



## Article

# Investigating Management of Transboundary Waters through Cooperation: A Serious Games Case Study of the Hueco Bolson Aquifer in Chihuahua, Mexico and Texas, United States

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**Abstract:** Management of transboundary aquifers is a vexing water resources challenge, especially when the aquifers are overexploited. The Hueco Bolson aquifer, which is bisected by the United States–Mexico border and where pumping far exceeds recharge, is an apt example. We conducted a binational, multisector, serious games workshop to explore collaborative solutions for extending the life of the shared aquifer. The value of the serious game workshop was building knowledge, interest, understanding, and constituency among critical stakeholders from both sides of the border. Participants also learned about negotiations and group decision-making while building mutual respect and trust. We did not achieve consensus, but a number of major outcomes emerged, including: (1) participants agreed that action is called for and that completely depleting the freshwater in the shared aquifer could be catastrophic to the region; (2) addressing depletion and prolonging the life of the aquifer will require binational action, because actions on only one side of the border is not enough; and (3) informal binational cooperation will be required to be successful. Agreeing that binational action is called for, the serious games intervention was an important next step toward improving management of this crucial binational resource.

**Keywords:** groundwater depletion; transboundary aquifers; binational resource management; serious games; stakeholder cooperation

## 1. Introduction

Excessive groundwater pumping is leading to rapid depletion of aquifers around the world, in the context of climate change, dwindling supplies, and increasing demand [1–6]. Aquifers have long been used as a means to buffer annual variation in meeting water demands in many regions, at the cost of long-term depletion. Aquifers thus represent the source of long-term adaptive capacity, but many are at risk. Moving forward, it will be crucial to establish trajectories of remaining freshwater over time, and to identify means of extending or prolonging the life of these aquifers. Transboundary aquifers have had

sufficient storage in the past to support autonomous, uncoordinated extraction, but the need for transboundary coordination is emerging rapidly.

Groundwater aquifers are common pool resources. Ostrom's [7] fundamental insight was that common pool resources without institutional structure governing use are vulnerable to over-extraction, as each user accesses them without consideration of overall impact. On the other hand, imposition of a single overarching authority, she demonstrated, tends to be less effective than shared collaboration, and we add that overarching regulation is particularly hard to achieve at international borders. Rather, she suggested that increased knowledge of future risk, shared information, and mutual trust in knowledge encourage the emergence of voluntary shared governance of such resources. Furthermore, while envisioning a watershed approach to water governance, all parties would expect some benefits and advantages from a transboundary approach to groundwater management.

Due to the characteristics described above, transboundary groundwater is an important common pool resource that is particularly at risk [8]. The international border means that conventional institutionalized governance by the jurisdictions involved does not cover all access sites and users. At borders, the risk of the open access situation is heightened, and sharing is made more difficult. The literature on transboundary groundwater cooperation/governance has two characteristics. It either (1) consists of cataloging cases where aquifers are transected by borders (e.g., [9] for the region and [10] globally), but noting the absence of transboundary governance institutions in most cases [11,12] or (2) addresses legal and political issues in envisioning such hypothetical transboundary institutions, [13–18]). Important work has been done on the hydrology of transboundary aquifers, cataloging knowledge and gaps around transboundary aquifers as physical entities (e.g., [19]). The central challenge is that there are few actual cases of transboundary governance to study, and little has been done in terms of researching efficacy of transboundary management in those cases.

There are just seven cases around the world of such aquifers with agreements of any kind (mostly data sharing) and only one transboundary aquifer (the Franco–Swiss Genevan aquifer) is effectively managed [20,21]. Notably, the Genevan aquifer has shown sustainable water levels over the last 30 years as compared to levels before the signing of the agreement between Switzerland and France in 1970s, and the governing agreement was recently renewed. The one scholarly case study [22] of the Genevan aquifer shows that cooperation emerged as a response to serious decline, via mutual recognition of a common resource and involvement of local (subnational) actors. Other transboundary aquifer governance cases are either too new, with limited empirical research, or so far have only been studied in terms of the legal/administrative framework, separate from the hydrological and climate dynamics [20–25]. An important need, among others, is research that addresses the key goals of increased knowledge of future risk, shared information, and building mutual trust across bounded jurisdictions.

We address the groundwater in the Hueco Bolson/Valle de Juárez aquifer (names used in the United States (US) and Mexico (MX) respectively, see Figure 1). The aquifer, hereafter referred to as the HB is bisected by the Rio Grande/Rio Bravo del Norte, which delineates the border between the Mexican state of Chihuahua (CH) and the US state of Texas (TX), and thus also separates the two largest users of groundwater in the region, El Paso Water, EPW (similar but not identical to the city of El Paso) and the Junta Municipal de Agua y Saneamiento, JMAS, conterminous with the municipality of Ciudad Juárez. There are many other smaller users on both sides of the border, including small rural utilities and agricultural users.

Surface water is governed at the transboundary scale in the region by the 1906 Treaty in this river particular segment [26]. Definite volumes are allocated to MX and the US, and within the US separate compacts divide that share between Colorado, New Mexico, and TX. Specific binationally-coordinated institutions, the International Boundary and Water Commission (IBWC, US) and Comisión Internacional de Límites y Aguas (CILA, MX), govern surface water. The IBWC and CILA, in Minute 242 (Minutes reflect decisions of the

IBWC and CILA that are binding obligations of the US and MX, once signed by the two governments), committed MX and the US to developing “a comprehensive transboundary solution to the extant and emerging groundwater disputes along the border” [27], but has never been fulfilled, although the joint US–MX Transboundary Aquifer Assessment Program (TAAP) has been successful in expanding knowledge around US–MX shared aquifers [12,28].

