and Mexico (adapted from R. Sanchez et al., 2018b).

Scott, 2011; Mumme, 2005, 2015; Wilder et al., 2010). Today, groundwater use and dependency in the borderland between Mexico and Texas varies. In much of West Texas, communities on both sides of the border are highly dependent on groundwater for domestic and agricultural use. Among others, these include the sister cities of Ciudad Juarez/El Paso in the Conejos-Medanos/Mesilla Bolson region, Ojinaga/Presidio near the Big Bend National Park region in Texas and Maderas del Carmen protected area in Mexico, and Acuña/Del Rio and Piedras Negras/Eagle Pass further downstream along the Rio Grande. It also includes other important cities further from the border, such as Guerrero, Allende, and Nava on the Mexico side and the small communities of Quemado, Spofford, and Bracketville on the Texas side. Moving further eastward from Piedras Negras/Eagle Pass toward the Gulf of Mexico, the level of dependency decreases as surface water from the Rio Grande becomes more relevant for most uses, especially agriculture. However, population growth in the border region, primarily in the middle and lower Rio Grande basin, is expected to double by 2060. As a result, groundwater increasingly is becoming a strategic new source of domestic water supplies (Meyer, 2014), as well as for new uses, such as for fracking activities in the Texas-Mexico border region (Cluster Minero Petrolero S. A de C.V., 2017).

Notwithstanding this attention, binational efforts to understand, assess, and manage shared groundwater resources remain limited, sporadic, and politically sensitive. On the Mexico side, long-standing centralized

groundwater governance structures, as well as a presumption that the International Boundary and Water Commission-Mexico Section (CILA) is the de facto authority for all waters shared with the United States, have created institutional barriers at the local and regional levels to the expansion of knowledge of and cooperation over these transboundary resources. On the Texas side, property rights related to groundwater resources limit the scope of options available for cooperative management of cross-border aquifers. Nevertheless, interest in the topic continues to grow as flourishing populations and expanding economies continue to burden existing freshwater resources, especially among the numerous sister cities that punctuate the border's arid landscape, many of which are entirely dependent on groundwater.

Considering the lack of data and research on the subject, as well as the challenges that existing institutional regimes will face as demand for groundwater resources in the border region grows, there is an urgent need to investigate and evaluate potential options for future transboundary groundwater management along the border. One way to begin this process is by assessing the perceptions and opinions of stakeholders in the region in order to better understand and visualize the possibilities for change in the short and long terms as well as to identify why transboundary groundwater resources have been neglected.

The purpose of this research is to identify and analyze the main perceptions and opinions of groundwater stakeholders in the border region between northeastern Mexico and southern Texas in relation to transboundary cooperation experiences and efforts, feasibility and likelihood of binational agreements at the national and subnational level, management perspectives and preferences, elements for change and success of management alternatives, and possible management and cooperation models. This research is based on the application of a survey, followed by personal interviews, conducted with 44 groundwater stakeholders representing federal, state, municipal, private, and agriculture sectors, as well as academics, groundwater experts, and nongovernmental organizations (NGOs) in the region.

Results from the analysis reveal significant findings. First, stakeholders appear to support a binational groundwater agreement as a means for assuring the sound long-term management of transboundary groundwater resources in the border region; however, the majority of stakeholders also suggest that short-term local or regional arrangements may be preferable over binational, border-wide agreements as local and regional approaches may be more achievable or realistic. Second, participants identified leadership and individual personalities as key factors for success at the local level but noted that such influence had limited sustainability over time and limited regional-systemic effects. Third, the stakeholders indicated that water quality, rather than water quantity, is the main driver of transboundary cooperation and communication efforts in the region. Fourth, participants suggested that failures and successes in groundwater cooperation efforts are based more on fear and political lobbying than on understanding of scientific facts.

It should be noted that the results of this study are not framed within a specific theoretical framework for groundwater governance (such as, adaptive groundwater governance). The findings do not provide enough evidence, examples, or elements of "groundwater governance" (if it actually exists) in the region that are mature enough to actually characterize their structure as falling within a specific identifiable, formal system or process. Moreover, there is no system of groundwater governance in place at all to underpin an argument that such potential governance could be evolving, failing, or succeeding. The objective of this paper is to report what the stakeholders are actually thinking, experiencing, and suggesting as potential options for managing shared groundwater resources on the border. The paper does not purport to make any additional claims or conclusions, in part, because the authors are unable to extrapolate what may evolve or result from the interviewees' perspectives and responses. Additionally, the authors strongly object and discourage application of a transboundary surface water framework for analyzing elements of success of cooperation over transboundary groundwater resources. While it is often tempting, this practice masks the actual factors and conditions that influence or impact cooperation and management of transboundary aquifers in the border region. Furthermore, it ignores the genuine incentives that stakeholders identify as elements of successful cooperation that are specifically relevant to transboundary aquifers. Therefore, the core of our paper is on how stakeholders along the border have approached, assessed, and conceptualized transboundary groundwater resources (separate from transboundary surface water resources) along the border and their perspectives on possible future mechanisms and approaches for managing these shared subsurface resources.

One additional point that should be made is that the results and interpretations of this study may be relevant and applicable to, and possibly representative of, other regions of the border between Mexico and the United

Table 1
Number of Questionnaires/Interviews by Categories (Texas/Mexico)

Categories	Texas	Mexico
State officials	4	2
Federal officials	2	5
City officials	4	2
Agriculture users	2	2
Academics/experts	7	5
NGOs	1	1
Private/industry	4	3

States. Many of the federal officials, academics, and representatives of NGOs and private industry interviewed for this study, from both sides of the border, have had prior experience working in one or more of the other sectors. As a result, it is reasonable to interpret their perspectives as being based on their broad, multisectoral experience. Moreover, on the Mexico side, there is no institutional framework at the regional or state level with regard to groundwater management. Accordingly, the Mexico side of the sample (with the exception of irrigators) generally represents perspectives applicable to the border region as a whole.

The first part of this paper will address the detailed analysis of the most significant findings of the survey conducted for this research. The second part will highlight and assess the transboundary groundwater management models that emerge from the study.

2. Methods

2.1. Questionnaire

This exploratory study was based on the application of a questionnaire of 18 closed and open-ended written questions followed by interviews with each of the participants to explore additional elements and variables that might arise during the conversation and were not contemplated in the original questionnaire. The goal of the study was to generate data related to groundwater use, level of dependency on groundwater resources, groundwater quality, aquifer connectivity, and the existence of formal or informal transboundary groundwater agreements, mechanisms, and practices that were encompassed by the questionnaire. Information related to experiences with cooperative efforts, potential models for groundwater management, and preference and feasibility potential for a binational groundwater agreement was mostly provided during the interviews. The individuals surveyed in this study represented different sectors and groups of groundwater stakeholders in the border region between Northeastern Mexico (Chihuahua, Coahuila, Nuevo Leon, and Tamaulipas) and Texas.

The sample population was designed to include representatives of different levels of authority and expertise on the topic on both sides of the border. As a result, the sampling was selective rather than random and based on two criteria: technical expertise and level of authority related to the management of transboundary groundwater resources. Although the focus area was the border region between northeastern Mexico and Texas, the level of authority and knowledge varied in space and scale on both sides. On the Mexico side, administration of groundwater is concentrated at the federal level; therefore, the largest grouping of groundwater stakeholders interviewed for the study included federal officials, followed by city and state officials who possess little authority and knowledge about the conditions of transboundary groundwater resources. On the Texas side, state and city officials comprised the largest clusters of interviewees primarily because of the decentralized structure governing groundwater in the state. Academics and experts constituted relatively large groups on both sides and were targeted because of their broad knowledge of the topic, which is recognized as both complex and limited in terms of data and research. They also were included in the study because they represent an important group of stakeholders that are part of many informal and formal task groups at federal, state, and local levels (e.g., the TAAP). Private industry was also an important constituency on both sides of the border because of its relevance in developing private groundwater resources and research in the region. Table 1 shows the sectors covered in this study, as well as the number of interviewees per sector.

