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Principal Investigator: Sharon B. Megdal

Submitted by **Sharon B. Megdal**, PI, The University of Arizona

Contributors

Elia M. Tapia, Contract researcher and Researcher-Professor at Departamento de Geología, Universidad de Sonora, Hermosillo 83000, Mexico

Mary-Belle Cruz Ayala, Postdoctoral researcher, Water Resources Research Center, The University of Arizona, Tucson, AZ 85719, USA

Eylon Shamir, Independent contractor, Hydrologic Research Center, San Diego, CA 92127, USA

Core Ideas

1. The Transboundary Aquifer Assessment Program (TAAP) is a Joint effort between the United States and Mexico to evaluate shared aquifers. The TAAP originated after the signing of the Transboundary Aquifer Assessment Act (US Public Law 109–448, TAA-Act) and the signing of the "Joint Report of the Principal Engineers Regarding the Joint Cooperative Process United States-Mexico for the Transboundary Aquifer Assessment Program." Particular areas of interest include the Arizona-Sonora transboundary aquifers of focus: The Transboundary San Pedro Aquifer and the Transboundary Santa Cruz Aquifer.
2. The 2017-2022 WRRC-TAAP activities included collaborative efforts identified through the TAAP Cooperative Framework, hydrologic and hydrogeologic characterizations, transboundary aquifer reconnaissance work, socio-economic analysis of border communities, and stakeholder engagement.
3. During this five-year effort, the WRRC participated in over 50 binational technical working meetings with the International Boundary and Water Commission (IBWC), the United States Geological Survey (USGS), Universidad de Sonora (Unison), and the Mexican National Water Commission (CONAGUA); published TAAP findings in 23 journal articles; gave over 50 presentations at regional, national, and international conferences; and organized various forums and seminars to improve transboundary groundwater knowledge in the Arizona-Sonora border region.

Executive Summary

In 2017, the University of Arizona Water Resources Research Center started working on a Five-Year Transboundary Aquifer Assessment Program (TAAP) effort funded by the federal government (Award No. G17AC00439). This bi-national effort came after the signing of the Transboundary Aquifer Assessment Act (US Public Law 109–448, TAA-Act) in 2006, the signing of the "Joint Report of the Principal Engineers Regarding the Joint Cooperative Process United States-Mexico for the Transboundary Aquifer Assessment Program" (TAAP Cooperative Framework) in 2009, and years of collaboration with the United States Geological Service (USGS), the International Boundary and Water Commission (IBWC), Universidad de Sonora (Unison), and the Mexican National Water Commission (CONAGUA). The objectives of both, the TAA-Act and the TAAP Cooperative framework, are to improve the knowledge base on the agreed-upon Aquifers of Focus, the Santa Cruz, San Pedro, Mesilla, and Hueco Bolson aquifers (Figure 1), and other transboundary aquifers if designated and approved by the two countries.

