

# **FINAL REPORT**

## **Water for Agriculture Coordinated Agricultural Project:**

### **Sustainable Water Resources for Irrigated Agriculture in a Desert River Basin Facing Prolonged Drought and Competing Demands: From Characterization to Solutions**

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#### **I. Target Audiences**

Stakeholder participation was a hallmark of our project from beginning to end. Our target audiences were all stakeholders concerned about the future of water in our region, and their involvement was a process that built upon each encounter. We made a major, successful effort to identify and engage stakeholders in Year 1 of our project, and to maintain engagement and direct participation throughout. Initially we engaged about 120 stakeholders representing agriculture, urban users, environmental needs, and social justice concerns from Texas, New Mexico, and Chihuahua, but through the course of the project, we engaged a total of about 150 stakeholders at various times and in various ways. The key stakeholders whom we targeted can be categorized as follows:

- a) Small scale Texas farmers
- b) Large scale Texas farmers
- c) Small scale New Mexico farmers
- d) Large scale New Mexico farmers
- e) Chihuahua (Mexico) farmers
- f) Urban/industrial users from El Paso, Las Cruces, and Ciudad Juárez
- g) U.S. and Mexican government agencies, state and federal
- h) Environmental stakeholders (mainly NGOs)
- i) Social justice stakeholders (mainly NGOs)

We continued to engage these stakeholders in various ways as described under the description of accomplishments below (Section II. Obj. 4).

#### **II. Accomplishments (by objective)**

##### **Objective 1. Model development, improvement, integration, validation.**

###### **General**

We organized and maintained interdisciplinary working groups to address different modeling tasks. They included: a) developing, testing, and implementing an aggregate-scale hydroeconomic optimization model (Bucket Model) and conjunctive water balance model (MRG Water Balance Model); b) testing, validating, and implementing a geospatially specific simulation model that could be used at a field scale or larger (SWATmf); b) models to simulate salt fate and transport/salinization at the field scale; c) remote sensing approaches to land

transition/land use change; d) climate projection formulation coupled with hydrologic models to evaluate climate scenarios; and e) an online user interface modeling system (SWIM). A project web portal was developed and is available at <https://water.cybershare.utep.edu>. In the following paragraphs we summarize the development and use of several of our key modeling products.

#### Middle Rio Grande Surface-Groundwater Balance Model (MRG Water Balance Model)

A basin scale hydrological model was developed for use in answering large scale questions regarding surface and groundwater. The model is a simulation tool that accounts for all inputs, internal cycling processes, and outputs in the Middle Rio Grande basin and associated aquifers. The development and implementation of this model was key for projecting future water availability from surface and groundwater, as impacted by climate change and changing demand in the region. The MRG Water Balance model was translated to Scilab and structured for online execution.

This model was used in several key ways including projecting the future of water resources in the region under “business as usual” conditions, projecting the future of water resources under a number of climate scenarios, projecting the future of water resources under changing demands for water, and assessing surface and groundwater “connectivity” through consequences of groundwater pumping, irrigation system efficiency, and seepage from the main channel of the Rio Grande and irrigation channels. It was also enhanced or combined with other cost accounting models to project future costs of urban water, costs of environmental flows, or address other economic questions.

The MRG Water Balance Model represents our most effective tool for addressing large scale hydrological questions, in time and space.

#### The GAMS “Bucket” Model

The Bucket Model represents a robust optimization modeling tool for evaluating future scenarios and interventions of various types, including policies, technologies, and management. Sub-models were developed for reservoir evaporation rates, reservoir elevation-storage-surface area, irrigated agriculture evapotranspiration and return flows, urban evapotranspiration and return flows, groundwater-surface water exchanges, and groundwater elevations. Data and sub-models were incorporated into an annual water balance model. The annual water balance model was calibrated by varying a small number of parameters (pan evaporation coefficient, return flow coefficients for irrigated agriculture and urban water users, and aquifer storage coefficients and recharge) over the period 1993-2014. The annual water balance model was converted from a calibration/historical period mode to a prediction/future periods mode. The predictive mode was used to simulate storages and flows for climate scenarios. The Bucket Model simulates all the major sources, sinks, uses, and losses of water for the Middle Rio Grande. It has been used as a decision support framework for improving our understanding of the basin, evaluating scenarios, and answering questions that are important to stakeholders. For example, it was used to estimate cost of appropriating water for environmental flows. It can be used as a regional water budget accounting model as well as a hydroeconomic optimization model.

