



# Five-Year Interim Report of the United States – Mexico Transboundary Aquifer Assessment Program: 2007 – 2012

By William M. Alley, editor

Open-File Report 2013–1059

U.S. Department of the Interior  
U.S. Geological Survey

U.S. Department of the Interior  
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U.S. Geological Survey  
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2013

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Suggested citation:

Alley, W.M., ed., 2013, Five-year interim report of the United States – Mexico Transboundary Aquifer Assessment Program: 2007 – 2012: U.S. Geological Survey Open-File Report 2013–1059, 31 p.

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# Five-Year Interim Report of the United States – Mexico Transboundary Aquifer Assessment Program: 2007 – 2012

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## Executive Summary

Transboundary aquifers are an essential, and in many cases, singular source of water for United States – Mexico border communities, particularly in arid regions. Declining water levels, deteriorating water quality, and increasing use of groundwater resources by municipal, industrial, and agricultural water users on both sides of the international border have raised concerns about the long-term availability of this supply. Water quantity and quality are determining and limiting factors that ultimately control agriculture, future economic development, population growth, human health, and ecological conditions along the border. Knowledge about the extent, depletion rates, and quality of transboundary aquifers, however, is limited and, in some areas, completely absent.

The U.S. – Mexico Transboundary Aquifer Assessment Act (Public Law 109-448), referred to in this report as “the Act,” was signed into law by the President of the United States on December 22, 2006, to conduct binational scientific research to systematically assess priority transboundary aquifers and to address water information needs of border communities. The Act authorizes the Secretary of the Interior, through the U.S. Geological Survey (USGS), to collaborate with the States of Arizona, New Mexico, and Texas through their Water Resources Research Institutes (WRRIs) and with the International Boundary and Water Commission (IBWC), stakeholders, and Mexican counterparts to provide new information and a scientific foundation for State and local officials to address pressing water-resource challenges along the U.S. – Mexico border. Objectives of the U.S. – Mexico Transboundary Aquifer Assessment Program are to

- Develop binational information and shared databases on groundwater quantity and quality;
- Assess the extent, availability, and movement of water in transboundary aquifers and the interaction with surface water;
- Develop and improve groundwater-flow information for binational aquifers to facilitate water-resource assessment and planning;
- Analyze trends in groundwater quality, including salinity, nutrients, toxins, and pathogens;

- Assess temporal and spatial variability of subsidence related to aquifer depletion;
- Apply new data, models, and information to evaluate strategies to protect water quality and enhance supplies; and
- Provide useful information to decision makers, including assessments of groundwater management institutions and policies.

The Act states that not later than 5 years after the date of its enactment, and on completion of the program in fiscal year (FY) 2016, the Secretary of the Department of the Interior “shall submit to the appropriate water resource agency in the Participating States, an interim and final report.” This interim report describes the U.S. – Mexico Transboundary Aquifer Assessment Program (TAAP) activities and accomplishments to date.

Activities in support of the Act are carried out through the TAAP, a unique Federal agency – university – binational partnership. The program is authorized for a total of \$50 million for FY 2007 through 2016. Appropriations were \$500,000 for FY 2008 and 2009, and \$1 million for FY 2010. No funding was provided in FY 2011 and 2012. The USGS received 50 percent of all funds, and the three State WWRIs (Arizona, New Mexico, and Texas) shared the other 50 percent equally. Part of the WRII funding was matched with contributions from Mexico to support the binational research.

The Act specified the Hueco Bolson and Mesilla Basin as priority aquifers for New Mexico and Texas, and allowed for additional aquifers to be identified for these two States. Based on the increasing use of the aquifer, lack of information, and stakeholder input, activities have focused on the Mesilla Basin in the United States and its counterpart in Mexico—the Conejos-Médanos aquifer system. For Arizona, the Act limits study to the Santa Cruz and San Pedro aquifers in south-central Arizona and northern Sonora. Accomplishments of the program to date include

- Binational research plans were developed in collaboration with State and local stakeholders to ensure the program meets user needs.
- A U.S. – Mexico Joint Cooperative Agreement was developed to allow the sharing of transboundary aquifer data, models, and information and to coordinate and collaborate on binational scientific investigations. The agreement was signed by the U.S. and Mexican Sections of the IBWC. Prior to this agreement, there had been limited and unofficial sharing of information or coordination of investigations.
- More than 24 binational meetings were held to develop the agreement, exchange information, and jointly plan and coordinate aquifer investigations.
- Existing U.S. hydrologic and geologic data, well records, associated databases, and geographic information systems were assembled, compiled, and analyzed to help determine information needs.
- Activities for the Santa Cruz and San Pedro aquifers focused on improved hydrogeologic characterization linked to institutional and sociodemographic assessments. Building on existing studies of both aquifers, the Arizona /Sonora team compiled and integrated water-level and geologic log data and undertook geophysical surveys to improve the definition of the hydrostratigraphic units, determine

hydraulic parameters, analyze groundwater levels, and provide an initial characterization of aquifer hydrogeochemistry.

- The Mexican National Water Commission (CONAGUA), the Mexican Geological Service, and the University of Sonora, with funding support from the Mexican Federal Government, conducted parallel collaborative research for the aquifers in Arizona/Sonora through the TAAP to develop and provide compatible aquifer information.
- Activities for the Mesilla Basin focused on (1) updating the geohydrologic framework for the U.S. and Mexican parts of the basin; (2) advances in the development of an integrated hydrologic model to account for agricultural water-budget components, the largest water-use category in the basin; (3) evaluation of surface-water and groundwater interaction and interbasin exchange with neighboring aquifers; and (4) water-quality sampling for isotopic and environmental trace constituents in selected wells to assist with a water-quality and age-dating analysis.
- A regional hydrogeologic reconnaissance study of the Conejos-Médanos aquifer system, with new aquifer and geohydrologic information, was completed by the Mexican Geological Service.

## Introduction

The U.S. – Mexico Transboundary Aquifer Assessment Act (Public Law 109-448), referred to in this report as “the Act,” was signed into law by the President of the United States on December 22, 2006. The Act authorizes the Secretary of the Interior, through the U.S. Geological Survey (USGS), to collaborate with the States of Arizona, New Mexico, and Texas through their Water Resources Research Institutes (WRRIs) to conduct hydrogeologic characterization, mapping, and modeling of priority transboundary aquifers. The Act specified the Hueco Bolson and Mesilla Basin as priority aquifers for New Mexico and Texas and allowed for additional aquifers to be identified for these two States. Activities to date have focused on the Mesilla Basin in the United States and its equivalent in Mexico—the Conejos-Médanos aquifer system. For Arizona, the Act limits the selection of priority aquifers to the Santa Cruz and San Pedro aquifers.