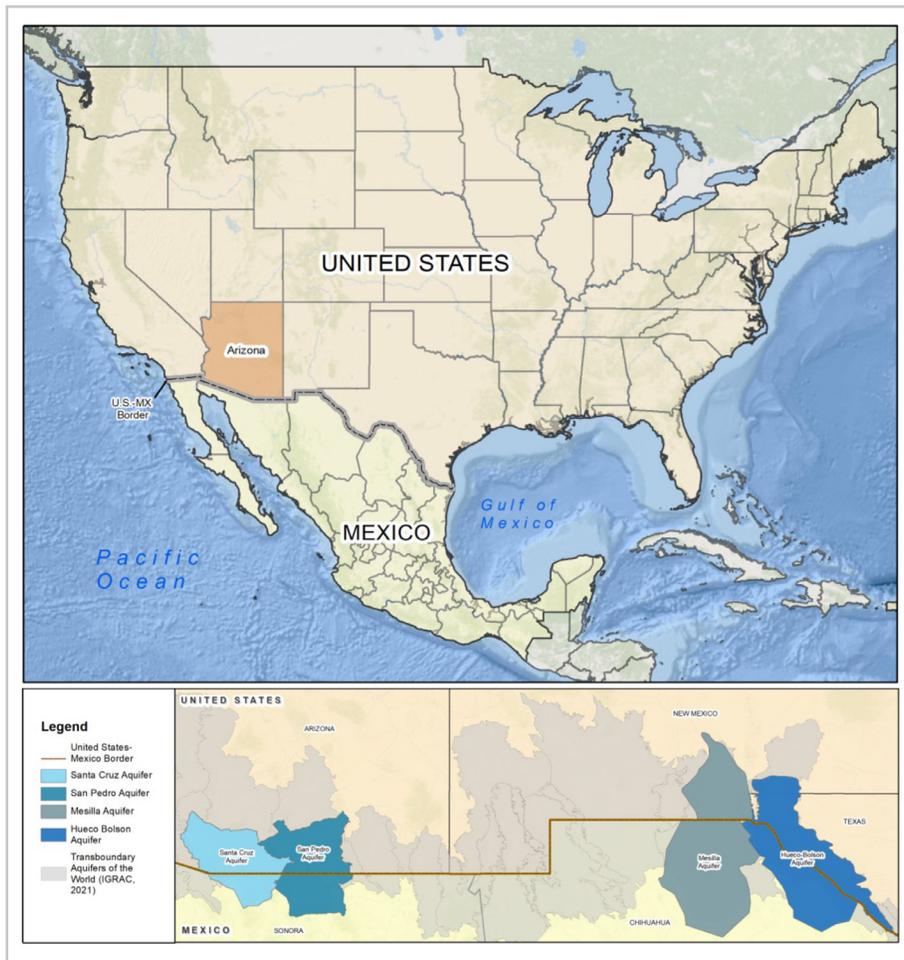


Figure 1. U.S.-Mexico Transboundary Aquifers of Focus. Source: WRRRC, 2022.

Problem and Research Objectives

The Transboundary San Pedro Aquifer and the Transboundary Santa Cruz Aquifer have been actively studied after the signing of the TAA-Act and the TAAP-Cooperative Framework. However, further investigation opportunities include assessing the impacts of climate uncertainties on groundwater resources, analyzing socio-economic dimensions and contrasting modes of governance in border communities, and identifying opportunities for transboundary groundwater collaboration. To address these topics, the WRRRC proposed the following objectives:

- Participate in completing the Binational Study of the Transboundary Santa Cruz Aquifer, facilitate the preparation of a bilingual summary brochure, and actively participate in the overall implementation of the TAAP with the USGS, IBWC, and other TAAP partners.
- Assess the impacts of climate variabilities, and effluent flows downstream of the Nogales International Wastewater Treatment Plant in the Santa Cruz Aquifer.
- Disseminate TAAP scientific findings through regional, binational, and international stakeholder forums and conferences, journal publications, web postings, and other materials.
- Conduct reconnaissance activities in other transboundary aquifers along the Arizona/Sonora border.
- Characterize alternative surface water flows and groundwater recharge scenarios in the Santa Cruz River Aquifer in Mexico.
- Analyze the TAAP Cooperative Framework and water management approaches in the TAAP aquifers of focus and assess their applicability to other binational water efforts.
- Investigate how transnational policies and contrasting modes of governance affect drought management in the Santa Cruz and San Pedro transboundary aquifers.
- Determine the opportunities for cooperative and collaborative drought responses in the Santa Cruz and San Pedro aquifer regions.
- Collaborate in and support efforts to develop binational groundwater models for the San Pedro and Santa Cruz Aquifers.
- Collaborate with TAAP partners on efforts identified through the TAAP Cooperative Framework.

Methods:

This section presents a brief description of the methods that were followed to achieve the research objectives:

- Participate in completing the Binational Study of the Transboundary Santa Cruz Aquifer, facilitate the preparation of a bilingual summary brochure, and actively participate in the overall implementation of the TAAP with the USGS, the International Boundary and Water Commission, and other TAAP partners.
 - The WRRRC has provided the information requested to complete the Binational Study of the Transboundary Santa Cruz Aquifer, which included chapter editions, translations, and bilingual mapping. The WRRRC has organized and participated in binational and regional meetings, workshops, roundtables, and seminars, among other efforts to implement the TAAP. In addition, the WRRRC team has participated in biweekly meetings to collaborate with partners in the U.S. and Mexico on the finalization of the Transboundary Santa Cruz Aquifer Study.
- Assess the impacts of climate variabilities, and effluent flows downstream of the Nogales International Wastewater Treatment Plant in the Santa Cruz Aquifer.
 - The WRRRC developed a conceptual water budget model to analyze the long-term impact of the different components of potential recharge and water losses within the aquifer (Tapia-Villaseñor et al., 2020). A literature review was conducted, members of the U.S. and Mexican IBWC/CILA sections were interviewed, and a field visit to LAWTP was conducted to determine the water budget's elements. Experts were engaged via email, telephone, and face-to-face meetings.
- Disseminate TAAP scientific findings through regional, binational, and international stakeholder forums and conferences, journal publications, web postings, and other materials.
 - The WRRRC designed and conducted engagement activities with stakeholders, particularly those familiar with the San Pedro and Santa Cruz transboundary aquifers. Engagement activities included in-person and online seminars, conference presentations, media appearances, etc.
 - Scientific findings from the TAAP were also shared through 23 scientific article publications on transboundary groundwater resources and governance.
- Conduct reconnaissance work in other transboundary aquifers along the Arizona/Sonora border.
 - The WRRRC performed an extensive literature review through different searching engines to identify available transboundary groundwater studies, including hydrologic, climatologic, and surface and groundwater modeling data. A binational database with all the available information was produced through this effort.