The Bucket Model also forms the basis of the user interface, SWIM. It represents our most effective hydroeconomic optimization model.

### Sustainable Water through Integrated Modeling (SWIM)

SWIM, the user interface with the Bucket Model, enables users to graphically: i) define default or customized parameters representing human activities and climate scenarios, ii) seamlessly run the Bucket Model, iii) graphically explore the outputs of the model, and iv) graphically explore the sources and processing (provenance) of the data for validation purposes. We evaluated the usability of the SWIM interface with stakeholders and tested the results generated from the hydroeconomic optimization model. A number of stakeholder workshops were conducted to introduce SWIM and train stakeholders in its use.

### Soil and Water Assessment Tool (SWAT) and SWAT Integrated with MODFLOW (SWAT-mf)

The SWAT model was calibrated and validated for both the HUC 8 watersheds that contains the Elephant Butte Irrigation District in New Mexico and for the Texas/Chihuahua portion of the study area. The model for the New Mexico portion of the study area was validated for streamflow and evapotranspiration, as well as available information on groundwater recharge. The model was validated in the Texas portion of the study area for a dry year, assessing the impacts of water supply, crop acreage, soil water storage, and groundwater recharge. Linkage of SWAT and RiverWare was developed to improve accuracy of simulation of flow as well as salinity loading. The model was used to assess climate change impacts on water availability.

We also successfully integrated SWAT and MODFLOW for simultaneous simulation of surface water and groundwater processes in our portion of the Rio Grande. MODFLOW models for the Hueco Bolson and Mesilla Basin were converted to the MODFLOW 2005 version for linkage between SWAT and MODFLOW. Impacts of climate change scenarios and extreme drought conditions were evaluated using the SWAT-MODFLOW models by incorporating climate inputs for inflows and weather patterns. Spatiotemporal variation of water budget of surface water and groundwater within the watershed was assessed using the SWAT-MODFLOW models, especially under extreme drought, normal, and extreme wet conditions.

The Mexican team ran an assessment for surface water using SWAT in the Chihuahua portion of the basin. Twenty SWAT modeling exercises were developed, in four of the five sub-basins in Chihuahua, for the years 2005, 2007, 2009, 2011 and 2013. For the Mexico side of the border, initial trial runs were built under SWAT using observed hydrological and climatological variables from 1994 to 2015. SWAT was used to evaluate climate change, population growth and water demand, land use, and water deliveries from the US – Mexico treaty for the timeframe 2020-2070. Groundwater modeling scenarios were also evaluated for the total area of the Valle de Juárez for the period of 2008-2070.

We also modified and validated a salinity module in SWAT. We simulated salinity processes in the HUC 8 watershed that contains Elephant Butte Irrigation District using the SWAT-Salt watershed hydrology model to assess biophysical factors that impact salinity.

SWAT-MODFLOW was used in a variety of ways, including climate change impact assessments to evaluate possible agricultural water management interventions and to inform adaptation planning to cope with warm-dry future. We evaluated sixteen different agricultural interventions that were selected based on previous experience of growers in the region, alternative drought-

tolerant crops, and SWAT model limitations to perform the simulations. The simulated interventions fall under three thematic categories: (1) implementation of deficit irrigation, (2) changing cropping patterns using existing crops, and (3) changing cropping patterns by introducing new crops. Agricultural water availability under current irrigation management would be increasingly vulnerable to severe droughts and fresh groundwater depletion in the future. Applying whole-season or regulated deficit irrigation and modifying crop patterns by replacing alfalfa and cotton with drip-irrigated pomegranate and pistachio could increase available water to sustain high-value pecan crops. Due to potential depletion of fresh groundwater, development of desalination for brackish groundwater for irrigation and water markets to increase flexibility in water use are compelling needs in order to maintain production of high-value perennial crops like pecan.

#### Salinity Modeling Tools

Accomplishments in modeling salinity processes include development of a Bayesian Network to simulate factors that impact salinity; developing a system dynamic model in STELLA® for field scale salinity in cotton; modification of MODFLOW to add unsaturated zone flows and unsaturated zone chemistry, and to modify the RT3D model; and investigation of the use of aerial sensing using UAS to assess crop yield, soil moisture, and salinity at a field scale. A spectral index was developed to determine salinity concentrations in the Juárez Valley, supported by field sampling. A georeferenced and vectorized process was used to define the apparent salinity map of the Juárez Valley.