The Act states that not later than 5 years after the date of its enactment, and on completion of the program in fiscal year 2016, the Secretary of the Interior “shall submit to the appropriate water resource agency in the Participating States, an interim and final report, respectively, that describes (1) any activities carried out under the program; (2) any conclusions of the Secretary relating to the status of priority transboundary aquifers; and (3) the level of participation in the program of entities in Mexico.” This interim report addresses items (1) and (3). The Transboundary Aquifer Assessment Program (TAAP) is well positioned to describe the status of priority transboundary aquifers as future funding enables the program to carry out planned activities.

Funding for the TAAP was split equally among the States of Arizona, New Mexico, and Texas. Furthermore, each State’s funds are split between the USGS and the State’s WRRIs, located at one of the State’s universities as stipulated by the Water Resources Research Act. The WRRIs have active, ongoing partnerships with the USGS, State agencies, and Mexico. This mechanism for TAAP implementation is a unique model of Federal agency – university – binational partnership for program implementation.

Six binational meetings were held with the Commissioners and Principal Engineers of the U.S. and Mexican Sections of the International Boundary and Water Commission (IBWC), Mexican National

Water Commission, USGS, and the three WRRIs to negotiate and finalize an agreement for scientific exchange, coordination, and collaboration between U.S. and Mexican agencies, organizations, and scientists regarding the TAAP. An agreement was signed by IBWC and CILA (Note: U.S. and Mexican Sections of IBWC are identified as IBWC and CILA (Comisión Internacional de Límites y Aguas), respectively) on August 19, 2009, in a ceremony on the International Bridge between El Paso and Juarez. This agreement allows USGS and WRRIs to coordinate the activities of the binational technical group participating in the project through the IBWC/CILA.

Activities of the Arizona/Sonora and Mesilla Basin/Conejos-Médanos sections of the TAAP are described in this interim report. The work is the joint effort of many individuals. The authors appreciate the efforts of three key individuals who unfortunately passed away during the course of the program: Carlos Marin, Commissioner, International Boundary and Water Commission; Arturo Herrera, Commissioner, Comisión Internacional de Límites y Aguas; and Bobby Creel, New Mexico Water Resources Research Institute.

# Arizona/Sonora Section of the Transboundary Aquifer Assessment Program

By James Callegary,<sup>1</sup> Sharon B. Megdal,<sup>2</sup> Christopher A. Scott,<sup>3,4</sup> and Prescott L. Vandervoet<sup>4</sup>

## Program Overview

The Upper Santa Cruz and the Upper San Pedro Rivers are binational watercourses that cross the international border between the State of Arizona and Sonora, Mexico. The basins that support these rivers are adjacent, with the San Pedro lying to the east of the Santa Cruz. Both the Santa Cruz and San Pedro Rivers flow north to join with the Gila River, which in turn forms part of the lower Colorado River Basin (Figure 1). Because of the semiarid climate with low rainfall and high evaporation, both the Santa Cruz and San Pedro Rivers are ephemeral in certain reaches. Human populations within each basin have depended on these rivers for thousands of years (Logan, 2002; Ferguson and Colwell-Chanthaphonh, 2006).

The San Pedro River Basin is one of the most important flyways for migrating birds in North America with more than 400 species identified. In 2004, Congress recognized the importance of the river at the continental scale in passing Section 321 of Public Law 108-136, which requires the restoration and maintenance of sustainable yield in the regional aquifer with the goal of maintaining flow in the San Pedro River (Upper San Pedro Partnership, 2004).

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Figure 1. Locations of Upper Santa Cruz and Upper San Pedro River Basins (adapted from Megdal and Scott, 2011).

Groundwater pumping, primarily for agricultural and urban development, increased through the 20<sup>th</sup> century in both basins. From 1990 to 2004, groundwater levels declined more than 30 feet in some areas (Arizona Department of Water Resources, 2011a and b). Mining activities, both historic and current, are substantial sources of water use and contamination in both basins. The Cananea mine, located in the Sonoran part of the San Pedro Basin, extracts ore from one of the largest copper deposits in the world. Similarly, a proposed copper mine called El Pilar is located in the Sonoran part of the Santa Cruz Basin, within a mile of the river (M3 Engineering & Technology Corporation, 2009).

The largest urban centers in the two basins are Sierra Vista and Nogales in Arizona and Cananea and Nogales in Sonora. The twin border cities of Nogales, Arizona, and Nogales, Sonora, have a combined population of more than 270,000; the population of Sierra Vista is about 60,000 and Cananea is about 33,000 (Arizona Department of Commerce, 2010; and Instituto Nacional de Estadística y Geografía, 2010). Currently (2012) the city of Cananea discharges raw sewage into the Upper San Pedro River. Plans are in place to build a treatment plant, but delays have plagued the project. Most sewage for the twin Nogales cities is treated in the United States. Flows in the downstream part of the Santa Cruz River are maintained by the effluent discharged from the plant. River seepage of wastewater effluent is an important source of recharge to the aquifer and helps to maintain groundwater levels (Nelson, 2007). Mexico is in the process of building a treatment plant that will treat and discharge about 50 percent of the wastewater into a river basin south of Nogales, Sonora. This treatment plant will almost certainly have substantial effects on flow in the river, the riparian ecosystem, and groundwater levels in the Santa Cruz aquifer.

Both the Mexican section of the San Pedro River Basin and the Sierra Vista subwatershed (the uppermost section of the river basin in the United States) are considered to be in groundwater deficit, because more water is removed by pumping from the regional aquifers than is recharged annually (Upper San Pedro Partnership, 2004; Comisión Nacional del Agua, 2009). Parts of the Upper Santa Cruz Basin have been designated as an Active Management Area (AMA) by the Arizona Department of Water Resources (ADWR). This designation represents the strictest level of water management possible under Arizona State law. According to ADWR, “the management goal of the Santa Cruz AMA is to maintain a safe-yield condition...and to prevent local water tables from experiencing long term declines” (Arizona Department of Water Resources, 2012). “Safe yield” is achieved when no more water is withdrawn annually from an aquifer than is replenished annually. In the Mexican section of the basin, less groundwater is withdrawn for human use than is naturally recharged (Comisión Nacional del Agua, 2009). The USGS Arizona Water Science Center and the University of Arizona Water Resources Research Center, both located in Tucson, were the designated entities to assume responsibility for carrying out the assessment of the Upper Santa Cruz and Upper San Pedro River Basins.

## Partners

The Arizona/Sonora team of the TAAP has worked continually to engage pertinent stakeholders as partners for designing and carrying out assessment activities in the shared aquifer regions. The goal of the Arizona/Sonora team has been to engage all stakeholders within the region under investigation, regardless of national setting/orIGIN. Partners are listed in Table 1.

Initial meetings among the U.S. collaborators began in early September 2007, with Mexican counterparts joining shortly thereafter, to address concerns related to groundwater assessment. This effort has been ongoing and primarily focused on engagement of stakeholders within each basin.

Table 1. Key partners in the Arizona/Sonora Transboundary Aquifer Assessment Program (TAAP).