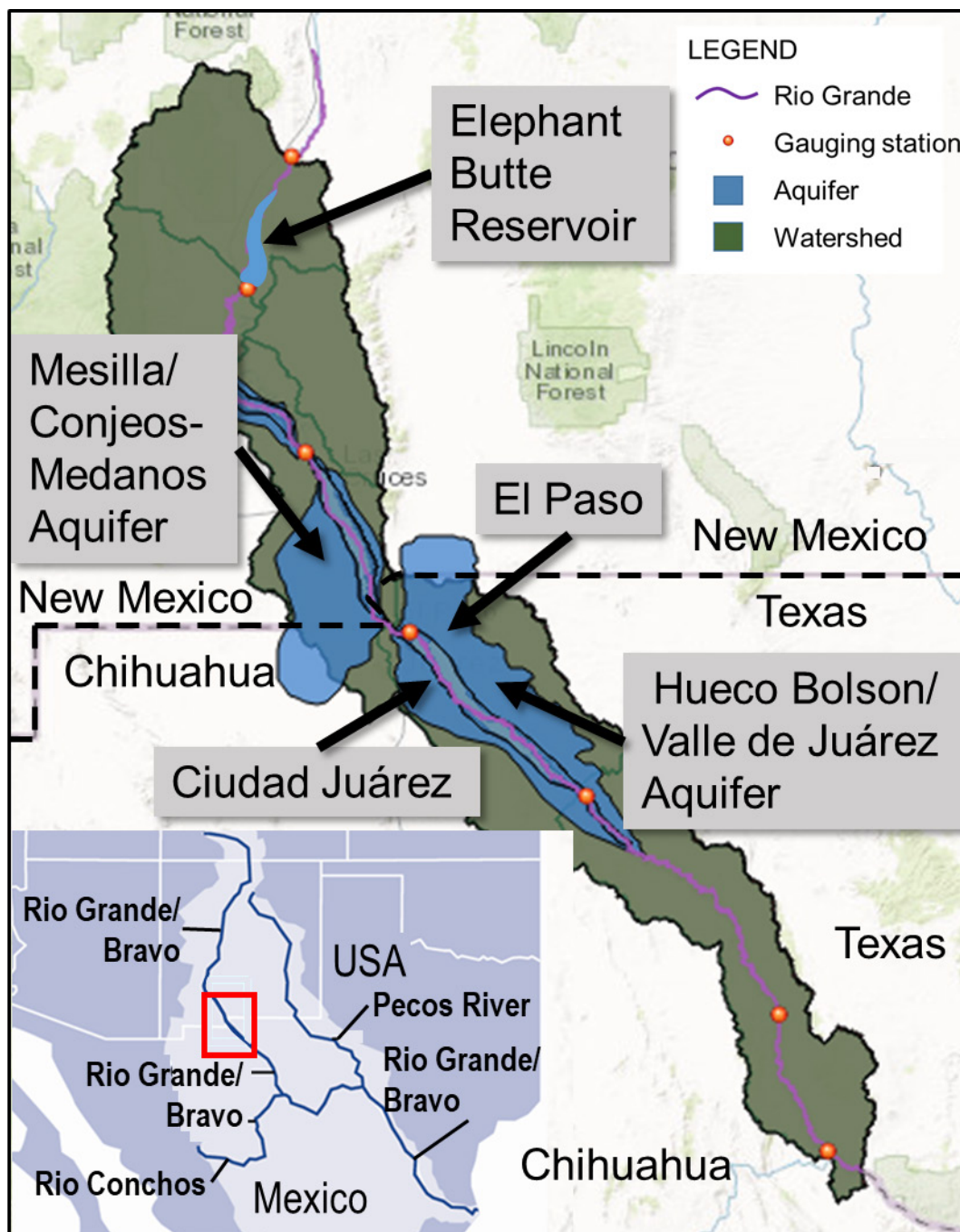


Figure 1. Study area.

Thus, at present, there is minimal shared governance over the groundwater in the HB. Hydrologically, the groundwater constitutes a transboundary common pool in the sense that the water is efficiently mobile across the border, and any one actor on one side, affects quantity and quality of the whole. However, this common pool resource

is governed by the rules and regulations of the individual states and/or countries who share the resource, chiefly TX in the US and the Federal Government of MX. In MX, access to groundwater is governed by the federal agency CONAGUA, and in TX access to groundwater is delegated to private surface owners [29]. These access governance regimes are uncoordinated binationally. Furthermore, the hydrological fact that surface and subsurface water are connected and that, as discussed below, subsurface water is used when surface water is insufficient, does not enter into this strictly delineated governance system.

The specific institutional gaps seen for US–MX transboundary groundwater are common to international borders [12,30]. The bureaucratic machinery of territorial nation states are effective for organized societal action inside borders, but less well-designed for transboundary action [31]. While some cooperative actions extend across borders [32], in most cases, actors' influence terminates at their national border. This causes a notable institutional disparity and sometimes incongruity at such sites [33], including the US–MX border. One example among many differences in approach among institutions is that water capital funding for JMAS in Juárez is mainly derived from federal sources, while EPW is able to set its own capital investment priorities, according to availability of resources from the state and national level.

Another barrier to governance at international borders is methodological nationalism, the ways that knowledge is enclosed inside of and limited by nation-state units (and replicated with smaller units like states) [34,35]. For example, the main planning document for TX shaping EPW's investments, the Texas Water Development Board Region E Plan [36], does not account for groundwater extraction in the HB by MX, let alone capital and policy measures south of the border. Yet the groundwater moves efficiently under the border. EPW likely does account for activities on the MX side, but there is no explicit shared modeling of the commons.