- Analyze the TAAP Cooperative Framework and water management approaches in the TAAP priority aquifers and assess their applicability to other binational water efforts.
 - The elements of collaboration described in the TAAP Cooperative Framework were compared with the components of six transboundary groundwater collaboration agreements. Stakeholder interviews implemented during 2019 and 2020 served to identify whether TAAP lessons can be generalized to other aquifers along the U.S.-Mexico border and elsewhere.
- Characterize alternative scenarios for surface water flows and groundwater recharge in the Santa Cruz River Aquifer in Mexico.
 - The WRRC assessed groundwater withdrawal sustainability in the Mexican portion of the Transboundary Santa Cruz River Aquifer through a water balance modeling effort (Tapia-Villaseñor et al., 2022).
- Investigate how transnational policies and contrasting modes of governance affect drought management in the Santa Cruz and San Pedro transboundary aquifers.
 - The WRRC employed process tracing and interviews and analyzed elements identified as enabling factors for good groundwater governance, as synthesized from the literature. Data were gathered by conducting interviews with government officials and scientists on both sides of the border, participant observation, and compiling secondary sources from binational technical meetings, conferences, and stakeholder meetings.
- Determine what opportunities exist for cooperative or collaborative drought responses in the Santa Cruz and San Pedro aquifer regions and examine the adaptiveness of drought management capacity of water governance networks in these regions.
 - The WRRC organized and conducted meetings with U.S. and Mexican partners to identify principles and practices to reach groundwater agreements between both countries.
- Collaborate in and support efforts to develop binational groundwater models for the San Pedro and Santa Cruz Aquifers.
 - Grounded on the information gathered for the San Pedro and the Santa Cruz reports, the WRRC has engaged in communication with USGS, CILA, and Unison to discuss the future development of binational groundwater models for the Transboundary San Pedro and Santa Cruz Aquifers.
- Conduct a socio-economic characterization of selected US-Mexico border communities.
 - Information from governmental websites was gathered, organized, and analyzed to characterize the socio-economic structure of five border counties and municipalities in Arizona and Sonora (United States Census Bureau, 2022; Secretaría de Economía, 2022).

Results:

The main results from the research mentioned above activities are:

- Five of the eight chapters of the Binational Study of the Transboundary Santa Cruz Aquifer have concluded the peer-review process, and five have been translated into Spanish.
- Water balance modeling results for the transboundary Santa Cruz Aquifer suggest that although significant uncertainty is associated with the projected future precipitation, many possible outcomes carry substantial risks, as most projections suggest a dryer future (Shamir et al., 2021).
- The WRRC participated in over 50 binational technical working meetings with the IBWC, USGS, Unison, and CONAGUA; published 23 articles and reports; and presented at 50 regional, national, and international conferences.
- A total of 106 transboundary studies were identified and included in a transboundary database, 32 studies focused on the United States-Mexico border region, 18 in the transboundary Santa Cruz aquifer, 12 in the transboundary San Pedro Aquifer, 12 in Ambos Nogales, and 8 in the Arizona Border region. Studies from the Valle de San Luis, the Yuma Area, the Altar Desert, and the Douglas-Agua Prieta were scarce.
- For the San Pedro River Basin in Sonora, monthly averages of daily minimum temperature have barely changed over the last available 40 years (1976-2015), while monthly averages of daily maximum temperature show pronounced increases during the winter months, except for December (Morales, 2022).