[CILA, Comisión Internacional de Limites y Aguas; UNESCO, United Nations Educational, Scientific and Cultural Organization]

Binational	Federal Government	State government	Local/municipal government
International Boundary and Water Commission (IBWC and CILA)	Mexican National Water Commission (CONAGUA)	Arizona Department of Water Resources (ADWR)	City of Nogales, Sonora
Water Committee of the Arizona-Sonora Commission	U.S. Bureau of Reclamation	Arizona Department of Environmental Quality (ADEQ) Sonoran State Water Commission (CEA)	City of Nogales, Arizona City of Sierra Vista, Arizona
Nongovernmental	International	Academic	
Friends of the Santa Cruz River (FOSCR) Upper San Pedro Partnership (USPP)	Internationally Shared Aquifer Resources Management (ISARM) Program, UNESCO	University of Sonora (UNISON) College of Sonora (COLSON) Sonoran Technical Institute (ITSON)	

On November 3–4, 2009, a workshop was held in Tucson, Arizona, with the goal of defining and reviewing work plans and programmatic priorities. A diverse set of stakeholders representing local, national, and international levels of management and assessment agencies and organizations attended, including a representative from the United Nations Educational, Scientific and Cultural Organization (UNESCO) Internationally Shared Aquifer Resources Management (ISARM) Program. The first day of the event was dedicated to presentations related to the Santa Cruz and San Pedro shared aquifers, Federal-level groundwater management and assessment issues from the United States and Mexico, as well as developments in shared aquifer resource management as defined by UNESCO. The second day of the workshop focused on breakout group discussions with the goal of acquiring workshop participant feedback on the Arizona/Sonora work plan.

Arizona/Sonora team members have maintained close communication with counterparts in New Mexico and Texas regarding TAAP activities carried out in those States. Concerted efforts have been made to engage Mexican, and particularly Sonoran, counterparts through participation at a variety of professional-level conferences. In addition to attendance at the bi-State Arizona-Mexico Commission meetings, held semiannually in either Arizona or Sonora, Arizona/Sonora team members participated in the 2009 Mexican Geohydrological Congress, hosted by the Sonoran section of the Mexican Geohydrological Association (AGM) in San Carlos, Sonora. Similarly, the Arizona/Sonora team organized and moderated two sessions in the 2010 Arizona Hydrological Society annual meeting related to transboundary groundwater with presentations by Arizonan and Sonoran team members.

## Binational Activities

The role of the IBWC (both U.S. and Mexican Sections) was solidified by the Joint Report of the Principal Engineers Regarding the Joint Cooperative Process United States – Mexico for the Transboundary Aquifer Assessment Program, signed on August 19, 2009.

Following the signing of the Joint Report, a series of meetings between U.S. and Mexican stakeholders was held at which the goals and initial extent of hydrological studies on a regional basis were outlined. Texas and New Mexico were to collaborate with Chihuahua to assess the Mesilla Basin/Conejos-Médanos aquifer system, and Arizona was to engage Sonora in assessing the Upper Santa Cruz and San Pedro River Basins. An agreement on first stage funding for assessment of the basins in Sonora, Mexico, was reached during a meeting in Rio Rico, Arizona, on May 18, 2010. The Mexican National Water Commission (CONAGUA) then set forth to engage researchers and faculty at the University of Sonora (UNISON), Campus Hermosillo, and to develop work plans for the Santa Cruz and San Pedro aquifers in Sonora. Hydrological studies to be carried out in the Santa Cruz and San Pedro River Basin aquifers in Sonora, Mexico, are outlined in the work plans submitted by the UNISON and International Boundary and Water Commission – Mexican Section (CILA) for each location. Arizona/Sonora team members at the USGS and the University of Arizona (UA) Water Resources Research Center reviewed the work plan for each aquifer; each work plan is included as a technical annex within the Memorandum of Understanding (MOU) between the UA and International Boundary and Water Commission – U.S. Section (IBWC). Work plans for the Santa Cruz and San Pedro aquifers in Sonora were reviewed during late summer 2010. Upon finalization, IBWC and the Office of Research and Contract Analysis at the UA began drafting an MOU to outline funding transfer and project oversight protocol, which ties the transfer of funds to UA approval of UNISON's progress on work plan goals. The MOU between the UA and IBWC was signed by IBWC contracting personnel on January 6, 2011, and by UA contracting representatives on January 10, 2011.

Counterparts at UNISON began preliminary background data gathering and analysis prior to final signing by the UA and IBWC. As required in the legislation authorizing TAAP, funding to Mexico was to be matched dollar for dollar by the Mexican Government through CONAGUA. Funding for hydrological studies in the binational basins for TAAP-related work was to begin at \$80,000 per basin (\$160,000 total, given that two Arizona/Sonora basins were being evaluated). Since the UA-IBWC agreement was signed, however, the Mexican Government has assumed financial responsibility for the entire \$160,000 (equivalent to approximately 2 million pesos). The U.S. contribution of \$80,000 was reprogrammed to develop reports on both aquifers to be written by U.S. and Mexican teams, as detailed in binational planning meetings held in June, August, and December 2011.

As defined by the MOUs between IBWC-UA and CILA-UNISON, the IBWC will serve as the official binational repository for all data collected within the Mexican sections of the Santa Cruz and San Pedro Basins. Following a review period, the data will be made available to the public.

The work plan definition for assessment activities in Mexico identified the following items as priority for initial studies:

- a. Compilation, integration, summary, and critical analysis of prior studies of the aquifer.
- a. Description of the physical geography and geological, geomorphological, climatological, and hydrological analyses.
- c. Compilation and integration of information related to wells, such as depth, water levels, and geologic logs.

- d. Definition of the hydrostratigraphic units, determination of the aquifer properties, and analysis of groundwater-level behavior.
- e. Geophysical surveys.
- f. Initial characterization of the hydrogeochemistry of the aquifer.
- g. Development of a conceptual hydrogeologic model.

Initial technical meetings between researchers from both Arizona and Sonora have begun to align research priorities and data collection to facilitate cross-border comparisons. Continued data collection for hydrogeologic modeling is a priority, especially in the Upper Santa Cruz River Basin near the border cities of Nogales, Arizona, and Nogales, Sonora. Aquifer properties of the Nogales Formation are being reevaluated for groundwater movement and storage on the basis of preliminary geologic mapping results.

Work plans for assessment activities in Arizona originating from the USGS (Part 1) and the Water Resources Research Center at the UA (Part 2) are summarized below:

**Part 1. Hydrological Modeling Framework** (USGS to take the lead on all activities except for item f.): Design the protocol for data collection and synthesis for the creation of a binational coupled surface-water and groundwater-flow model.