An important aspect of our serious game was an attempt to transcend the knowledge gaps implied in methodological nationalism by creating a shared water budget for the HB and bringing it for discussion and consensus to a binational group of water stakeholders. By focusing on the unified groundwater budget as a knowledge object, we emphasized discussion of joint groundwater stocks and volumes extracted (see [21]), rather than rules for which parties within nations are allowed physically to access aquifers, consistent with the admonitions in [37] to distinguish groundwater from aquifers. Methodological nationalism is part of a wider range of bridges and gaps, such as cultural and linguistic differences, and ambivalent attitudes toward the other country: beneficent feelings based on shared relationships, but also deep-seated prejudices of nationalism and superiority/inferiority [38]. While unequal power over water is widespread, perhaps unavoidable, at borders, we follow the findings of Zeitoun and Warner [39] that there is opportunity within hydrohegemony for the construction of more equitable and cooperative relations.

The need for a binational forum, or space for interaction, where stakeholders could evaluate the most recent data and scenarios regarding groundwater evolution along the binational HB has been a continuous challenge for local and regional water users. Furthermore, water agencies responsible for water management on either side of the border struggle to communicate to local water users about management the HB. We implemented a serious games approach to address these issues in the HB with the specific aim of exploring binational cooperation as an approach to prolonging the life of the transboundary aquifer. To our knowledge, we report insights from the first such effort in the Paso del Norte region of the US–MX border.

## 2. Materials and Methods

### 2.1. *Serious Games Background*

Preparing for and managing water security risks is complicated by a wide variety of challenges, including scientific uncertainty and complexity, limited resources, competing priorities, and differences in risk perception. To move towards effective mitigation and adaptation strategies, stakeholders need to develop a collective sense of the risks that they



face, how they could prepare for and manage water security risks, and the decision-making approaches that will allow them to respond collaboratively and adaptively to emerging threats. Achieving these goals requires that stakeholders learn together and from each other to create a collective intelligence and shared understanding [40–43]. Serious games have gained attention as a way to advance actions to mitigate or adapt to risks associated with the environment and natural resources [44–48]. A serious game is an exercise that directly engages participants in working to solve a realistic but hypothetical challenge with the intent that they learn new material or approaches. Serious games can provide an opportunity for participants to experiment with solutions in an environment where they can freely express opinions.

With increased concern over the suitability of current management arrangements to handle future water security issues, water resource management has been at the forefront of many serious games efforts (Madani et al. [45] estimated that about one-third of environmental management-serious game topics had a water resources management theme) Applications have included watershed planning, drought management, drinking water access and safety, and conflict resolution [49–57]. In these applications, researchers have evaluated the effect of the games on the participants has been a focus, including assessing the degree of social learning [44,53–57], change in beliefs and values [58], and success in conveying the complex interconnectedness of water resources problems [59,60]. Researchers have investigated whether serious games can inform modeling; for example, Aubert et al. [61] argue that serious games can be used to elicit preference weights in the context of multi-criteria decision analysis and Addamatti et al. [62] use serious games to develop agent-based models of water users. The apparently few serious games applications to groundwater resources [59,63,64] have emphasized the notion of groundwater as a common pool resource and the necessity for users to collaborate to sustainably manage the resource.

The approach taken in the present work to the game objectives fits best with the “Design and Recommend” model in the typology described by Bots and Van Daalen [65]; or, in other words, using the game as “design studio”. Since the objective of the present work is to identify better solutions through cooperation, our efforts also fit with the description of “games as interventions” by Rodela et al. [44]. In the games as interventions model, it is important that the management scenarios be as realistic as possible, and that participants play their real roles to the greatest extent possible. Social learning is also emphasized in the games as interventions model. As far as the authors know, the current effort is the first to apply serious games to binational management of a transboundary groundwater resource.

## 2.2. Modeling Methodology

We rely on past, substantial work on the hydrogeology of the HB to develop our groundwater balance model (e.g., [66–71]). We embedded the following key concepts into the groundwater model used in the games: (a) a simple model of a single aquifer compartment with binational pumping is sufficient for exploring the sustainability of the aquifer; (b) accordingly, the lifetime of the freshwater portion of the aquifer can be quantified by a depletion time which could be lengthened or shortened by changing pumping rates in either country; (c) current situation and projected business as usual scenarios and the associated depletion times are useful for exploring alternative, binational management strategies; (d) extending the lifetime a meaningful amount beyond the business-as-usual projection requires reducing pumping by substantial amounts; (e) the basis for assigning shares of reduced pumping to each city (e.g., equal percentage vs. equal volume) significantly impacts the relative burden of pumping reductions for each city; and (f) an array of potential water supply and demand reduction options exist for offsetting pumping reductions, each with a different costs.

The single compartment groundwater model is stated as an aquifer water balance:  $D = \sum Q - \sum R$ , where  $D$  is the depletion rate or change in storage,  $\sum Q$  is the sum of pumping over both countries and all water use sectors and  $\sum R$  is the sum over all

sources of aquifer recharge. We implicitly assume that there is no groundwater outflow except via pumping. The associated depletion time is then  $T = V_{fw}/D$ , where  $V_{fw}$  is the volume of recoverable freshwater in the aquifer. We first estimate depletion rates and times according to present day circumstances, which we call the current situation, summarized in Tables 1 and 2. For demand from the HB, we use the average pumping rates from the most recent five years of available pumping data to reflect the most recent patterns of use by El Paso, Ciudad Juárez, and other users. Other users include agricultural wells in the Valle de Juárez irrigation district in CH, the El Paso County Water Improvement District #1 in TX, industrial users not served by EPW in TX, and small rural water utilities in both TX and CH. Recharge estimates for the HB are highly uncertain, but estimates for potential sources of recharge have been derived from groundwater elevation mapping, geochemical surveys, and groundwater flow modeling (see Table 2). In addition to values for pumping from the HB, we note in Table 1 the other water supply sources to which each city has access.