The number of interviewees should not be understood as a straightforward category considering the different roles that an interviewee might represent or have represented in the past. For example, though Agriculture users reflect a sample of four interviewees (two from each side of the border), there were District officials with the same level of knowledge related to agricultural use in the region who presented the official District role for this survey. Likewise, some academics and experts played a different role in the past (such as City Official) and their current role during the interview, thereby contributing to the development of propositions that incorporated both perspectives. Considering the different roles that some interviewees played at different times and levels of authority over the course of their careers, the results of this

study are not divided nor analyzed per category but rather based on the findings. Therefore, these categories presented here simply serve as indicators of the sectors covered under this study and should be understood as fluid rather than fixed.

2.2. Interviews

Along with the application of the survey and based on the answers provided by the interviewees, a series of additional questions were presented during the interviews to complement, add findings to, and elaborate on specific topics not covered in the questionnaire. The technique applied for this process is based on Grounded Methodology. This approach was developed by Glaser and Strauss in 1967 and is defined as a process that uses systematic qualitative data to generate theories. The theory development process uses the inductive method to generate concepts, categories, and propositions from a constant analysis, comparisons, and development of theoretical relationships. Grounded theory is “inductively derived from the study of the phenomenon it represents. One begins with an area of study and what is relevant to that area is allowed to emerge” (Glaser & Strauss, 1967; Strauss & Corbin, 1990). Contrary to the scientific method, hypothesis are not tested to prove theories, but rather, theories are allowed to emerge as prepositions are developed (R. Sanchez, 2010). For the purpose of this research, data were collected using the qualitative process proposed by Dick (2005). The approach entailed beginning the interview with an open-ended, general question and thereafter adding specificity. The preliminary general question usually was as follows: Do you see any problem with the way groundwater is being managed in the border region? This method is designed to help define saturation of a proposition (where nothing new is added), or add new elements to a new line of relationships. Using this technique, one can obtain as much information as needed to answer the research questions in a shorter amount of time (Dick, 2005). Though 44 interviewees might be considered a modest sample size, this technique provides the interviewer the ability to identify the threshold where no new information is added to the theories and prepositions, and, therefore, the sample size is appropriate.

The type of questions that generate the emergence of new propositions or lines of relationships varied: For example, why do you think there is no binational groundwater instrument to govern transboundary waters on the Mexico-U.S. border? What would you say are the elements of success for any attempt to develop a binational groundwater instrument? Do you think it is feasible to achieve a binational agreement for the border region? If yes, at what political level or geographic scale, and what specific issues? Do you think we need a binational groundwater instrument or should we keep the status quo? Why? What is your experience in terms of success of groundwater cooperation? ... and so forth.

Under this research process, unlike the written questionnaire, the interviews were not standardized with a prescribed set of questions. Questions emerged as the propositions, identified relationships, and new elements of analysis arose and led to the development of theories that are analyzed in the following section.

For the purpose of this research, when discussing binational cooperation that results in some sort of accord, “formal” refers to the involvement of federal entities on both sides of the border in the cooperative process regardless of whether implementation occurs at the binational or local level. The chief criterion is that the accord requires “official” approval by both federal governments. In contrast, binational cooperation that does not involve federal institutions or require their consent, and which are applicable only at the local level, are described as “informal” arrangements. Supplementing these distinctions, in this study, “agreements” refer to binding instruments that derive their authority from the involvement of federal institutions (formal efforts), whereas “arrangements” reflect instruments of cooperation that have limited binding authority because of the absence of federal involvement (informal efforts) and which typically are implemented at the local level (Eckstein & Hardberger, 2009). Lastly, the term “achievability” used in Figure 3 refers to the feasibility or possibility of those binational efforts to occur or evolve given the corresponding conditions or variables in place.

3. Results

3.1. Local Versus Systemic Impacts and the Notion of “Success”

Nearly two thirds of the interviewees agreed that there is a genuine need for a binational instrument to manage in some way transboundary groundwater along the border (Figure 1). However, a significant majority (69%) of interviewees believed that before undertaking any attempt to manage groundwater resources

across the entire border, a series of local and regional models for groundwater management should be tested. The rationale behind this belief relies on perceived successes with prior experiences and their understanding of what “success” entails. For example, 68% of the interviewees provided positive opinions of the following agreements: *the Joint Report of the Principal Engineers Regarding Information Exchange and Mathematical Modeling in the El Paso, Texas and Ciudad Juarez, Chihuahua Area Aquifer* (IBWC/CILA, 1997); data sharing and research initiatives undertaken by Arizona, USA, and Sonora, Mexico, for the San Pedro and Santa Cruz transboundary aquifers funded under the TAAP (Callegary et al., 2016); and Minute 242 of the International Boundary and Water Commission, which addresses the Yuma Aquifer shared by Sonora, Arizona, and California (International Boundary Water Commission, 1973). All three agreements were viewed as successful because all achieved some degree of involvement and approval by both the Mexican and American sections of the International Boundary and Water Commission (IBWC/CILA). This belief highlights the understanding that for these interviewees, “success” is measured, in part, by the extent to which binational, federal institutions are involved, even where the project or agreement focuses on a local issue.

Other interviewees (almost one quarter of the sample), however, pointed to other examples that they deemed “successful” and that involved local, informal cooperative efforts related to shared groundwater resources and no involvement by official, federal institutions. In these examples, the interviewees described success in relation to the ease of implementing an informal, “low level” arrangement and not having to deal with the complexities of federal bureaucracies. From a broader perspective, some of these findings have been previously reported over the Rio Colorado basin (Mumme, 2005, 2015; Wilder et al., 2010).

For example, according to city officials and academics, El Paso under Ed Archuleta's leadership (serving as manager of the El Paso Water Utilities Public Service Board) in the early 1990s was relatively effective in terms of achieving transboundary groundwater cooperation with Ciudad Juarez, which included data exchanges, conservation programs, reclaimed wastewater trainings, periodic but consistent communication, and improved groundwater tools for modeling groundwater flow and contamination threats. Results from these efforts allowed Mexico to replace some of its wells that had high levels of salinity and facilitated El Paso's efforts to construct the largest inland desalination plant in the United States/world. In addition, and in the absence of any involvement by federal institutions on either side of the border, the projects initiated under Archuleta eventually resulted in improved aquifer condition in terms of ground water quality and the management of depletion (Academic A, 2017). These local efforts had two dimensions: They were successful in achieving constructive transboundary cooperation and, at the same time, successful in improving groundwater conditions in the region without the need for an agreement involving federal institutions. As one city official stated, “There was no need for a formal agreement at that time and we were able to successfully stop mining the aquifer by ourselves ... IBWC/CILA do not have legal authority to govern or manage groundwater in the border, therefore we were able to do by ourselves without any problem” (City Official A, 2017).