- a. Geophysical studies requiring a combination of airborne and surface- and ground-based surveys to identify the three-dimensional distribution of hydrogeologically relevant structure and properties in each basin.
- b. Surface- and groundwater-flow measurements and analyses: It is imperative to maintain current USGS streamflow gaging stations along the rivers and the ADWR groundwater-level monitoring network. The re-introduction of new or historical streamflow gages also would be beneficial. Both CILA and USGS have identified such locations along the Nogales Wash and Santa Cruz River in Sonora.
- c. Coupled groundwater and surface-water flow model for each binational basin: Currently only separate groundwater and surface-water models exist and most stop at the international border. The model resolution typically is different on each side of the border, partly because of asymmetric data collection, which can lead to conflicting or misleading results.
- d. Assessment of the effect of recently installed flood-detention basins on surface-water quality and recharge in the Nogales Wash subbasin.
- e. Increased precipitation monitoring networks in Ambos Nogales watershed: These networks serve the dual purpose of being used as required input for groundwater modeling and helping with flood warning.
- f. Binational coordination for modeling: Engage stakeholders in Arizona and Sonora, as well as Federal agencies responsible for each region, in the design of and data collection for binational hydrological models.

**Part 2. Vulnerability Assessment:** With a focus on urban areas, evolving vulnerability in Cananea, Sierra Vista, and Ambos Nogales is an important issue for transboundary groundwater due to dependence on the resource.

- a. Data collection of land use, zoning, economic and population growth, infrastructure, etc.: Develop profiles and identify corresponding pressures on groundwater resources originating from urban and rural areas using geographic information systems (GIS) and remote sensing tools, census data, and economic indicators.
- b. Urban growth characterization and effect on watershed land use and hydrology: The effect of land-use change, primarily due to urban growth, affects basin hydrology. Increased runoff and sediment in surface flow and decreased infiltration are primary results of urban growth.
- c. Binational water balances and supply/demand analysis: Urban and rural development rates and climate change have important effects on groundwater usage. Evolving usage for agriculture, industrial, and residential purposes has a direct impact on groundwater pumping within each basin.
- d. Groundwater vulnerability to contamination: Integrate land use, climate, and hydrogeologic (soil type, depth to groundwater, and so forth) data to evaluate the potential for groundwater contamination in the Santa Cruz and San Pedro aquifer systems.
- e. Water-quality assessments: These include industrial and other contaminants originating in urban areas and contaminants associated with mining operations from Cananea and wastewater treatment from Ambos Nogales.
- f. Assessment of institutional asymmetries and binational cooperation frameworks: Because of differing groundwater management strategies between the United States and Mexico, it is imperative to understand how cross-border cooperation can best function.
- g. Improved links with international best practices (via ISARM): Continue engagement with global and regional (Americas) ISARM initiatives. Participate as a case study in order to provide other ISARM participants with information on the TAAP activities as well as learn from other shared resource scenarios.

## Accomplishments

- Organization and management of workshop, “*Developing a Workplan for the Santa Cruz and San Pedro Aquifers*” November 3–4, 2009, Tucson, Arizona.
- Development and signing of an MOU with IBWC for transfer of funding and data related to hydrological assessment of the Santa Cruz and San Pedro aquifers in Sonora, Mexico.
- Presentations and materials for publication (see Project Publications list below).
- Initial work on hydrogeologic framework model for Upper Santa Cruz Basin:
  - Development of binational wells database with geologic log information.
  - Initial modeling of geophysical data for determination of structure and distribution of hydrogeologic units.
  - Consultation with USGS geologic mapping project to reevaluate and remap geologic units (Nogales Formation). Initial results indicate the need to reevaluate estimated hydraulic properties of the deepest sedimentary layer in the aquifer.

- Collaboration with the USGS – Mexico Border Environmental Health Initiative (<http://borderhealth.cr.usgs.gov/projectindex.html>) to support studies of groundwater contamination, including the following:
  - Groundwater vulnerability to contamination: USGS and University of Arizona scientists and students are using the U.S. Environmental Protection Agency DRASTIC model, which takes into consideration a range of variables related to infiltration and recharge potential. Contaminants originating from households, mining, agriculture, and industry, including the Nogales International Wastewater Treatment Plant, may be released into the Santa Cruz and San Pedro Basins where migration into groundwater used for potable supply may occur.
  - Development of a binational geochemical database with information on the location and concentration of contaminants and other chemical constituents in groundwater, surface water, soils, and bed sediments.
  - Groundwater contaminant transport modeling (using USGS MODFLOW/MT3D) of the portion of the aquifer downstream from the Nogales International Wastewater Treatment Plant. The model is being used to study the movement of contaminants, such as nitrate, arsenic, and cadmium, from surface-water sources to wells.
- With combined funding from the U.S. Environmental Protection Agency Border 2012 Program, the Arizona Department of Water Resources, and TAAP, a new stream gage was installed and operated in Nogales Wash the main tributary to the Santa Cruz River flowing out of the twin cities of Nogales. Surface drainage from this urban area may be contaminated, and this streamflow is a source of recharge to the aquifer system.
- Runoff-recharge measurement and modeling in the Sierra Vista subwatershed of the Upper San Pedro Basin, being carried out by USGS scientists, UA faculty, and a Ph.D. student:
  - Maintenance of a network of 11 gages in ephemeral stream channels in Sierra Vista and on the Fort Huachuca Military Installation. Data are to be used to update estimates of aquifer recharge.
  - Support of the development of a surface-water model using KINEROS (Woolhiser and others, 1990) that incorporates measured rainfall and streamflow information to estimate infiltration and recharge via soil and stream channels.
- Analysis of population growth and related groundwater demand in the Ambos Nogales region.
- Development and distribution of fact sheets in English and Spanish (see project Web page link below).
- Development of project Web page (with English and Spanish versions) hosted by The University of Arizona Water Resources Research Center (WRRC; <http://wrrc.arizona.edu/taap/>).
- Support for six graduate research assistants.
- Funding support for laboratory analysis of surface-water sampling by the local nongovernmental organization, Friends of the Santa Cruz River, maintaining a multiyear sampling record.
- Creation of two databases, in English (and partially in Spanish), compiling metadata related to previous studies and publications related to the binational Upper Santa Cruz and San Pedro River aquifers (available at <http://wrrc.arizona.edu/taap/>).



- Geophysical surveys: USGS scientists working with the UA Geophysics Field Methods course brought to light new information on the distribution of water-bearing and impermeable units within the section of the aquifer from which Nogales, Arizona, extracts about 50 percent of its water.