**Table 1.** Current situation: annual water demand from El Paso and Ciudad Juárez (kAF).

User	Total Demand	Hueco Bolson Aquifer	Rio Grande	Mesilla-Conejo-Medanos Aquifer	Desalination
Ciudad Juárez	151	121	NA	30	NA
El Paso	118	53	30	27	8
Other	NA	14	NA	NA	NA
Total	269	188	NA	NA	NA

**Table 2.** Annual recharge rates for the Hueco Bolson (kAF).

Recharge Component	Recharge
Mountain front	9
Lateral inflow from Tularosa basin	0
Engineered artificial recharge	6
Seepage from Rio Grande channel	1
Leakage from irrigation & return flow canals	17
Total	33

The amount of freshwater remaining in the HB is calculated using historical estimates of freshwater volumes in the aquifer and estimates of pumping that have occurred from the timing of the freshwater volume estimates to the present. Estimates of recoverable volumes of freshwater and brackish water in the HB range from 7.5 MAF to 10 MAF and up to 20 MAF, respectively [71–75]. We use the Heywood and Yager [72] estimate of recoverable freshwater volume of 9 MAF as of 2003 because this estimate is within the range of other freshwater volume estimates and the conceptual basis for the estimate is consistent with other hydrogeologic models proposed for the HB. We estimate that approximately 2.5 MAF of groundwater have been depleted from the HB since 2003, leaving about 6.5 MAF of recoverable fresh groundwater. Using the current rate of depletion of 155 kAF/yr and the recoverable freshwater volume estimate of 6.5 MAF, the recoverable freshwater will be completely depleted in approximately 42 years.

The Business-as-Usual (BAU) scenario (see Table 3) is meant to set the stage for the discussions by envisioning a future that assumes that urban populations and thus water demands will increase and there will be no significant change in policies or human behavior that would slow depletion of the HB. The BAU scenario spans a 50-year period (2020–2070) and pumping from the HB over the period is based on assumptions regarding (a) increases in population and corresponding water demand for the two cities; (b) climate-change-induced reduction in surface water available to EPW; (c) proportional increases in pumping from the HB in response to increased demand overall for the cities and reductions in surface water availability for EPW, the only utility that also uses surface water; (d) pumping by users other than EPW and JMAS would remain the same as in the current

situation; (e) recharge would remain constant; and (f) per capita use rates would remain constant. Table 3 summarizes the basis for the projected demand for the two cities and sources of the associated information. Given the BAU depletion rate of 209 kAF/yr and the recoverable freshwater volume estimate of 6.5 MAF, the recoverable freshwater could be completely depleted in 31 years.

**Table 3.** Summary of business-as-usual scenario.

	Ciudad Juárez	El Paso	Other	Total	Units
Population increase	66%	33%	NA	NA	
Reduction in Rio Grande supply	NA	40%	NA	NA	
Average demand	204	141	NA	NA	kAF/yr
Average HB pumping	164	63	14	242	kAF/yr
Recharge	NA	NA	NA	33	kAF/yr
Depletion rate	NA	NA	NA	209	kAF/yr

Reductions in HB pumping, if any, would result in mismatches between future supply and demand. Based on experience in prior stakeholder meetings and informal interactions with the two city water utilities, we identified alternatives for offsetting pumping reductions in Table 4. We used values from state reports (TWDB) for estimates of unit costs for each option (also in Table 4, unit costs include amortized capital and operating costs.) and used a simple calculation of volume multiplied by unit costs to determine total costs associated with implementing each option. Upper limits for each of the options also were established.

**Table 4.** Options for offsetting pumping reductions.

Option	Description	Cost (US\$/kAF)	Maximum Amount (kAF/yr)
Desalination	A desalination plant is constructed and operated to jointly serve Ciudad Juárez and El Paso and would draw from brackish portions of the HB.	518	CJ: total demand EP: total demand
Aquifer recharge with treated wastewater	Treated tertiary effluent is applied to recharge basins overlying the HB to recharge the freshwater aquifer and reduce brackish water intrusion.	1000	CJ: 133 EP: 71
Direct potable reuse	Treated tertiary effluent is piped to water treatment plants and blended with current water supplies.	850	CJ: 133 EP: 71
Imported water	Groundwater is secured in remote aquifers and pipelines and pumping plants are constructed.	2400	CJ: total demand EP: total demand
Incentivized household water conservation	Educational and financial incentive campaigns are implemented to reduce household and commercial water use.	367	CJ: 15 EP: 30
Reduce infrastructure leaks	The cities repair leaking water distribution systems and continue leak detection and replacement campaigns.	2295	CJ: 27 EP: 4

### 2.3. Workshop Implementation

Stakeholders from both sides of the border were invited to participate, with the intention to have roughly equal participation from US and MX stakeholders. We also intended to recruit roughly equal numbers of participants from the municipal and industrial (M&I) sector and the non-M&I sector. We did not include agricultural users, both in order to simplify the framework of the discussion and because that the agricultural sector has a significantly lower impact currently on the long-term trajectory of the HB. We compiled a list of 30 potential participants and sent invitations by email. Where necessary, we followed up with phone calls or text messages. In several cases, contacts from our initial list of invitees recommended additional or alternative potential participants. We received 20 positive responses and we communicated the final details of the workshop to them. To prepare, participants were provided with and asked to read two documents one week before the first session: one describing the intention and schedule of sessions and key

questions to be addressed in each session, and another with a more detailed description of the activities in the first two sessions.