One additional factor supporting the perceived success of these informal efforts lies in the fact that eventually, they evolved into the formal *Joint Report of the Principal Engineers Regarding Information Exchange and Mathematical Modeling in the El Paso, Texas and Ciudad Juarez, Chihuahua Area Aquifer* entered into by IBWC/CILA in 1997, which established a mechanism and framework for binational scientific collaboration and data exchange (IBWC/CILA, 1997). For more than two thirds of interviewees, the progression from informal arrangement to a formal, bilateral agreement that involved federal institutions on both sides of the border equated with a successful project. It is noteworthy that the interviewees identified several variables as important for the “success” of this particular informal-to-formal progression. First, the binational agenda during the early 1990s concentrated on the North America Free Trade Agreement (NAFTA), which created favorable political momentum for communication and cooperation. Second, the absence of legal instruments governing transboundary groundwater resources in the region left the door open for low level and alternative possibilities for cooperation and negotiation without the need for federal or even state-level institutional approval. Third, the individual personalities of key players from both sides of the border, as well as the leadership actions they initiated, escalated the level of formal institutional involvement, which eventually transformed the informal effort into a formal agreement.

Surprisingly, interviewees reported that since the signing of the 1997 Principal Engineers Agreement, additional informal cooperative groundwater-related efforts have not been attempted in the Mexico-Texas border area and there have been no formal efforts involving IBWC/CILA. One city official stated, “the reality of today’s local conditions, such as violence, crime, and the political environment, has limited the communication and therefore cooperation ... There is no communication these days as we used to have in the past” (City Official B, 2018).

Outside the state of Texas, there are a number of examples of informal cooperative efforts over transboundary groundwater resources at the local level that were mentioned by interviewees as “successes.” According to some academics, there are ongoing communications between the region’s sister cities of Nogales/Nogales and Douglas/Agua Prieta in the Arizona/Sonora border region on both surface and groundwater resources. Issues discussed and coordinated have included infrastructure matters, water quality/treatment, and emergency situations (such as water shortages), and both sides continue to share experiences and host joint events as a means of strengthening links among stakeholders and with nongovernmental organizations. It is important to emphasize that these efforts are not occurring under the umbrella of the IBWC/CILA. Rather, they are taking place grounded in a common basis of communication and personal linkages across the border in a manner that transcends institutions and legal mechanisms. As one water expert mentioned, “these linkages are beyond any policy; they are part of our history, families and culture, and they have expanded to all sectors including water” (Academic E, 2017).

As has been noted, the notion of “success” was a main disagreement among the interviewees. According to a significant majority of interviewees (more than two thirds), including Federal Officials from both Mexico and Texas, NGOs, and approximately half of the academics from both countries, “success” is measured according to the formality of the agreements led by federal institutional involvement. Officials from nongovernmental organizations, for example, emphasized the need for a formal groundwater framework as a means of improving regional policies and addressing the challenges inherent in transboundary groundwater systems. As one official stated, “Local efforts tend to be limited and non-significant at a systemic level” (NGO B, 2018). With regard to the example of El Paso and Ciudad Juarez, the same official also noted that the absence of additional local success stories since the achievements of the 1990s indicates that significant impact at a systemic level will more likely arise from formal efforts involving official institutions (NGO B, 2018). These perspectives paralleled previous assessments on formal binational efforts to address transboundary groundwater quality issues on a more systematic basis, including through the La Paz Agreement Annex and Minute 289 regarding the involvement of IBWC/CILA in assessing transboundary groundwater contamination risks (International Boundary Water Commission, 1992; Mumme, 2015).

In contrast, the majority of city and state officials, farmers, private industry, and half of the academics in the survey supported the notion that the level of success of cooperative efforts is not necessarily related to formality of agreements but rather to actual communication and cooperation across the border. In their opinion, formal transboundary groundwater agreements would create more conflict than informal efforts, and the more formal the process, the greater the tension and lower the likelihood for actual “success” (Academic A, 2017; State Official A, 2017).

Additionally, the question of how to measure success was also a point of disagreement among interviewees. Nearly two thirds of the sample (mostly Federal, State, City, NGO officials, and a few academics) agreed that success should be measured according to measurable improvement in groundwater conditions, or what was referred to by a NGO official as “systemic long term measurable impacts” that can only be achieved through formal agreements (Federal Official A, 2017; NGO B, 2018; State Official D, 2018). According to these interviewees, the “success” of informal connections, which take place on a daily basis, and efforts to solve mostly short-term situations have not necessarily led to measurable long-term groundwater improvements (Academic B, 2018).

Alternatively, more than one third of interviewees explained that “success” can be measured as improvement in the exchange of effective communications, which have occurred on a consistent basis at the informal, local level (Academic C, 2017; Academic D, 2017; Agriculture User A, 2018; City Official A, 2017; City Official C, 2017). The case of El Paso and Ciudad Juarez is particularly instructive given that it started as an informal local level arrangement that achieved “success” in terms of productive communication and cooperation and at the same time had a “systemic impact” without federal intervention.

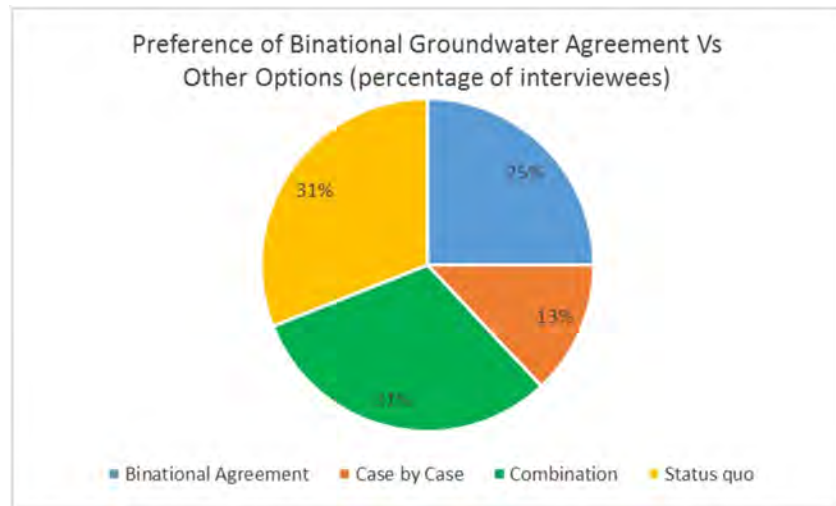


Figure 2. Preference of binational groundwater agreement versus other options (percentage of interviewees).

Notions of “successes,” as described by the interviewees, are not applicable to all cases. Rather, each “success” story is dependent on very specific, locally driven circumstances. Moreover, they are propelled by the perspectives and priorities of the various stakeholders in terms of the sector and level of government in which they function.

To what extent do the stakeholders want a binational groundwater agreement?

Figure 2 shows the preferences of the interviewees with regard to their perceived need for transboundary groundwater agreements on the border. One quarter of interviewees favored a formal, binational agreement that encompasses all transboundary aquifers on the border. Thirteen percent preferred a case-by-case approach, which could be achieved as an individualized agreement for each aquifer developed at the official binational level or aquifer-specific arrangements developed unofficially (without the consent or endorsement of the two federal governments) by members of the “local” or “regional” community and/or governmental units. Interestingly, 32% favored a combination of both a border-wide agreement coupled with aquifer-specific agreements. In fact, within this group, 93% of these interviewees agreed that before getting to a border-wide, binational agreement, it is necessary to begin with locally specific, small-scale agreements to establish the conditions that will make a broader binational agreement more likely to succeed.