### Future Plans (subject to funding level)

- Continue analysis of population growth and related groundwater demand in the Ambos Nogales region.
- Compilation and analysis of data created by UNISON researchers.
- Hydrogeologic framework model – Upper Santa Cruz Basin.
  - Finish ground-based geophysical surveys.
  - Create three-dimensional model of subsurface.
- Binational monitoring.
  - Water quality: Santa Cruz River water is primarily treated effluent. Evaluate whether residual chemicals are contaminating wells. After assessing results of previous work, sample wells in Nogales, Rio Rico, and Tubac areas in which Arizona Department of Environmental Quality (ADEQ) found trichloroethylene and emerging contaminants.
  - Expand and maintain groundwater-level network in Santa Cruz and San Pedro Basins.
  - Maintain and add streamflow gages in both basins on both sides of the border.
  - Conduct annual seepage runs in San Pedro and Santa Cruz Basins.
  - Expand and maintain precipitation monitoring network: Install rain and snow gages in the Huachuca and Santa Rita Mountains.
- Data analysis.
  - Process, analyze, and publish water-quality data, including trends and exceedances of standards.
  - Process, analyze, and publish geophysical data.
  - Process ephemeral channel streamflow data from the Sierra Vista and Fort Huachuca gages.
  - Analyze groundwater-level and streamflow data.
- Modeling.
  - Create and calibrate binational groundwater/surface-water flow model for both basins in Mexico and the United States.
  - Perform contaminant transport modeling with new binational groundwater/surface-water flow models.

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# Mesilla Basin/Conejos-Médanos Section of the Transboundary Aquifer Assessment Program

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## Program Overview

The Mesilla Basin/Conejos-Médanos aquifer system constitutes one of the largest transboundary aquifer systems in the Rio Grande/Rio Bravo Basin region of the United States and Mexico (Figure 2). The part of the Mesilla Basin occupied by the entrenched valley of the Rio Grande, the Mesilla Valley, contributes to the largest rechargeable groundwater reservoir in the region and includes the western part of the El Paso (Texas) – Ciudad Juárez (Chihuahua) – Las Cruces (New Mexico) metropolitan area with a population of about 2.5 million (Creel and others, 2006). Because of stakeholders' needs for a better understanding of groundwater availability, use, and quality, as well as a long history of prior multiagency water-resource investigations, the binational Mesilla Basin/Conejos-Médanos aquifer system was selected for primary initial focus of the New Mexico – Texas assessment program.

Scientists from the New Mexico State University Water Resources Research Institute (NMWRI), the Texas Water Resources Institute (TWRI), part of Texas AgriLife Research, the Texas A&M University system, and the USGS Texas and New Mexico Water Science Centers conducted studies in collaboration with Federal and State agencies and organizations, as well as with Mexican partners. New and existing data were collected and evaluated in order to understand the availability and use of groundwater in the Mesilla Basin/Conejos-Médanos aquifer system, and evaluate strategies to protect water quality and enhance water supplies for sustainable economic development.

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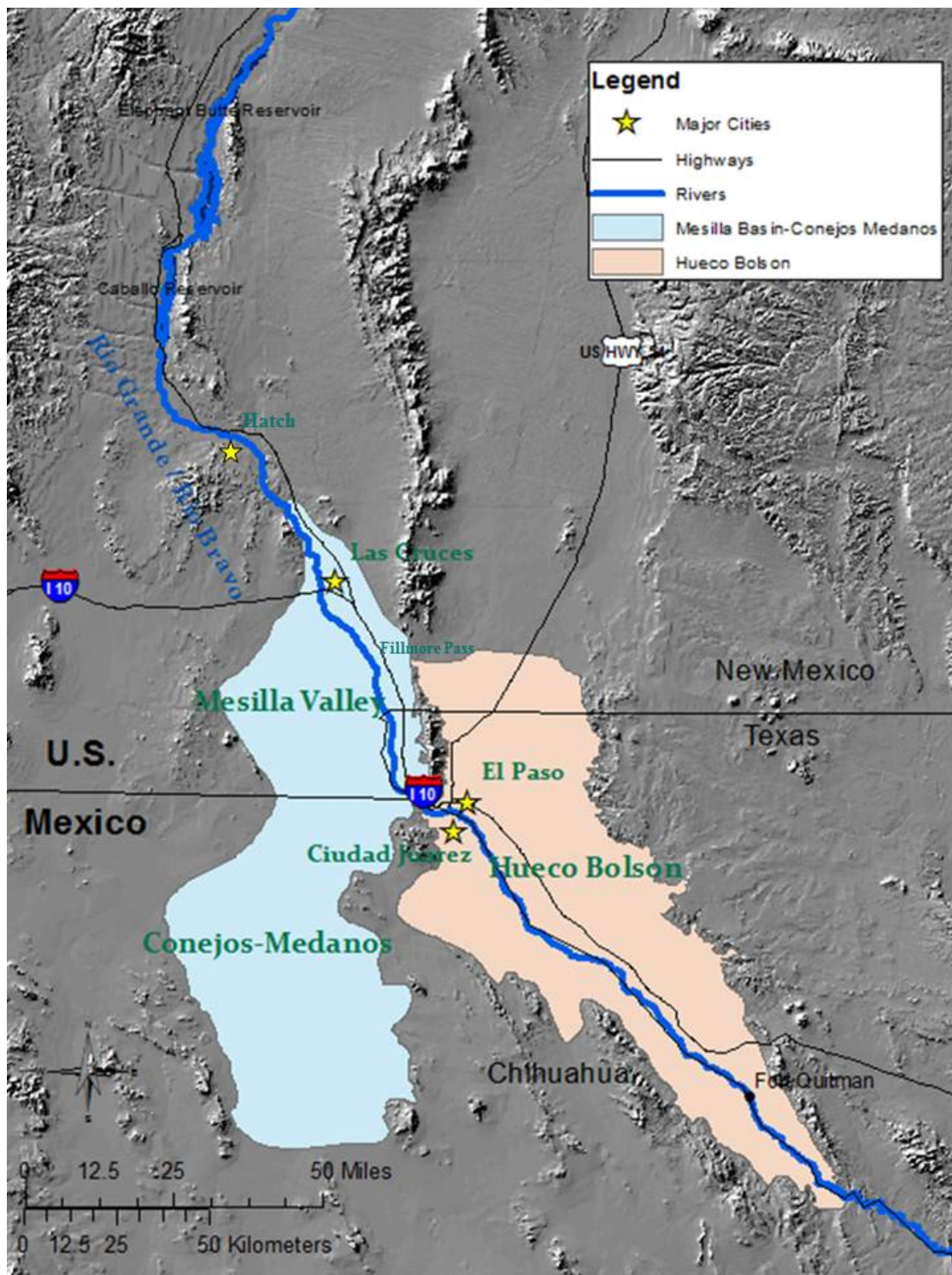


Figure 2. Locations of the Mesilla Basin/Conejos-Médanos and Hueco Bolson aquifer systems.

A joint binational, USGS and WRI work plan was developed for comprehensive assessment of the Mesilla Basin/Conejos-Médanos aquifer system and reviewed by stakeholders. The work plan identified the following general goals and strategies:

- a. Develop and implement an integrated scientific approach to assess priority transboundary aquifers, including evaluation of available data and publications, creation or enhancement of a GIS, and the implementation of field studies where additional data are needed;
- b. Consider the expansion or modification of existing agreements, as appropriate, between the USGS, the WRIs, the States, and authorities in Mexico to conduct joint scientific investigations, archive and share relevant data, and carry out other activities consistent with the program; and
- c. Produce scientific products that can be widely distributed and that provide the scientific information needed by water managers and natural resource agencies on both sides of the U.S. – Mexico border to effectively accomplish the missions of the managers and agencies.