Six sessions, each 60–80 min, were held over a four-month period. The first session was held in November 2020 and the remaining five sessions were held in consecutive weeks in January and February 2021. Due to restrictions imposed by the COVID-19 pandemic, the sessions were held on Zoom with simultaneous Spanish and English translation. Agendas were sent out ahead of each session and, in some cases, participants were asked to read documents and use spreadsheets calculations to support their decisions in the upcoming sessions. All documents used in the workshops were provided in both Spanish and English and numerical values were presented in both metric and English units. Each session began with a recap of the preceding session and ended with a description of goals for the next session and, in some cases, assignments to complete ahead of the next sessions.

In Session 1, the participants were introduced to each other, the format of the sessions, and the key questions to be addressed in each session. The workshop organizers presented the concepts behind the single compartment groundwater model, the calculation of depletion rates and times, and the information supporting the calculations. The basis for the current situation depletion rate and times were explained, followed by a similar presentation on the projected, BAU scenario. The presentations were followed by moderated small group discussions of the following questions. (a) Are the current situation and BAU scenarios reasonable? (b) What can be done to mitigate or adapt to the BAU scenario? (c) What would be the potential impacts of depletion of the HB?

Session 2 focused first on the exploration by participants of setting targets for reducing depletion rates and extending aquifer depletion times. The results of pre-session participant polling on acceptable reductions and binational sharing in the reduction of the depletion rate were used as foundation for a discussion of factors motivating the selection of targets. A second pre-session poll on options for technologies, policies, and broader approaches for meeting the target reductions was used to motivate preliminary discussions of advantages and disadvantages and potential binational approaches for implementing the options.

In Session 3, participants worked with the first version of a spreadsheet that provided estimates of recoverable freshwater depletion time based on potential reductions in HB pumping rates for the two cities. Two general schemes were offered for apportioning the reductions in pumping rates for the two cities: equal volumetric reductions and equal fractional reductions. For either scheme, no reduction corresponds to the BAU scenario. The spreadsheet was used to motivate discussion of how to share the reduction in depletion and, correspondingly pumping rate between the two cities.

In Session 4, participants explored strategies for offsetting pumping reductions using a second spreadsheet that provided unit cost estimates (US\$/kAF see Table 4) for the options in the spreadsheet. Participants were asked to identify annual volumes for each of the options, based on their individual preferences, to offset the deficit between supply and demand. The spreadsheet calculates the cost of each option and total costs, given the annual volume of water to be used by Ciudad Juárez and El Paso. Several combinations of options were presented, to give the participants an idea of the range of possible volumes and associated costs.

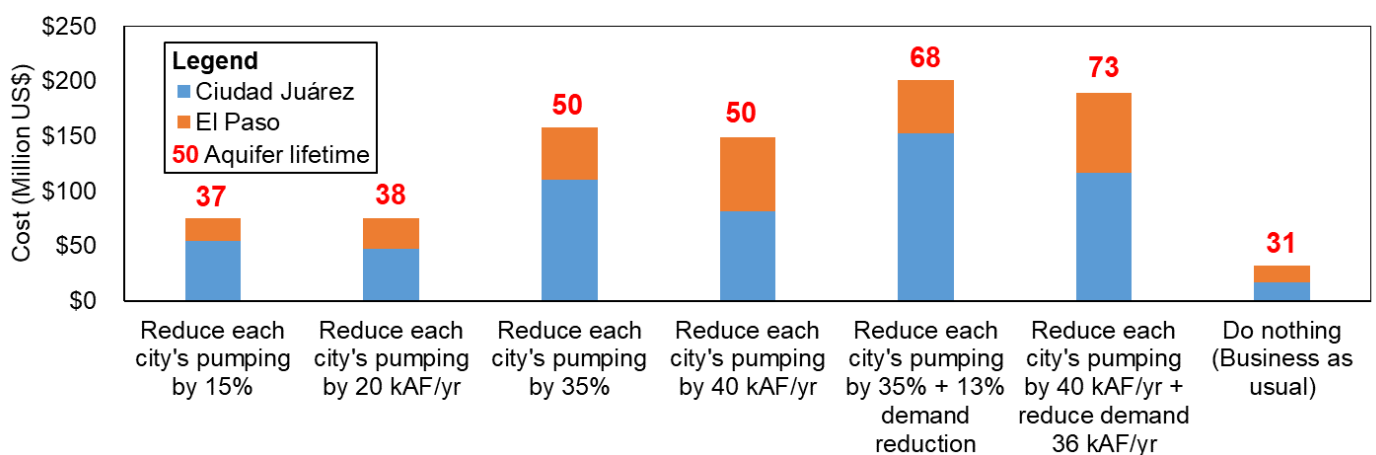
In Session 5, the workshop organizers presented estimates of the cost of doing nothing (BAU scenario); that is, what would happen if fresh groundwater in the HB were depleted in 31 years. The basis for these costs was as follows: (a) 57 kAF/yr of HB pumping would have to be replaced for El Paso, (b) the current cost of groundwater for El Paso is US\$150/AF, (c) HB pumping for El Paso is replaced by a 50/50 mix of imported water (US\$2,400/AF) and desalination (US\$518/AF), and (d) an estimated cost of replacing El Paso HB pumping of US\$74 million. The cost of replacing 147 kAF/yr of HB pumping for Ciudad Juárez was not estimated precisely, given that unit costs of water replacement for Ciudad Juárez were unreliable, but a coarse estimate of a US\$100 million to US\$200 million was deemed reasonable. Participants were again asked to choose options and how much water supply would be gained or demand would be reduced for offsetting pumping reductions.



In the last session (Session 6), a poll was given for participants to choose their top three choices from seven options for meeting a target reduction in depletion times and associated reductions in pumping. The options are described in Table 5 and the costs and freshwater aquifer lifetimes are shown in Figure 2. After the selection of the options, the workshop organizers presented two options for sharing the costs between the two cities: (a) each city pays for implementing their options alone and (b) the total cost for the two cities is shared 50/50 between the two cities. Finally, a summary of what was learned over the entire workshop was presented, followed by a discussion of next steps.