Finally, nearly one third of interviewees preferred the status quo and did not favor any type of border-wide, transboundary groundwater agreement. Their main argument was that an additional agreement was not necessary because the framework of the 1944 Treaty between Mexico and the United States for the Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande was broad enough to cover groundwater issues. A second important reason mentioned by this group was the low likelihood of achievability of a border-wide agreement. They believed that the dissimilarity of institutional structures and legal regimes in Mexico and the United States would make the development of a formal, border-wide agreement at the federal levels unworkable. In Mexico, the federal government owns and manages groundwater throughout the country, while the states and cities have limited authority over such resources. In contrast, in the United States, the individual states have jurisdiction over groundwater allocation, and in the case of Texas, the resource is considered private property under state law and owned by the overlying landowner (Academic D, 2017; Agriculture User D, 2018; Federal Official A, 2017). This perspective might explain why more than half of the interviewees supported a border-wide, binational transboundary groundwater agreement, and yet 32% of this same group preferred to start with a local approach to the management of transboundary aquifers and later to move toward a more formal, border-wide binational framework “if necessary” (Academic E, 2017; State Official B, 2017). In fact, federal officials (from both Mexico and the United States) referred to Groundwater Conservation Districts (GCDs), currently utilized in Texas for groundwater management, as a model that, potentially, could be extended on a transboundary level. One federal official asserted that “They [the GCDs] have the governance framework and elements to be

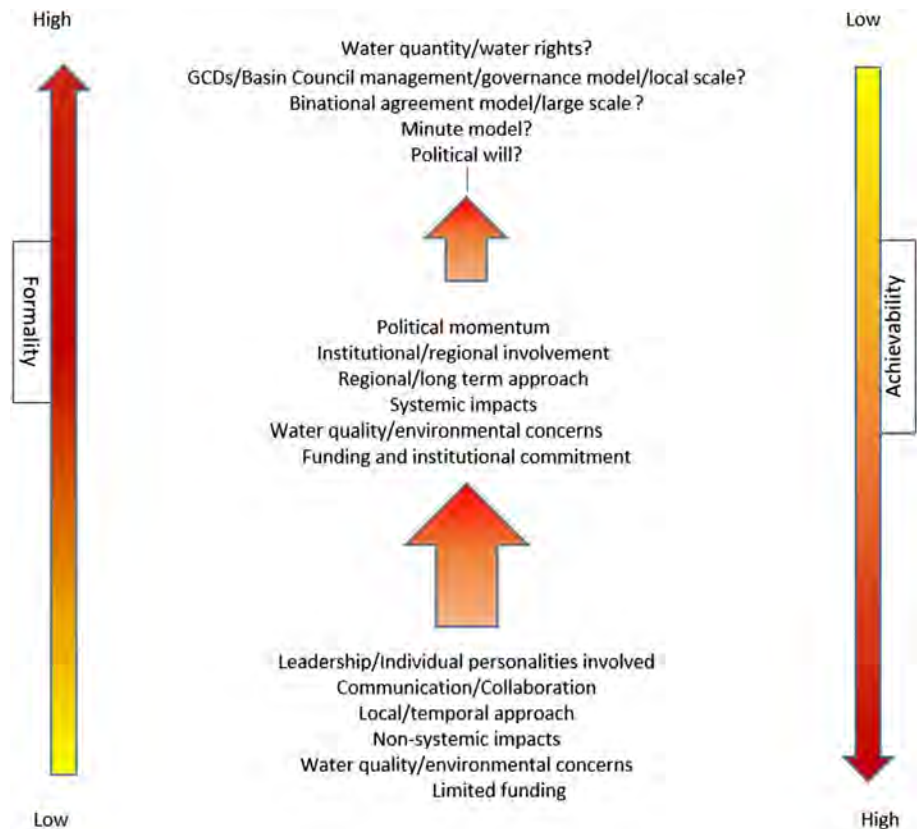


Figure 3. Though the formality of a potential binational agreement over transboundary groundwater resources might be desirable between Mexico and the United States, small-scale, informal, nonbinding approaches seem to be more preferable and feasible in the borderland between Mexico and Texas.

potentially used across the border with Mexico and it can be successful at a regional scale” (City Official F, 2018; Federal Official B, 2017). The counterpart on the Mexico side for this option would be the Groundwater Technical Committees (COTAS), which are the technical advisory groups for the Basin Councils. However, when compared to GCDs in Texas, COTAS have limited managerial, financing, and enforcement capabilities. They operate solely as liaisons between users and the Basin Council to incentivize compliance with the regulatory framework (R. Sanchez & Eckstein, 2017). Additionally, even though there is the presumption that CILA is the de facto authority for all waters shared with the United States based on Minutes 242 and 268 (International Boundary Water Commission, 1973, 1984), groundwater management (which, in Mexico, essentially entails the administration of water rights) in aquifers recognized as transboundary by the Mexican federal government, is directly administered and regulated by National Water Commission (Conagua) central offices in Mexico City, not by the Basin Councils of the corresponding state (Federal Official C, 2017).

3.2. Formal Versus Informal Groundwater Efforts

Another important finding revealed by this study involves the role of informal efforts (usually guided by distinct leadership capabilities) in the development and “success” of informal arrangements. As suggested above, if success at the local level is understood as the capacity to engage, communicate, and collaborate in the near-term, then the role of individual personalities and their personal efforts can explain the effectiveness of the collaborative experiences over groundwater resources across the border over the past 25 years. In contrast, if success is measured as an effective improvement of the quality and sustainability of groundwater resources in the region over the long term, the role and impact of individual personalities—and therefore informal and more local efforts—become less pronounced while the role of formal institutions becomes

more significant. Although experiences of cooperation over groundwater resources at the federal, institutional level have been few and limited, their long-term and regional effects have been significant.

Federal officials identified several examples that incorporated some groundwater elements as “successes” in terms of institutional collaboration across the border, including the 2000 Memorandum of Understanding (MOU) between Conagua and the U.S. Environmental Protection Agency (EPA) (Minute 304 Joint Grant Contribution Program for Drinking Water and Wastewater Infrastructure Projects for Communities in the United States-Mexico Border), which addresses water supply and water quality (water treatment) in border communities. This MOU also involved the participation of the Border Environment Cooperation Commission, the North American Development Bank (NADBANK), IBWC/CILA, and collaboration with state and city authorities (International Boundary Water Commission, 2000). Although this effort focused primarily on surface water, it stimulated various groundwater-related projects, including aquifer recharge and storage (ARS) pilot programs on the Valle de Mexicali and Rio Alisos transboundary aquifers, which were funded by NADBANK. Both projects aimed to complement the water treatment projects in the Mexicali and Nogales areas on the Mexico side and inject treated water back into the aquifer (Federal Official D, 2017; Private Industry D, 2017). These projects, however, were mostly guided by private industry in Mexico with limited participation from the United States side.

Likewise, interviewees also reported important informal “successes,” such as ARS projects along the border that do not include federal involvement from either side. For example, the city of Rio Colorado in Sonora developed an ARS project on its own initiative using the sand dunes region of the Rio Colorado delta as infiltration lagoons for treated wastewater, which recharged the transboundary Valle de San Luis Rio Colorado aquifer. This effort did not involve cooperation or collaboration with the United States side at any level or the federal authorities on the Mexico side. The city, however, is trying to gain support from both sides to secure funding for further technical studies and to negotiate with Conagua potential changes in Mexico’s legislation, which currently does not incentivize, legally or financially, ARS projects (Private Industry E, 2017).