Specific tasks to accomplish the general objectives also were described in the work plan. Each objective is described in the “Accomplishments” section of this report, along with an update of the status.

Research findings have been shared with stakeholders and presented at regional, national, and international conferences. Though funding for this program has not been provided since fiscal year (FY) 2010, a study plan for possible research has been developed by research team members to complete the assessment of the Mesilla Basin/Conejos-Médanos aquifer system and expand the research efforts into other aquifers, including the Hueco Bolson and Presidio Basin in west Texas and the Mimbres Basin in southwest New Mexico.



## Partners

In the first year (FY 2008) of this project, the project team of the New Mexico and Texas WRRIs and USGS Water Science Centers focused efforts on coordination with stakeholders and invited them to form a Steering Committee to identify priority issues that could be addressed. The invited stakeholders included Federal and State agencies, city/county governments, water utilities, irrigation districts, regional water planning groups, and others as listed in the table below.

Table 2. Key partners in the Mesilla Basin/Conejos-Médanos Transboundary Aquifer Assessment Program (TAAP).

<u>Federal agencies</u>	<u>New Mexico State agencies</u>
<ul style="list-style-type: none"> <li>- U.S. Bureau of Reclamation</li> <li>- U.S. Bureau of Land Management</li> <li>- U.S. Army Corps of Engineers</li> <li>- U.S. Environmental Protection Agency - Region 6</li> <li>- International Boundary &amp; Water Commission (U.S. Section)</li> <li>- Sandia National Laboratories</li> <li>- Los Alamos National Laboratory</li> </ul>	<ul style="list-style-type: none"> <li>- New Mexico Office of the State Engineer/New Mexico Interstate Stream Commission</li> <li>- New Mexico Environment Department</li> <li>- New Mexico State Land Office</li> <li>- New Mexico State Parks</li> <li>- New Mexico Department of Agriculture</li> <li>- New Mexico Institute of Mining and Technology</li> <li>- New Mexico Bureau of Geology and Mineral Resources</li> <li>- New Mexico Energy, Minerals and Natural Resources Department</li> <li>- Utton Transboundary Resources Center at University of New Mexico</li> <li>- Border Outreach &amp; Coordination Office at New Mexico State University</li> <li>- City of Las Cruces</li> <li>- Dona Ana County</li> <li>- Dona Ana Mutual Domestic Water Consumers Association</li> <li>- Town of Mesilla</li> <li>- Village of Hatch</li> <li>- Elephant Butte Irrigation District</li> </ul>
<u>Texas State agencies</u>	
<ul style="list-style-type: none"> <li>- Texas Water Development Board</li> <li>- Texas Commission on Environmental Quality</li> <li>- Texas State Soil &amp; Water Conservation Board</li> <li>- Texas Rio Grande Compact Commissioner</li> <li>- El Paso County Water Improvement District No.1</li> <li>- El Paso Water Utilities</li> <li>- University of Texas at El Paso</li> <li>- City of Anthony</li> <li>- Keystone Heritage Park</li> <li>- The Texas State Senate</li> <li>- El Paso County Commissioners</li> </ul>	
<u>Mexican agencies</u>	
<ul style="list-style-type: none"> <li>- Mexican Geological Service (SGM)</li> <li>- International Boundary &amp; Water Commission (Mexico Section)</li> <li>- National Water Commission (CONAGUA)</li> <li>- The State of Chihuahua Central Water and Sanitation Board (JCAS)</li> <li>- Ciudad Juárez Municipal Water and Sanitation Board (JMAS)</li> </ul>	
	<u>Regional organizations</u>
	<ul style="list-style-type: none"> <li>- Paso del Norte Water Task Force</li> <li>- Paso del Norte Watershed Council</li> <li>- Rio Grande Council of Governments</li> <li>- Rio Grande Compact Commission</li> </ul>

## Binational Activities

The New Mexico and Texas Water Resources Research Institutes developed a request for proposals (RFP) and a proposal template, and provided these documents to Mexican researchers. Proposal development was initiated through the IBWC/CILA. The initial phase of proposed work was

conducted in 2010 and 2011, and is summarized in the Accomplishments section (Mexican Geological Service, 2011a and 2011b). Additionally, eight binational meetings were held to coordinate research activities and provide scientific exchange and data sharing.



Figure 3. Project team members participate in binational meeting of the IBWC, August 20, 2009.

## Accomplishments

The achievements made toward the objectives set in the Mesilla Joint Work Plan developed by the project team and reviewed by stakeholders are summarized below.

**OBJECTIVE: Organize and conduct at least one stakeholder meeting to review project progress and plan for future studies and technical team collaboration.**

A Steering Committee was formed to provide guidance for the project, technical assistance, and review of documents through the project management team. A stakeholder meeting was held on June 11, 2008, in El Paso, Texas. The Mesilla Basin/Conejos-Médanos aquifer system was selected as the primary initial focus of the New Mexico and Texas TAAP portion because of the importance and

immediate need for information regarding this aquifer. The Committee also reviewed a joint work plan prepared by the New Mexico and Texas WRRIs and USGS.

**OBJECTIVE: Collaborate with Mexican partners to conduct research on the Mexico portion of the Mesilla Basin/Conejos-Médanos aquifer system.**

TAAP funding was provided through a TWRI subcontract to Mexico of mutually agreed upon study plans for Mexico scientists to conduct research on the Mexico portion of the Mesilla Basin/Conejos-Médanos aquifer system. Exchange and analysis of available United States and Mexico aquifer data and other information took place under this task.

To facilitate binational cooperation, an agreement was developed through the IBWC/CILA. Research partners in Mexico were identified, and communications were established. Numerous Technical Committee meetings were held to exchange ideas, identify issues of concern by binational stakeholders, and develop protocol for information exchange and data sharing. The Technical Committees were made up of scientists from the USGS and WRRIs, as well as the Mexican Geological Service and the Mexican National Water Commission (CONAGUA). Technical Committee meetings were hosted by the IBWC/CILA.

**OBJECTIVE: Consolidate and expand the bibliography with annotations of previous and current research and information regarding the Mesilla Basin.**

More than 800 publications were reviewed. An annotated bibliography was developed in Microsoft Word and EndNote with Web links to various data sources; this document was provided to Mexican collaborators. Additional citations are included from the Mexican literature, which continues to be updated.

**OBJECTIVE: Acquire and compile GIS data.**

Numerous Mesilla Basin geospatial datasets have been developed and added to the Paso del Norte Watershed Council coordinated database and GIS Web site-hosted data, including well information, pumping, water-quality, and surface-water data (<http://www.pdnwc.org/>).

Data are available from two ftp sites at the NMWRI (<http://river.nmsu.edu/> and <http://wrrri.nmsu.edu/wrdis/ftp.html>). New GIS components related to geologic structure and stratigraphy have been compiled, and numerous drillers' logs from New Mexico and Texas have been scanned and placed in a database.