**Table 5.** Primary water supply gain or demand reduction alternatives for each option and city.

Option	CJ Portfolio	EP Portfolio
1. Reduce each city’s pumping by 15%	<ul style="list-style-type: none"> <li>• aquifer recharge w/treated wastewater</li> <li>• imported water</li> </ul>	<ul style="list-style-type: none"> <li>• desalination from local aquifers</li> <li>• aquifer recharge w/treated wastewater</li> </ul>
2. Reduce each city’s pumping by 20 kAF/yr	<ul style="list-style-type: none"> <li>• aquifer recharge w/treated wastewater</li> <li>• imported water</li> </ul>	<ul style="list-style-type: none"> <li>• desalination from local aquifers</li> <li>• aquifer recharge w/treated wastewater</li> </ul>
3. Reduce each city’s pumping by 35%	<ul style="list-style-type: none"> <li>• aquifer recharge w/treated wastewater</li> <li>• imported water</li> </ul>	<ul style="list-style-type: none"> <li>• desalination from local aquifers</li> <li>• aquifer recharge w/treated wastewater</li> <li>• imported water</li> </ul>
4. Reduce each city’s pumping by 40 kAF/yr	<ul style="list-style-type: none"> <li>• aquifer recharge w/treated wastewater</li> <li>• imported water</li> </ul>	<ul style="list-style-type: none"> <li>• desalination from local aquifers</li> <li>• aquifer recharge w/treated wastewater</li> <li>• imported water</li> </ul>
5. Reduce each city’s pumping by 35% + reduce demand by 13%	<ul style="list-style-type: none"> <li>• aquifer recharge w/treated wastewater</li> <li>• imported water</li> <li>• household conservation</li> <li>• leak reduction</li> </ul>	<ul style="list-style-type: none"> <li>• desalination from local aquifers</li> <li>• aquifer recharge w/treated wastewater</li> <li>• imported water</li> <li>• household conservation</li> </ul>
6. Reduce each city’s pumping by 40 kAF/yr + reduce demand 36 kAF/yr	<ul style="list-style-type: none"> <li>• aquifer recharge w/treated wastewater</li> <li>• imported water</li> <li>• household conservation</li> <li>• leak reduction</li> </ul>	<ul style="list-style-type: none"> <li>• desalination from local aquifers</li> <li>• aquifer recharge w/treated wastewater</li> <li>• imported water</li> <li>• household conservation</li> </ul>
7. Do nothing (business as usual)	<ul style="list-style-type: none"> <li>• not applicable</li> </ul>	<ul style="list-style-type: none"> <li>• not applicable</li> </ul>



**Figure 2.** Costs of options for meeting a target reduction in pumping and associated depletion times (numerical values in red bold).

2.4. Data Collection

Note takers kept detailed notes of discussions, and comments in the Zoom chat function were saved. Several survey or polling instruments were used to collect information regarding the participants’ beliefs and attitudes and their choices for increasing the aquifer lifetimes, including:

- a short, 29-item survey (available upon request) administered at the beginning of Session 1 and again at the end of Session 6, which was designed to learn about participants' knowledge about water use and conservation in the HB, and their beliefs about groundwater use responsibility and cooperation for management. Surveys were administered online, in English and Spanish, and followed IRB protocols for human subjects.
- polling on acceptable reductions and binational sharing in the reduction of the depletion rate and on options for technologies, policies, and broader approaches for meeting the target reductions (prior to Session 2)
- polling on options for meeting target reductions in depletion times and associated reductions in pumping (Session 6)
- a survey regarding participants' opinions on the workshop salience and relevance, format of the workshop, and overall satisfaction with the workshop. In addition, bilingual students took notes during all sessions, and the notes were analyzed to develop common themes that arose during the discussions.

Due to a low response rate from participants in Mexico on the post-workshop survey ( $n = 1$ ), it was not possible to conduct a pre-post analysis of individual perspectives as we had anticipated. However, the survey responses to the preworkshop were sufficient for descriptive analysis, and for an aggregated analysis that allows group-level comparisons of perspectives before and after the workshop, both of which we discuss below, along with a synthesis of session observations.

### 3. Results

#### 3.1. Participation in Sessions

Table 6 shows the participation in sessions. While more participants came from the US, substantial participation came from both countries. Organizations with participants included JMAS Juárez; the Mexican Society of Engineers—Chihuahua; Junta Central de Agua y Saneamiento—Chihuahua; Proteccion Civil Juárez; El Paso Water; the Bureau of Reclamation; El Paso Electric; TCEQ; EPA; Ysleta del Sur Pueblo; Friends of the Rio Bosque; Fort Bliss; The Frontera Land Alliance; the Lower Valley Water District; and the Hunt Companies (a large business and residential real estate developer and manager).

**Table 6.** Summary of participation in the sessions.

Participation	Mexico	US	Total
any session	7	13	20
more than 1 session	6	12	18
more than 2 sessions	5	10	15
more than 3 sessions	5	9	14
more than 4 sessions	2	4	6
all 6 sessions	1	2	3

#### 3.2. Synthesis of Session Observations

The most important outcome to emerge was that, although discussion moved progressively through issues as described above, in the end, a consensus list of pumping reduction measures could not be achieved. The technical demand of numerous, detailed, interlocking decisions at that level were beyond a short group discussion. However, we did effectively discuss major policy parameters. In all, the sessions generated a foundation of relationships that, if pursued and developed further, could allow for even more movement toward a consensus on pumping reductions.