In addition, there have been other semi-informal “successful” efforts related to ARS guided mainly by private industry on the Mexico side with funds from NADBANK and the World Meteorological Organization (WMO), with participation from Conagua but not from the United States side. For example, monitoring sensors were installed on the Mexico side of the Allende-Piedras Negras aquifer in 2005 to measure the static level of groundwater in the region. Measurements were not taken on the Texas side as adequate data from that side of the border was already available (Private Industry A, 2017). This effort, however, was abandoned after 10 years due to a lack of continuing funding from Conagua, 2017 (Private Industry B, 2017). Another study funded by WMO that involved Conagua concerned the feasibility of an ARS project in the Mexicali Valley that produced positive results; the project did not include participation from the United States side apart from some data sharing and superficial communication from academic institutions (Private Industry F, 2017).

Interviewees noted that formal and “semiformal” efforts to collaborate with counterparts in Mexico over transboundary groundwater resources that were considered “successes” have also occurred on the Texas side. The Water Task Force Group, which is considered by interviewees as a “semiformal” working group that includes representatives from city water utilities in the Mesilla/Hueco region (El Paso and Ciudad Juarez), as well as the University of Texas at El Paso, New Mexico State University, U.S. Bureau of Reclamation, and various state and city agencies, meets periodically to assess water issues in the region. “It is not a forum to reach any commitments, but mostly a technical committee, to communicate, engage and share experiences and it does not require the presence of IBWC/CILA” (Academic F, 2017). Likewise, the Paso del Norte Watershed Council, which includes state universities, city mayors, and state officials from both sides of the border (but not IBWC/CILA), meets regularly and occasionally is able to develop joint projects. For example, in 2001, the Council was able to secure funding from EPA to develop regional water plans designed to mitigate water scarcity in the region, though no funding was committed from the Mexican side (Academic G, 2017). Additionally, the task forces developed under the umbrella of the Border 2020 Program to assess very specific environmental issues at local and regional scale are addressed in the literature as semiformal efforts. Even though groundwater is not included within their realm, they could have the potential to address groundwater quality issues because of their local approaches (Mumme, 2015).

The only joint effort in the region that may be considered purely informal is the lawsuit instituted against the Mexican government in 2005 before an arbitral tribunal constituted under Chapter XI of NAFTA. In that case, Bayview Irrigation District, 16 other Texas irrigation districts, and Irrigation District 025 in Tamaulipas sued Mexico for failing to fulfill water deliveries to Texas and irrigation districts in the lower Rio Grande (State Official F, 2017). While the lawsuit did not involve groundwater and was ultimately dismissed by the tribunal, it showed the capabilities of local water user entities to collaborate across the border without the need for federal participation.

On the Mexican side, the current institutional regime led by the federal government, which limits participation and funding from state and city institutions, effectively restricts local initiatives to informal communication efforts and hinders their long-term impact. Only those efforts with strong stakeholder support and political agendas can survive to maturity and eventually gain the attention of IBWC/CILA, with the goal of becoming a formal effort in the long term (Federal Official E, 2017). “There are many informal communications related to coordination efforts usually supported by a greater formal agreements, because funding can only support formal agreements” (Federal Official F, 2017). According to Mexican and U.S. federal officials, the “success” of a transboundary agreement for transboundary groundwater resources will only be possible if it is developed between formal institutions at the federal level. Federal officials from both sides of the border believe that the role of state and city officers, in terms of groundwater collaboration, is very limited given the duration of their political appointments (usually 3 years). Moreover, they view such local efforts as self-limiting by their typical focus on water supply and drainage and constrained by the lack of funding for research and alternative projects (Federal Official G, 2017; Private Industry G, 2018; State Official C, 2017).

To summarize, according to the results of this study, the majority of cooperation efforts tend to take place, or at least to begin, at the local level with temporal and limited systemic impact. However, according to a small minority of interviewees (8%), those efforts are generally more feasible and successful than formal attempts, which are fewer in number and harder to achieve. In contrast, if “success” is interpreted by whether a local effort matures into a formal agreement between the two countries (federal involvement), then only those efforts with continuous communication, leadership, support, and resilience in the face of political change should be deemed “successful” since they are the ones that achieve the highest level of recognition and therefore institutional formality in the long run (Academic K, 2017; NGO A, 2018). Of course, a significant dosage of luck and political momentum also helps (Academic L, 2017; Federal Official B, 2017).

3.3. The Transboundary Groundwater “Conversation”

Based on the results of this study, a number of experiences have affected indirectly the way transboundary groundwater is considered on both sides of the border, and how domestic measures implemented on one side of the border unintentionally can impact groundwater conditions on the other side. According to state and federal officials on the Texas side, a number of private companies have attempted to extract groundwater from certain border aquifers in Texas and transfer it to cities such as San Antonio and San Angelo, as well as near Van Horn in west Texas. However, efforts to transfer groundwater out of basins in the border region have not proceeded because of questions regarding the scientifically unsupported yet plausible surface-groundwater connectivity of those aquifers to the Rio Grande River (Academic H, 2018; State Official E, 2018). For example, according to one federal official, a few years ago, an oil and gas company tried to obtain a groundwater permit to transfer groundwater from Fort Stockton to Midland and Odessa. Its application was denied by the Middle Pecos Groundwater Conservation District (GCD) based on concerns regarding the impacts of potential connectivity to the baseflow of the Rio Grande. These concerns were voiced by both Texas and Mexican water agencies through the formal communication channels of IBWC/CILA (Federal Official A, 2017).

Likewise, according to U.S. federal officials, in recent years there have been formal attempts between Texas, Mexico, and New Mexico to start discussions over groundwater. However, the interstate dispute over water rights between Texas and New Mexico involving the Rio Grande Compact has affected the binational talks, and efforts are on hold (Academic C, 2017; Federal Official A, 2017).

In addition to the above examples, interviewees identified other circumstances that have been important promoters or initiators of conversations over transboundary groundwater resources, at both informal and

formal levels. One of the examples they highlighted was the lining of the All American Canal in California whose seepage was shown to be connected to groundwater levels on the Mexico side (an estimated 80 Mm³/year of water seeped into the Mexicali Valley aquifer). While the case was highly contentious, it nevertheless spurred discussions, including on some groundwater issues that led to the adoption of Minutes 307, 308, 309, 316, 319, and 323 (International Boundary Water Commission, 2001, 2002, 2003, 2010, 2012, 2017). “This case was an unintentional detonator of cooperation at every level among the two countries” (Federal Official D, 2017). Although, ultimately, only Minute 316 included groundwater resources within its scope (taking into account surface-groundwater interactions in order to preserve the Santa Clara Delta Wetland), the discussions emerging from the All American Canal dispute indicate that groundwater issues are being recognized as critical resources for both sides of the border (Ries, 2008; V. Sanchez & Munguía, 2006).

In addition, interviewees reported about other efforts to pursue formal cooperation involving transboundary groundwater resources that did not succeed. For example, one interviewee related that in 2008, the mayor of Brownsville sought to engage with Conagua about plans to construct a small reservoir on the Rio Grande for water supply and irrigation, and to create a type of “river walk.” The proposal failed, however, because Conagua opposed the project arguing that it would increase groundwater levels in the city of Matamoros and, as a result, damage the city’s urban infrastructure. A similar attempt was made by the city of Laredo, which also failed because it was opposed by Conagua based on the same argument. Just like the cases of interbasin water transfers mentioned above, although no technical studies were presented in these two scenarios by either side, the mere possibility of potential groundwater impacts on the Mexico side frustrated any attempts to negotiate over the proposals and prevented the effort to produce formal agreements.