Preliminary elements of the Conejos-Medanos aquifer subregion have been determined as well as the location of the well field that will provide supplemental water supply to Ciudad Juarez (Mexican Geological Service, 2011a and 2011b).

**OBJECTIVE: Evaluate selected wells in the Mesilla Basin aquifer.**

A comprehensive assessment of the water resources of the Rincon and Mesilla Valleys was performed. More than 300 wells were sampled and analyzed for major ions, and a subset of about

40 wells were sampled and analyzed for trace elements and radionuclides (previously sampled in the 1970s). Some wells sampled for major ions were sampled at earlier dates, from the 1940s to 1960s.

Groundwater geochemical samples were collected from 44 wells in the Mesilla Basin aquifer in New Mexico and Texas. The groundwater samples were analyzed for major ions, trace elements, nutrients, organic compounds, radon, stable and radiogenic isotopes, age tracers, and bacteria. Geochemical sampling of wells in Mexico was accomplished by the Mexican Geological Service and the data were published (Mexican Geological Service, 2011a, and 2011b).

Trace elements provide insight into the processes controlling the movement of water through the Mesilla Basin aquifer. Changes in water chemistry are of particular interest to New Mexico and Texas and local governments and entities (such as irrigation districts) that are concerned with salinity issues in the Lower Rio Grande Valley. Interpretation of the data could be published in subsequent years, if sufficient additional funding becomes available through the TAAP.

### **OBJECTIVE: Expand hydrogeologic framework model.**

The New Mexico WRRI updated the existing hydrogeologic framework model on the basis of an evaluation of both newly acquired hydrogeologic and geophysical information, as well as a reevaluation of all previous work and original databases. Information on more than 100 key wells and test holes completed in the Mesilla Basin aquifer, commonly referred to in New Mexico as the Rio Grande flood-plain alluvium/Santa Fe Group aquifer system, includes best-available interpretations on the elevation ranges of the four major hydrostratigraphic units (HSUs) and aquifer zones (Rio Grande alluvium and the Upper, Middle, and Lower Santa Fe HSUs). New structure-contour maps of hydrogeologic-model layer bases for the basin and Rio Grande Valley areas between Hatch and El Paso have been completed. These maps illustrate best-available interpretations of subsurface topography and locations of major structural features/bedrock boundaries for four (potential) model-layer bounding surfaces:

- Base of the inferred “shallow-aquifer” system of the Rio Grande alluvium,
- Upper/Middle Santa Fe (USF/MSF) HSU surface,
- Middle/Lower Santa Fe (MSF/LSF) HSU surface, and
- Basal contact of basin and (or) valley fill on bedrock.

These structure maps could form a core component of future groundwater-flow models. The latter hydrogeologic unit includes (1) inner-river valley fill (the sole alluvial aquifer of the eastern Rincon Valley-Selden Canyon and El Paso Narrows areas) and (2) the upper 300 to 500 feet of hydrologically well-connected, Santa Fe Basin fill units in the east-central and southeastern Mesilla Basin area (within 3 to 5 miles of the inner Mesilla Valley). These maps extend about 9 miles south of the New Mexico/Chihuahua boundary into the Conejos-Médanos aquifer system area. A total of 20 schematic cross sections have been developed or updated, with base elevation lowered to mean sea level where possible.

The Mexican Geological Service (2011a and 2011b) compiled piezometric data from selected well sites, configured depth-to-static groundwater level, and calculated static level elevation. In general, the static level elevation indicates that there is equilibrium throughout most of the aquifer in Mexico that maintains the natural direction of the groundwater flow. The withdrawal of about 23 million gallons per

day of groundwater in the well field area has led to an immediate decrease in the static levels. Well surveys in 2007 and 2010 show an increase in public urban use from 2 percent in 2007 to 16 percent in 2010; the percentage of inactive wells decreased from 44 percent in 2007 to 17 percent in 2010.

Evaluation of groundwater pumping by Mexican water users was initiated, particularly pumping in the Juárez well field, in May 2010. Water levels in the aquifer system, in particular near the well field, responded quickly to the withdrawals. Within 2 months of commencing operations, water levels dropped as much as 16 feet in the well field. Depending on the schedule of groundwater pumping, water-level drawdowns may be temporary or continue to increase. The physical and chemical properties for groundwater quality were measured in the Conejos-Médanos aquifer system, and specific-capacity tests were performed for this study to determine the transmissivity of the aquifer. A technical report summarized findings for the initial phase (Mexican Geological Service, 2011a and 2011b). Data and GIS coverage have been exchanged through the IBWC/CILA.

**OBJECTIVE: Develop the Farm Process for the groundwater-flow model.**

Work was conducted to further the development of an integrated hydrologic model for the Mesilla Basin and Lower Rio Grande Valley. The hydrologic model is based on the existing MODFLOW-2005 groundwater-flow model currently used by the Office of the State Engineer (S.S. Papadopoulos & Associates, 2007), but the new model will add the Farm Process (FMP1) module (Schmid and Hanson, 2009), which simulates landscape and surface-water processes in addition to groundwater flow.

The Farm Process model simulates farm recharge and irrigation well production and, hence, could supersede the former use of specified recharge and well production datasets. The streamflow routing package (SFR) input dataset has been revised to accommodate the surface-water deliveries estimated externally from the Lower Rio Grande 2007 model (S.S. Papadopoulos & Associates, 2007) and needed internally by the Farm Process model. A preliminary version of the model was developed and tested, and the results are consistent with the existing Lower Rio Grande model. The Farm Process model could be applied in the future to more comprehensively simulate the hydrology of the Mesilla Basin.

**OBJECTIVE: Investigate the hydrologic characterization of the aquifer at Fillmore Pass in collaboration with Fort Bliss.**

Interbasin exchange between adjacent aquifers, particularly at Fillmore Pass between the Hueco Bolson and the Mesilla Basin, are not well defined in previous groundwater-flow model studies (Frenzel and Kaehler, 1990; Hamilton and Maddock, 1993; Weeden and Maddock, 1999; CH2M-Hill, 2002; Heywood and Yager, 2003; S.S. Papadopoulos & Associates, 2007). Based on a preliminary assessment of the current status of groundwater within the Fillmore Pass area, the project team had identified research needs and developed a work plan for further investigation of groundwater exchange between the basins. The limited borehole and well-drilling data identified unconsolidated deposits in the Upper and Middle Santa Fe Group with a maximum thickness of 960 feet at the Fillmore Pass gap and deep groundwater level at a depth of approximately 350 feet below land surface. However, the interconnection between the Mesilla Basin and Hueco Bolson at this location is not well defined. Long-term monitoring data made available by the USGS and other data from State agencies have been compiled. With assistance from Fort Bliss personnel and local well owners, additional water-level

measurements have been made and water samples have been collected. Additional analysis for the characterization of groundwater flow is ongoing.