Participants found the basic model that produced scenarios for the HB to be reasonable and credible. The knowledge and beliefs survey revealed that participants from MX and US both were aware that pumping rates far exceed recharge rates, and that groundwater depletion is a serious problem. Notably, participants from the US were more likely than participants from Mexico to disagree with the statement that “decreases in groundwater

elevation are greater than 1 foot per year". Conversely, participants from Mexico were more likely than participants from the US to agree with the statement "El Paso and Ciudad Juárez contribute equally to groundwater depletion", to agree that "freshwater in the HB will be completely depleted in a few decades", and to believe that the lack of water in the future will limit future economic growth.

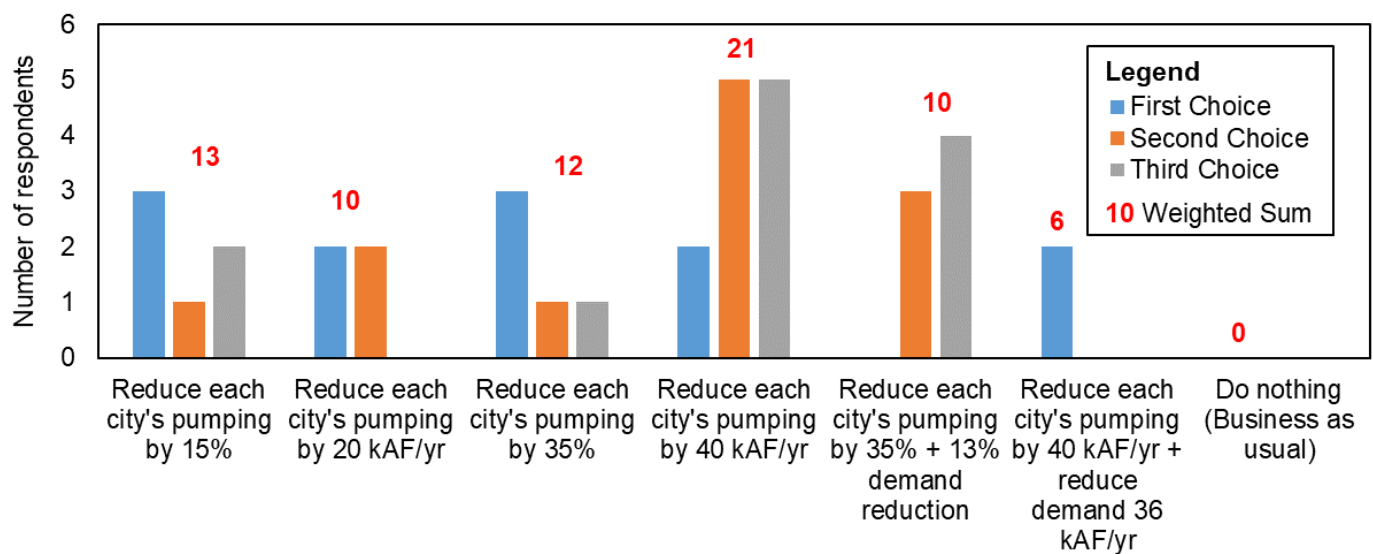
When examining the BAU scenario of depletion of HB freshwater in approximately 31 years, all participants were motivated to consider ways to extend it or avoid it altogether. Likewise, they agreed that HB depletion is a shared issue. Groundwater was understood to be mobile, a common pool good: that which is consumed on one side is lost from both sides; that saved on one side is saved for both. Moreover, the social-economic fate of each side (especially Juárez, the more groundwater dependent side currently) was understood to matter to all. A sense of mutual engagement and commitment was palpable.

Lurking in the background was a model result that participants felt was revelatory. In 2051, if pumping from the HB has to be completely replaced because it is depleted, the one-time, sudden replacement costs would be US\$100s of millions. Participants wrestled—in an engaged and serious fashion—with three considerations. A shorter freshwater depletion timeline would require less expensive measures to replace supplies or reduce demand, but it would mean quicker introduction of costly alternative supplies and/or drastic conservation measures. A longer timeline puts off the expensive full transition and gives more time to adjust. However, it is costlier to accomplish a long depletion timeline as more/larger alternatives to pumping need investment.

In the first round, pumping reductions were proposed, ranging from 3–97% (translating to a 46-year lifetime to an indefinite time). The most commonly chosen reduction was about 38%, which gives a 50-year lifetime (instead of 31-year lifetime with BAU). Fifty is an easy number to envision, a typical planning horizon, and falls approximately in the middle range of the discussion amongst all participants. The group then wrestled with the question of how to partition the responsibility of reduction between the two countries. An equal volume reduction has a large percentage impact on El Paso, as it does not currently pump as much volume, but an equal percentage reduction would have a huge impact on Ciudad Juárez, as an equal percentage of a large pumped volume is a larger amount to replace. Initially, the most common assigned responsibility was a reduction of 70% in MX (ranging from 50% to 70%).

The conversation turned when participants from JMAS made it clear that Ciudad Juárez would have trouble reducing pumping by more than 15% without significant financial help from, for example, the Mexican federal government or the US. A 15% reduction on both sides would extend the lifetime from 31 to 37 years. It is notable that realizing this constraint did not keep the participants from discussing deeper reductions in pumping, but with a recognition that these larger reductions would need to be funded and overcome in a binational sense. The sessions that followed worked their way through hard considerations: the difficulty but desirability of affecting the timeline; impact and fairness of reductions on two sides; and the kinds of measures (volume saved, cost, applicability to the US, Mexico, or both) needed to reduce pumping to the chosen goal.