3.4. The Driver for Cooperation: Water Quality (Not Quantity)

Worldwide, there seems to be greater concern for, and therefore investment in, water quality issues over water quantity concerns (Biswas et al., 2006; ILO, UNCTAD, UNDESA, & WTO, 2015; United Nations, 2014; World Health Organization, 2013a, 2013b). However, not much attention has been given to water quality as a driver for cooperation in transboundary river basins. In the case of Mexico and the United States, there is evidence suggesting that water quality issues and related concerns have played a significant role in promoting cooperation between the two countries and among their transboundary states (Mumme, 2015; R. Sanchez & Eckstein, 2017; R. Sanchez et al., 2016; Varady & Mack, 1995). In fact, even though water quality was addressed only superficially in the 1944 Treaty between Mexico and the United States, the great majority of the Minutes concern issues relate to water quality (R. Sanchez & Eckstein, 2017). Furthermore, IBWC/CILA has become the main authority on this topic regardless of the fact that jurisdiction over water quality is not explicitly provided for in the treaty (Colorado-Rio Grande Water Treaty, 1944).

The cooperation and collaboration experiences on the Mexico-U.S. border over transboundary surface and groundwater resources that were raised by the interviewees as “successful” at the formal level were all prompted by, or had as their main driver of consensus, a public health concern directly related to water quality conditions on one or both sides of the border. They were able to transit from a local or regional effort and reached maturity as they evolved into a formal agreement between the two countries (see Figure 3) (Federal Official E, 2017; State Official A, 2017). Investment in water treatment plants along the border that benefit both sides is a clear example of formal joint collaboration that has improved surface water conditions, and in some cases also positively affected groundwater/surface water interactions (Minutes 242, 319, 316, and 323) (Academic B, 2018; Federal Official C, 2017; Federal Official D, 2017; International Boundary Water Commission, 1973, 2010, 2012, 2017).

Environmental concerns have also coupled with water quality issues, and indirectly with groundwater conditions, as interest in ecosystems protection has evolved in recent years (Academic N, 2018; Federal Official E, 2017; NGO B, 2018). According to one federal official, the recent IBWC/CILA Minutes related to the protection of the Rio Colorado Delta, Santa Clara Delta, and the estuary of San Diego are all examples of water quality/environmental/ecosystem protection efforts that have been successful in terms of cooperation and actual improvement of the environment and that could be used as examples for future cooperation (Federal Official F, 2017). Although these efforts are concentrated on surface water, there is an indirect link to groundwater as surface/groundwater interactions play an important role in ecosystem conservation.

Nevertheless, as a number of interviewees noted, this link has yet to be recognized “officially” at a formal level (Academic H, 2018; Federal Official E, 2017).

In the survey, interviewees explained that, generally, there are very few formal or informal arrangement or formal agreement that addresses groundwater issues (quality or quantity) on the Mexico-U.S. border as a primary concern (Academic L, 2017) (Academic L, 2017; Agriculture User B, 2018; Federal Official F, 2017). The only exceptions they pointed include Minutes 242 and 268, and the *Joint Report of the Principal Engineers Regarding Information Exchange and Mathematical Modeling in the El Paso, Texas and Ciudad Juarez, Chihuahua Area Aquifer*. In addition, they noted that informal efforts have occurred in the form of data sharing and research initiatives undertaken by at the state level by Arizona, USA, and Sonora, Mexico, for the San Pedro and Santa Cruz transboundary aquifers under the TAAP. Furthermore, they agreed that the only potentially successful strategy to reach transboundary cooperation on groundwater at any level (formal or informal) is to use water quality concerns related to groundwater and avoid including water quantity (Academic G, 2017; City Official B, 2018; NGO B, 2018), “at least not at the beginning” (State Official D, 2018). Indeed, apart from the examples mentioned above, all of the transboundary water cooperation efforts that have addressed groundwater at some level have done so as a secondary issue or priority (e.g., Minutes 316 and 323 and presumable Minute 261) (International Boundary Water Commission, 1979, 2010, 2017).

Figure 3 shows the maturity process of an informal effort on its transit to reach a formal agreement based on the elements and conditions provided by the interviewees. The likelihood that an informal effort will be attainable is higher with less formality involved and lower as it transits toward a more formal environment. The elements that play an important role later in the maturity process clearly differ from those in the early stage, mainly in terms of long- versus short-term commitments, funding, and local versus systemic impacts. What remains unresolved by the interviewees are the potential management models that could be applicable at the end of the maturity process and the likelihood of including water rights in the discussion without compromising the long-term negotiation process. The maturity process can also explain the different perceptions of “success” at different maturity stages. While there are some informal efforts that do not reach the last stage of formality, a number of interviewees still considered them as “successful” at a local level. Nevertheless, as mentioned previously, those efforts that were able to reach the highest maturity stages are considered successful by the majority of the interviewees given their long-term and systemic impacts, though a few stakeholders regarded them as unsuccessful because of the complex bureaucracies that were required to maintain them at that formal level.

3.5. Perspective Versus Reality

One of the most common responses when interviewees were questioned about their perception of transboundary aquifers between Mexico and Texas was that it is a “sensitive topic,” “common taboo,” “something that nobody wants to talk about” (Academic L, 2017; Federal Official G, 2017; State Official F, 2017). With the exception of the provisions pertaining to the Yuma Aquifer under Minute 242, the fact that there are no formal, binational regulations on transboundary aquifers on the Mexico-U.S. border at any level of governance has created an emerging but silent crisis given the scope and extent of the unknowns and their potential consequences. Like everything else that encounters an artificial, anthropogenic border, groundwater faces special circumstances that are complicated and linked with local realities that can either ameliorate or exacerbate its original social, economic, and political implications and transform it into a different reality (what is referred to as transboundariness by R. Sanchez et al., 2018a).

Groundwater is a hidden security concern for both Mexico and the United States; however, the risks of the unseen and unknown do not seem to be pressing concerns for either country. Moreover, the assumed responsibility shared by the two countries to manage groundwater resources on the border is limited by the corresponding geopolitical jurisdictions of the two nations. Unfortunately, this reality results in neglect at every institutional level on both sides of the border, which transforms the issue of groundwater sustainability in the border region into an expensive commodity given that the resources needed to study the unknowns are as limited as is existing information. “Funding availability has been prioritized to solve water supply and drainage shortages, infrastructure development, irrigation development, and water treatment projects, but nothing really on groundwater assessments as we do not know much about it” (Agriculture User A, 2018; Federal Official D, 2017).

One possible exception to this scenario involved the well-known case of the lining of the All American Canal on the United States side of the Mexicali Valley and its implications for groundwater levels on the Mexico side. In this case, U.S. stakeholders fought to line the canal to prevent subsurface leakage of water into the Mexicali Aquifer in Mexico, which had occurred since the 1940s. Stakeholders in Mexico, however, had become reliant on the half century of inflows to develop an intense agricultural sector reliant on the underlying aquifer. As a result, considerable sums were spent by local stakeholders in Mexico who wanted to maintain the status quo by producing numerous studies showing the hydrologic connection between the canal and aquifer. Likewise, local and federal stakeholders in the United States funded various research projects supporting their goal of changing conditions and protecting what they perceived as their rights. Since the canal was entirely within U.S. territory, the case went before a U.S. judge who ruled in favor of the Americans finding that there was no legal obligation to maintain the cross-border leakage. “The facts did not and will not supersede users groundwater rights” on the United States side (State Official F, 2017). Nonetheless, it suggests that under certain conditions, especially where water rights and livelihoods are at stake, attention and resources can be mobilized to develop groundwater data and information.