**OBJECTIVE: Characterize surface-water and groundwater interaction.**

Understanding the interaction of surface water and groundwater within the Mesilla Basin is critical to the assessment of groundwater availability and configuration of the groundwater-flow model. The team compiled long-term groundwater-level data and seepage investigation data both from the USGS. Preliminary evaluations of historic trends in groundwater-level changes, cross-formational exchange, and impacts of groundwater withdrawals on the interaction of groundwater and surface water were initiated. A detailed assessment of patterns of exchange between streams and groundwater and estimation of trends in gains and losses is planned.

**Future Plans (subject to funding level)**

Future work is planned in the Mesilla Basin to finalize the initiatives begun under TAAP, to further the progress achieved to date, and publish and release all data, methodology, and results of analyses. Contingent upon funding, the following activities will be conducted for the Mesilla Basin: (1) expand groundwater-level monitoring and groundwater-quality analysis; (2) investigate stream-aquifer interaction; (3) examine interbasin groundwater exchange near El Paso Gap and outflow to the Hueco Bolson; and (4) create a joint transboundary groundwater-flow model. These activities will result in an improved understanding of the water resources of the Chihuahua – Texas – New Mexico area and allow water-resources managers to more effectively share this critical resource.

As part of a separate program, the USGS conducts groundwater-level monitoring at more than 200 sites in the Mesilla Basin on an annual basis. Additional monitoring wells near the U.S. – Mexico border would help to define water-level drawdown changes recently observed in a number of key border area wells. A pipeline from the Conejos-Médanos well field to Ciudad Juárez, Mexico, was completed in 2010, and existing border wells are responding to the drawdown created by the initiation of full production at the well field. The Mexican Geological Service included recommendations for additional monitoring sites in their March 2011 report (Mexican Geological Service, 2011a and 2011b ), as well as long-term aquifer testing at the new production wells. Finally, installation of a deep well cluster in the border area would allow cost-effective monitoring of the shallow, intermediate, and deep aquifer zones as the cones of depression from municipal pumping eventually overlap.

Groundwater-quality samples were collected in November 2010 at 44 Mesilla Basin aquifer wells with supplemental funding from the USGS National Water-Quality Assessment Program. Future funding would be applied to the laboratory analysis of additional samples from key wells in Mexico, which would greatly improve the dataset and include cooperative sampling with the Mexican Government. Finally, the team plans to examine and interpret the results and apply these water-quality data to questions of groundwater-quality trends, aquifer residence times, and groundwater-flow paths.

Work is in progress to investigate the exchanges between streamflow and the groundwater-flow system, using seepage investigation data, historic surface-water flows, and water-level monitoring data. Using statistical analysis or simple hydrologic models, patterns of stream-aquifer exchange will be identified and trends in river gains and losses will be determined. Movement of groundwater between different hydrostratigraphic units will be evaluated in relation to stream-aquifer interactions. It is

anticipated that these research findings will provide guidelines for reconfiguration of streamflow or Farm Process modules in the groundwater-flow model. A parallel effort seeks to further characterize interbasin groundwater flow between the Hueco Bolson and Mesilla Basin through Fillmore Pass using geophysical and geochemical data. Fort Bliss and other local groundwater users are interested in these aspects of the study because they are important to assess local groundwater availability. Depending on funding levels, these important elements could continue to advance.

Hydrologic modeling of the Mesilla Basin has long been a key aspect of TAAP Mesilla Basin activities. The next steps of the integrated groundwater-flow model are to refine the model to reflect more detailed irrigation systems (or service areas) and to allow climate, evapotranspiration, and land-use updates by using remotely sensed data. This ultimately will require enough spatial and temporal resolution to allow the separation of the supply and demand components of the regional hydrologic budget from the groundwater, surface-water, and landscape components. The refined model would better address water management questions about resource development and sustainability that are of concern to the various agencies. These improvements are already in the planning stages and some progress has been made to date. As the project moves forward, the integrated groundwater-flow model will be documented and archived periodically, in order to ensure that this important water-resources assessment and management tool is available for future use.

The Conejos-Médanos well field began full operation in 2010 with initial drawdown effects observed across the southwestern part of the basin. This new hydrologic stress is not yet accounted for in existing groundwater-flow models. A fully binational resource such as the Mesilla Basin/Conejos-Médanos aquifer system requires a coordinated approach and a joint effort to achieve consistency and acceptability from all parties. Accordingly, future plans include (1) integration of the hydrogeologic framework across the border, (2) development of a joint conceptual water budget for the Mesilla Basin/Conejos-Médanos aquifer system, and (3) selection, construction, and application of a mutually acceptable, fully integrated hydrologic flow model that will simulate the inflows and outflows of the groundwater and surface water of the transboundary region. Depending on funding levels, the TAAP may further the development of a binational model and promote the exchange of information between specialists in the United States and Mexico.

The integration of the hydrogeologic framework is a critical step in improving the understanding of the transboundary resource. Recently completed TAAP hydrostratigraphic studies (J.H. Hawley, New Mexico State University, written commun., 2011) extend across the border area and will be digitized and distributed. Although these studies are based on preliminary data from test holes at the Conejos-Médanos well field, the recently completed TAAP study of the Conejos-Médanos aquifer system (Mexican Geological Service, 2011a and 2011b) provides new data and suggests a much broader aquifer extent toward the southeast, with important inferences on regional basin recharge and inflow of saline groundwater. Electromagnetic profiles in Mexico and other new data in the TAAP Conejos-Médanos report (Mexican Geological Service, 2011a and 2011b) will be compared with the newly published interpretations (J.H. Hawley, New Mexico State University, written commun., 2011) and integrated into a basin-wide hydrogeologic framework. Analysis of microseismic events may also allow definition of faults and flow boundaries, which have been found to play an important role in Mesilla Basin hydrogeology. The final product of joint work sessions would be an improved understanding of the hydrogeologic framework across the entire basin.

Development of a joint conceptual water budget is also needed for the development of the groundwater-flow model. Estimates of agricultural pumpage and evapotranspiration can be extracted from the Farm Process, having been revised to more accurately reflect the processes of the largest water use in the Mesilla Basin, agriculture, and to more accurately simulate groundwater/surface-water

interactions that may affect the Rio Grande. Municipal pumpage estimates can be integrated from State and municipal agencies, including data from the Conejos-Médanos well field, which began full operation in mid-2010. If available, seasonal deformation using remotely sensed data could be incorporated to update pumping data periodically. Exchange between surface waters (the Rio Grande, canals, and drains) and the aquifer system, deep infiltration from agricultural applications, interbasin flows, cross-border groundwater flow, water-table elevations and drawdowns, mountain-front recharge, riparian evapotranspiration, and other discrete water budget components will be defined in joint working sessions.

Lessons learned from the Mesilla Basin activities could also be used in developing joint work plans for the Hueco Bolson and Presidio-Redford Basin in west Texas and the Mimbres Basin in southwest New Mexico.

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