- The analysis of the TAAP Cooperative Framework as a model for transborder groundwater collaboration revealed five common features of collaboration between transboundary groundwater agreements: 1) the presence of data exchange provision; 2) the concurrence for binational aquifer assessments; 3) the establishment of technical advisory committees; 4) the presence of technical groups, and 5) respect for the legal framework and jurisdictional requirements of each country (Tapia and Megdal, 2021).
- The assessment of groundwater withdrawal sustainability in the Mexican portion of the Transboundary Santa Cruz aquifer indicated that the amount of withdrawal that maintains sustainable conditions for 1954-2020 is 23.3 MCM/year. However, sustainable annual groundwater withdrawal obtained using moving averages of 20 years revealed variations ranging from 36.4 MCM/year to 8 MCM/year (Tapia et al., 2022).
- The TAAP Sonora–Arizona assessment case study (Tapia-Villaseñor and Megdal, 2021) was identified as an example of transboundary groundwater governance since the production of scientific information evolves in reciprocal synchronicity, where cooperation can enhance science production and advance policy advancements (Tapia-Villaseñor and Megdal, 2021).
- The population growth patterns between border municipalities and counties in the US and Mexico were identified. In general, Mexican border municipalities are growing faster than the US counties.

Principal findings and significance:

According to the project results, assessing transboundary aquifers is essential for developing groundwater management strategies and promoting the sustainable use of groundwater resources. These assessment activities can lead to advances in governance, yet, transboundary groundwater governance can also enhance science production due to its bidirectional relationship with science (Petersen-Perlman et al., 2022). As a result, transboundary aquifer assessment, reconnaissance activities, and stakeholder engagement efforts in transboundary settings are necessary to promote collaboration on groundwater resources between the United States and Mexico.

Groundwater and surface water availability are key factors determining the community's economic development. Climate uncertainties and groundwater demands also condition these factors. The development of water balance modeling tools to characterize the effects of system changes, particularly those related to climate uncertainties and changes in groundwater demand, can enhance the current understanding of aquifer recharge and eventually guide decision-making processes. During these five years, groundwater modeling efforts developed by the WRRRC proved to help drive and improve decision-making processes in transboundary settings (Tapia-Villaseñor et al., 2020 and Tapia-Villaseñor et al., 2022). It was also noted that due to future climate uncertainties, adaptive water management, and planning, it is necessary to promote sustainable conditions and long-term groundwater reliability in the Transboundary Santa Cruz Aquifer (Tapia- Villaseñor et al., 2022).

The importance of social science in applied hydrologic research was also evaluated during these five years (Callegary et al., 2018). Mutual trust and capacity building are long-term processes that, in the case of the Arizona-Sonora TAAP effort, were fed by the will of the binational team members and the partnership between academic institutions and international and federal agencies. The TAAP Cooperative Framework fostered this partnership with the International Boundary and Water Commission, serving as the coordinating binational entity for the program. The TAAP elements of collaboration are consistent with existing binational groundwater agreements, and the positive outcomes of the program have proven to be helpful as a model for transborder groundwater collaboration (Tapia and Megdal, 2021). Regarding the socio-economic structure in border US counties and Mexican municipalities, population growth and industries differ (United States Census Bureau, 2022; Secretaria de Economía, 2022). For instance, in Douglas, AZ, the population has been decreasing, while in Cananea, Sonora is increasing. Concerning the industries, health care, social assistance, and retail trade are the most relevant on the US side, while manufacturing, mining, and agriculture are the most significant on the Mexican side (United States Census Bureau, 2022; Secretaría de Economía, 2022).

Lastly, while this technical report presents the objectives, results, and principal findings of the WRRC effort on the TAAP for the 2017-2022 period, there are more than 13 years of binational groundwater collaboration among the AZ-Son TAAP members. In addition to the contributors to this report, Jacob D. Petersen Perlman, David Morales, and Paul La Farga from the WRRC should be mentioned as participants in the project. Researchers from the Universidad de Sonora, USGS researchers of the Arizona Water Science Center, officials from the IBWC/CILA, Mexican officials from the National Water Commission (CONAGUA), and many other researchers and government officials have contributed with their time, revisions, and information to this valuable effort. We are thankful for the relationship built, and we hope the collaboration will continue for many more years.

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Student support

Four students from the University of Arizona have been supported by the "Transboundary Aquifer Assessment Program (TAAP) - Arizona Water Resources Research Center Effort." Table 1 shows the name, department, title, degree, and graduation date of these students.

Table 1. Student Support				
Name	Department	Title	Degree	Grad. date
Elia M. Tapia	Arid Lands Resource Sciences	Doctor of Philosophy- Arid Lands Resource Science	Ph.D.	2020
Mary-Belle Cruz Ayala	Arid Lands Resource Sciences	Doctor of Arid Lands Resource Sciences	Ph.D.	2021
David Morales	Hydrology and Water Resources	Master of Science in Hydrology and Water Resources	M.S.	In progress
Paul Daniel La Farga	College of Architecture Planning & Landscape Architecture.	Master of Science in Urban Planning	M.S.	2021

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