The All American Canal example, however, offers additional insight into perception and reality based on fear of the unknown. In fact, one of the driving factors impacting perceptions and understanding of groundwater in the border region is fear. Grounded in the unknown conditions of transboundary groundwater resources, fear has often been used as a political tool against attempts to intervene with the status quo of groundwater use. As was mentioned above in the examples of interbasin water transfers (Fort Stockton case) and reservoir construction (Laredo and Brownsville cases), infrastructure development projects have sometimes been halted irrespective of their positive or negative impacts. Stakeholders who opposed the projects for various reasons simply were able to raise the “necessary doubt” through dubious claims of impact, without having to provide any scientific proof (City Official C, 2017; State Official C, 2017). Fear of the alleged impact was a strong enough tool to divert support away from the projects.

Additionally, in the case of the TAAP, there seems to be a “silent understanding” between Mexico and the United States under which they both recognize the perceived constraints of the project in relation to the limited information available, the real differences in institutional and legal frameworks, and the political risks associated with changing the status quo. This is evident in the TAAP research agenda, which does not address groundwater management strategies (quantity or water rights issues) but rather focuses on information exchange and joint collaboration to assess groundwater conditions, as well as groundwater quality matters.

Interesting results arise from the perceptions that stakeholders hold and the realities that surround them. First, the number of unknowns can serve as an important weapon for those that consider themselves “at risk” of losing the status quo. Second, regardless of evidence and facts, protection of private water rights on the Texas side and federal water rights on the Mexico side is a priority. The status quo reigns over groundwater use in the region as fears support maintaining the current status of regulation (or lack of regulation). For example, although CILA is considered the *de facto* authority for all water shared with the United States, according to Federal Officials from the Mexico side, all issues concerning transboundary aquifers are dealt with directly in Conagua’s central offices (not in the Basin Council) and delegated to official recommendation of CILA only when necessary (Article 9 National Water Law, 1992). “That topic is delegated to CILA, though CILA does not have any legal grounds to deal with groundwater in the region” ... “It seems that nobody wants to deal with the hot potato ... it’s risky” (State Official D, 2018). In the case of Texas, groundwater is considered private property, which is probably why a considerable 31% of the interviewees prefer the status quo rather than risk or invest in any other option of groundwater management in the region. As one interviewed said, “As long as you do not challenge the current system of water allocation in Texas, you are safe” (State Official A, 2017). Moreover, the absence of data and information does not seem to persuade the local, regional, or national communities to change that regime, at least not in the short run.

3.6. The Way Forward

Based on this exploratory study, a number of elements present in the binational water agenda emerge as potentially useful tools for encouraging the two sides to develop “some kind” of “cooperation mechanism” over transboundary groundwater resources (Agriculture User B, 2018; Federal Official A, 2017; Federal Official B, 2017; NGO A, 2018; State Official B, 2017). The more prominent ones include environmental

concerns primarily related to water scarcity, contamination risks, lack of cross-border regulation, and the exhaustion of surface water rights. Taken together, these concerns have raised numerous questions regarding the region's transboundary aquifers, including whether these groundwater resources should be taken more seriously as a future water supply source, and how their transboundary nature should be considered and managed in the coming years (Academic M, 2018; City Official D, 2017; Federal Official D, 2017; State Official F, 2017).

Along the Mexico-U.S. border, there appears to be political momentum and institutional recognition at local and federal levels for the need to address transboundary aquifers in the border states dependent on the Colorado River, but less on those reliant on the Rio Grande. However, interest in the topic is growing at the institutional federal level in both countries (Federal Official B, 2017). Although existing cooperation efforts have been limited mostly to data sharing, joint data collection, communications, and the development of modeling tools for common use at the local scale (Hueco Bolson, for example) primarily driven by water contamination threats, these efforts exemplify the growing interest along the Mexico-U.S. border to address joint transboundary aquifer use. Current U.S. funding under the TAAP is also a sign of the rising interest on the topic.

In summary, according to the majority of the interviewees, and as depicted in Figure 2, currently, there are important elements in place that could drive informal efforts toward a more long-term cooperative environment. However, they are still concentrated at the local level with limited systemic impact, and although they might be considered "successful" at the informal/local level, they require additional elements if the objective is to transform them into formal efforts in the long run. Leadership and political will are key elements that have yet to manifest at a larger scale to push the local efforts into a more reliable and mature environment for transboundary groundwater collaboration (Academic L, 2017; Agriculture User C, 2018; City Official E, 2018; Federal Official A, 2017). According to one stakeholder, "We need a champion. We need political will" (Private Industry C, 2017).

3.7. Potential Models of Transboundary Groundwater Management

The interviewees surveyed in this study envisioned a variety of options or models for transboundary groundwater agreements and arrangements. These models, as described below, were proposed by the interviewees and analyzed by the authors. The level of detail of each option depends on the information compiled through the survey and was complemented using available literature related to the proposed structure. The main objective of this section is to identify possible alternatives for transboundary groundwater agreements and arrangements that could be used in future negotiations between Mexico and the United States, as well as the pros and cons of each model considering the current legal frameworks applicable in the border regions.

3.7.1. National/Formal Level Model

3.7.1.1. Border-Wide, Binational Treaty

As mentioned previously, close to one third of interviewees support and recommend the development of a border-wide, binational treaty for transboundary groundwater management. A binational agreement, however, has both limitations and advantages that are worth considering. Such an agreement, necessarily, would be a general framework instrument that includes a broad spectrum of general principles and practices recognized within the international law arena. It likely also would be limited in terms of management, governance, exploitation, conservation, and sustainability practices given the complexity and variety of aquifers, conditions, and needs across the vast Mexico-U.S. border, as well as the different levels of transboundaryness of each aquifer (R. Sanchez & Eckstein, 2017).

The advantages of a formal, binational agreement are not insignificant. Implementation of a general framework for groundwater management on the Mexico-U.S. border could further the development of international law for transboundary aquifers. Moreover, it could establish a baseline for governance and practices on the border that would have important binational and systemic implications for the region. Among others, these include official acknowledgement of shared groundwater resources by the federal governments, states, and other stakeholders; formal appreciation of the need to cooperate and collaborate jointly to better protect these shared aquifers; and proper recognition of the need to share information among the various stakeholders. Achievement of just these three points, by themselves, already could result in important progress in the way groundwater resources in the border region are managed and shared.

However, depending on its scope and extent, a border-wide, binational agreement could require some modification of domestic regulations that, given the current political situation, may be not feasible for either nation (Federal Official A, 2017; State Official A, 2017).

3.7.2. Subnational Level Models

3.7.2.1. Formal Regional/State or Substate/Local Transboundary Agreements

Another model proposed by some of the interviewees considers a regional, local, or other subnational perspective where two or more subnational units, such as states, counties, or cities that share an aquifer across the border, incorporate federal participation in a formal cooperative agreement. Such an agreement, conceivably, could be structured by two or more states on either side of the border sharing a portion or all of a transboundary aquifer; it could also be pursued by local irrigation districts or other very “local” subnational units in a scheme that, arguably, would provide the most locally specific approach to the management of a transboundary aquifer.

The transboundary groundwater agreement between Switzerland and France is one example of this model as it constitutes a local, aquifer-specific agreement entered into, managed, and enforced locally with direct engagement of and leadership of local authorities—the Community of the “Annemassienne” region, Community of the “Genevois” Rural Districts, and Rural District of Viry on one part, and the Republic and Canton of Geneva on the other—albeit authorized by the respective federal governments (R. Sanchez & Eckstein, 2017).