The seven-option poll (see Table 5 and Figure 2 for description of options) captured many of the elements of the discussion. The results of the poll are shown in Figure 3, including a simple weighted sum of the choices, where the first choice is given three points, the second two points, and the third one point. Option 4 scores highest; Options 1, 2, 3, and 5 cluster about half the score for Option 4; Option 6 was least preferred of the reduction alternatives, and no one chose BAU (Option 7). Option 4's notable qualities are its moderate timeline (50 years to depletion, weakly favored throughout the workshop) and its choice to reduce pumping by an equal volume, not percentage, which is relatively favorable to Juárez in a situation that would generally be very stressful.



**Figure 3.** Results of polling on options for reducing depletion times (numerical values in red bold are weighted sums of choices).

We then moved to discuss possible policy measures. This conversation occurred in the frame of the achieved recognition that the burden and benefit of managing a common pool resource affected both sides—the US cannot go it alone—and acknowledgement that for Ciudad Juárez to reach reductions of pumping above 15%, external funding would be necessary. Conservation was identified as important for both cities. The most effective actions to achieve significant conservation included incentivized reduction in outdoor water use in EP and reduction of infrastructure leaks in Ciudad Juárez. For EP, incentivizing reductions in outdoor water use is more expensive than continuing to use local groundwater, but it is a relatively inexpensive way to reduce pumping. For Juárez, reducing infrastructure leaks is relatively expensive and it would require additional funding to reconstruct old water infrastructure. The participants also found desalination to be an attractive option for both sides: more expensive than local freshwater but less expensive than other interventions like long distance importation and direct potable reuse, but no consensus or clear direction emerged on the level and mix of specific measures.

Although we cannot say that the serious game resulted in a single, clear resolution, it certainly did constitute an effective common dialogue about a common concern and put many important perspectives and considerations on the table. Furthermore, it was shown that stakeholders were capable of interacting in an open forum to discuss sensitive issues of the common problem, binational water management, and to envision common solutions.

#### 4. Discussion

The evolution of the conversation was notable and seemed to demonstrate a degree of social learning. In the end, no one proposed accepting the business-as-usual timeline of 31 years to freshwater depletion. However, target reductions in pumping varied widely (33%–99%). Over the course of the workshops, participants were capable of understanding the relevance, or importance, of joining a collaborative effort. That is, the serious games provided an opportunity to take a more holistic view, and to appreciate how we are all together in the “same boat” in facing aquifer depletion.

The discussions meaningfully brought out value-based issues in a format that was otherwise not available to participants. For example, when the discussion identified the difficulty that Ciudad Juárez would have in reducing pumping by much more than 15% without significant outside help, the dialogue in all sessions that followed took that concern seriously. Some voted for a 15% reduction or 20 kAF (its equivalent) in the final vote among options, and even those who voted for longer timelines did so with accompanying discussion of how to fund added help for Ciudad Juárez. The serious games format proved



helpful in creating an open but thoughtful dialogue about important variables and values among actors of differing viewpoints, and in turn, in creating the shared community needed for common pool governance of the Hueco Bolson.

The small number of participants and the irregularity of participation were shortcomings for this activity. Ideally, it should be done in a format where the activity could be completed in one to two days and conducted in person, face-to-face. The participation would have been more consistent, the use of the model for determining impacts could have been more efficient, and the decision points could likely have been made with more consensus/agreement. In addition, the consensus building process would likely have been improved by having professional facilitators who were not part of the project and who were seen as more “neutral”. The lack of consensus or agreement does not nullify our results but points to the difficulty of the decision making and to the need for thorough consideration, negotiation, and consensus building that would have been better accomplished at an in-person event.

The workshop sessions occurred between 9 and 12 months into the COVID-19 pandemic and the accompanying formal restrictions against travel across the border and holding in-person meetings in general. While we did not formally question the participants about potential impacts of holding the workshop by teleconference, our impression is that most participants had experienced other meetings on these types of platforms, both before and after the conditions imposed by the COVID-19 pandemic. They felt comfortable expressing their opinions and broadly participated in the different tasks during the sessions. Nevertheless, some participants expressed that an in-person setting may have generated a friendlier environment because they would have mingled with other participants during the process. In addition, participants could not easily have one on one discussions among themselves as they might have at an in person event. For the session moderators, it was not easy to follow who was present at the sessions, and thus to ensure that everyone had a chance to speak and provide input. In addition, the session moderators noted that facilitators could have helped participants use the spreadsheet models at an in person event and perhaps this would have motivated the participant to experiment with the spreadsheet between sessions.

The participants generally agreed that binational cooperation and solutions are needed, but the dialogue was still partly limited by institutional (methodological) nationalism, evident in for example, the tendency to allocate quantitative responsibilities and costs to major utilities of each respective country. However, considerable progress was made in discussing problems and solutions as a shared problem, and this is not a trivial outcome. Considering the long and tricky history of tension and suspicion—as well as cooperation—between the two countries, and especially considering the political context of the serious games during the time period of late 2020, the tenor of the serious games should be viewed positively. Furthermore, trust was a very important moral value between participant stakeholders since most of them were very interested as well as knowledgeable of the current situation on binational water resources. Some of them had a long history of local interest on the issue and direct involvement on addressing water problems along both sides of the border and the serious games approach facilitated a common ground approach to a complex, binational water management problem.

Finally, the serious games intervention was but a moment in the long-term trajectory of the management of transnational water. Such an approach had not been applied in this region before, despite the recognized history of binational collaboration in regard to transboundary water resources at the Paso del Norte. The history of past US-Mexico border water agreements is very incremental and multiactor, but such an approach is a first step into potential informal agreements to extend the life of the most important water resource in the region, one which if completely depleted would result in catastrophic consequences for society on both sides of the border. Notably, our approach supports the Texas–Mexico stakeholder survey findings in [29] suggesting starting with incremental regional arrangements. Such platforms keep stakeholders talking and informed about the

main water issues that could affect future sustainable development along a critical section of US–Mexico border.

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