Considering the different jurisdictions and legal mechanisms that govern transboundary water resources among states within the United States, some level of federal involvement is necessary if the subnational units want to make the arrangement formal and binding. Likewise, on the Mexico side, federal participation is required for any state or city to cooperate over a transboundary groundwater basin. Considering the current institutional differences between the two countries and among the various subnational jurisdictions, this model may be the most feasible and effective in terms of having positive impacts on groundwater quality and sustainable management. From a legal perspective, a transboundary groundwater agreement under this model would not require any changes to existing federal legislation in either Mexico or the United States, and any issues with local or state laws would be addressed directly by the stakeholders at those governmental levels. Ultimately, such an agreement may be the most successful in terms of involving stakeholders at all relevant levels of government (local, regional, and federal), as well as in addressing locally specific needs and groundwater conditions.

Despite the potential effectiveness of this model, it does have one important limitation. This model would require approvals from federal authorities and institutions on both sides of the border, suggesting that achievability is more challenging while effectiveness can only be expected in the long term as depicted in Figure 3 (Academic N, 2018; Federal Official B, 2017). Accordingly, as preferred by some interviewees, the subnational approach may be more achievable if, instead of pursuing a formal agreement (requiring federal authorization from both countries), the level of commitment is limited to an unofficial arrangement that does not involve the federal governments. However, as Figure 3 describes, although achievability is higher at the early stage of maturity, informal efforts do not usually result in long-term systemic impacts and funding is limited.

3.7.3. Informal Regional/State or Substate/Local Transboundary Arrangements

Informal arrangements are unofficial and unenforceable under law. Yet they can create viable cooperative schemes that, as depicted in Figure 3, may be more achievable than formal agreements but whose effectiveness can be limited. Under such an informal arrangement, subnational units, such as states, counties, or cities that share an aquifer across the border, engage with each other without including any federal institutions or representatives in the effort. According to interviewees, this model can provide a more direct and specific response to local and regional needs without the complications that federal approval and involvement often create. The ongoing Sonora-Arizona Commission is possibly the closest example of this approach. The states of Arizona and Sonora as well as their corresponding border cities have worked closely through the Commission since 1959 on topics such as economic development, transportation, infrastructure, tourism, security, and even environmental issues without compromising their respective political and jurisdictional limitations—such as with water management on the Mexico side, which can only be addressed at the federal level. This relationship, which has been in place for 60 years, potentially could serve as the basis

for future unofficial arrangements, which could include nonbinding commitments on groundwater resources at a regional level.

One particular informal, local transboundary arrangement example proposed by a number of interviewees is especially noteworthy. They suggested that the structure of Texas' Groundwater Conservation Districts (GCDs) might be adapted into a transboundary management unit that would incorporate both Texas and Mexico's stakeholders. "The current structure of GCD's can have a binational component and it could act similar to a River Authority ... it is manageable, site-specific and with local control" (Federal Official A, 2017). The institutional design of the GCDs on the Texas side could potentially allow management of the portion of a transboundary aquifer that lies within the district's sovereign boundaries in coordination with a counterpart on the Mexico side (Federal Official B, 2017). That counterpart, they propose, could be the COTAS (Groundwater Technical Committees), which could function in a similar manner allowing both entities to work cooperatively over the management of the entire aquifer as mirror institutions on their respective sides of the border. Of course, if proponents of this model ever intended it to transform into a formal agreement, it would require federal involvement in the same manner described above in the discussion of formal, subnational units engaging in an official agreement. Conceivably, such a local arrangement could seek to transform into a formal agreement without direct federal involvement; however, this would require considerable legal and political changes on both sides of the border. In particular, it would require the decentralization of water institutions and authorities on the Mexico side, which could mean a drastic change in that country's current legislation (Federal Official C, 2017; State Official F, 2017). It would also require changes in the federal laws of both nations to allow subnational units (GCDs and COTAS) to engage in official decision-making over border water matters.

It is important to mention that these model options were proposed by the interviewees but there certainly could be other informal approaches to achieving transboundary groundwater management in the border region. Instruments such as the La Paz Agreement Annex have been described as quite adaptable for addressing discrete, localized transboundary water quality problems. Additionally, the regional work groups or task forces under Border 2020 program also could provide a means for local binational collaboration that is convened by federal environmental agencies but acted on by state and local governmental and nongovernmental stakeholders, often as partners (Mumme, 2015).

3.7.4. Case-by-Case Basis

At the subnational level, interviewees also proposed an ad hoc or case-by-case approach throughout the border region whereby each aquifer would be managed according to its corresponding needs. In some cases, that would mean a formal agreement among an aquifer's transboundary stakeholders, while in others an informal arrangement. Such an approach depends entirely on each specific aquifer and its unique circumstances and could include any of the above models, a combination of them, or a different structure. According to interviewees, this approach leaves the door open for innovation and creativity and is preferred by 13% of the sample. However, a combination of the case-by-case option under the framework of a border-wide, binational agreement was preferred by nearly one third of the interviewees. In essence, this group envisions a general agreement that applies to all transboundary aquifers on the border, but that also allows states and local communities to develop subagreements or subarrangements for specific aquifers based on local circumstances. This approach could assure the applicability of general international principles regarding transboundary groundwater resources and, at the same time, adaptability to local conditions and priorities. However, as indicated above, the formal/binding subnational agreements are unlikely to be pursued given the existing legal systems in both countries. Nonbinding, subnational/local arrangements seem to be the most feasible models of transboundary groundwater management, at least under current legal conditions.

4. Conclusions

The results from this study reflect important findings. First, there seems to be a preference for a border-wide, binational groundwater agreement to establish a basis for long-term, coordinated groundwater management on the border. However, the interviewees also favor implementation of more informal, local efforts as they believe that such arrangements are likely to be more successful approaches for achieving regional arrangements, at least in the short term, as compared to the formal, large-scale efforts. While the

two priorities appear incompatible, they are in fact consistent to the extent that the interviewees want a border-wide, binational agreement but recognize that such an objective would be difficult to attain. As a result, they also prefer local arrangement simply because they are more realistic and attainable. Some of these findings were supported by a recent survey of transboundary groundwater legal mechanisms between Mexico and the United States (Foster, 2018).

Second, leadership approaches and individual personalities represent important factors for success at the local level but with limited sustainability over time and limited impact on a broader regional-systemic scale. Interviewees highlighted the importance of local politics and relationships, especially within cross-border communities, for developing locally specific cooperative arrangements over shared groundwater resources. However, they also emphasized their belief that without institutional support at higher levels of government, such efforts cannot be sustained over time. Third, water quality vis a vis water quantity is the main driver of transboundary cooperation and communication efforts in the Mexico-U.S. border region. While water scarcity continues to be a growing challenge along most of the boundary, interviewees reported that concerns over water quality are more likely than inadequate water supplies to bring stakeholders to the table and generate cooperation. Fourth, the reported experiences of failed and successful cooperative efforts over shared groundwater resources are often based more on fear and lobbying than on scientific facts. As interviewees explained, the lack of trust in people and data across the border can be a barrier to even the most logical and reasonable proposals.

As it has been mentioned, the results and interpretations of this study may be relevant and applicable to other regions of the border between Mexico and the United States. Considering that many of the interviewees have had prior experience working in one or more sectors, it is reasonable to interpret their perspectives as being based on their broad experience rather than on a specific region case. Additionally, on the Mexico side, there is no institutional framework at the regional or state level with regard to water management. Accordingly, the Mexico side of the sample (with the exception of irrigators) generally represents perspectives applicable to the border region as a whole.

The transboundary groundwater models proposed by the interviewees seem to be representative of experiences of success stories as well as their most ideal desires; they also reflect both the current binational legislative capabilities as well as the feasibility of desired institutional changes. Accordingly, future transboundary groundwater management could be as feasible as the political will available at every institutional level, as complex as the fears of the unknown, and as necessary as each stakeholder considers appropriate.

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