#### Other Specialized Models and Geospatial Products

The GIS team produced historical and current land use/land cover maps and the results were used for the Bucket model as well as by the SWAT modelling teams, to model the water use implications of land use change. We generated the initial data for conversion of agriculture land use to urban land use, from which we identified systematic classification errors. We developed a methodology for improving classification through analyzing patterns of temporal change. We successfully completed the generation of the annual LULC maps from 1990-2015 for the entire USA-Mexico study area. The generation of LULC change models for the years 2020, 2025, 2030, 2035, and 2040, using the MARKOV model were accomplished.

In Mexico, a special web page for the USDA project was created on the Universidad Autónoma de Ciudad Juárez (UACJ) servers in Spanish. <http://mexusda.uacj.mx/> A map server was also integrated into the project website using the ArcGIS Online platform. <http://mexusda.uacj.mx/WebMap.html> An information transfer protocol was generated using a secure file transfer protocol (sftp) and remote instructions on the server using a secure shell (SSH) to place links to compacted geographic data files. This process facilitated the transfer of massive data among the members of the work team.

The Water Balance Model was modified to estimate evaporative consumptive use in semi-arid urban areas. An economic component was added to estimate the future costs of water for urban consumers in El Paso. To better assess urban water use, a daily water demand prediction model for El Paso was developed. We used this model and our climate scenarios to evaluate long-term water trends, especially increasingly more costly alternative supplies, and their social impacts on vulnerable consumers. These data can be linked to Bucket Model projections.

Spreadsheet models were developed for evaluating: a) multi-modal irrigation of salt-sensitive and salt-tolerant crops; b) desalination in agriculture; and c) water demand and energy production from cultivating algae in a semi-arid region.

We designed and evaluated an online pecan irrigation scheduling tool based on real-time and historic climate data. The tool is being made available to pecan growers.

#### Experimental Work Aimed at Improving Models

A complex surface drip irrigation system was installed in 2017 in a 10-acre block of 'Pawnee' pecan trees at the NMSU Leyendecker farm near Las Cruces, NM. The system was used to test the use of partial root zone drying and regulated deficit irrigation to conserve water while minimizing yield/economic losses where insufficient water is available to fully meet annual orchard evapotranspiration demands. The results were used also to calibrate our models with respect to water use by pecans, management interventions, and new technology.

We attempted to construct a typical water balance for irrigated pecans. We conducted a workshop on the water balance for irrigated pecans, attended by eight faculty and six students from NMSU, UACJ, TX AgriLife, and UTEP. Participants reported on published and unpublished results for various components of the water balance. The largest unknowns are associated with evaporation losses and deep percolation and the fate of water that percolates below the root zone. We developed a review article on the water balance for irrigated pecans; the article is under peer review.

#### Objective 2. Climate scenarios.

We developed several different climate scenarios to use for simulations in the Bucket Model and the MRG Water Balance Model. "Climate" for our project includes temperature and precipitation in our study area, together with the input of Rio Grande flow into Elephant Butte Reservoir which is largely determined by snowpack far upstream. Our initial climate scenarios included a historical baseline time series using observed data for a 20-year period (1994-2013); two "extended drought" scenarios, in which the driest year in the data record (2011) was repeated five times, and another in which the driest three years (2011-2013) are repeated for a 20-year drought; and a climate change scenario in which projected streamflow into Elephant Butte Reservoir and precipitation over the study area through 2070 were adapted from a climate model simulation adapted from the CMIP5 archive.

A medium stress climate scenario was incorporated into the Bucket Model reflecting a series of climate stressed inflows through the year 2040. For two time periods (1994-2013 and post-2013), the climatic inputs that create streamflow in the simulation — snowpack in the headwaters, precipitation downstream — came from a freely-running coupled ocean-atmosphere climate model (the British HadGEM model). In addition, this particular simulation included an imposed increase in future atmospheric greenhouse gases such that an additional  $8.5 \text{ W/m}^2$  of longwave radiation reaches the surface by 2100 (the so-called RCP 8.5 scenario). Thus, the temperature gets warmer and snowpack ultimately decreases as the 21st Century proceeds, but with lots of precipitation variability superimposed on the greenhouse gas-forced long-term trends. The natural variability of this simulation included a relatively wet decade in the 2020s;

so it provided an illuminating ‘Future Baseline’ simulation that contrasted dramatically with an imposed 20-year drought.

Two climate scenarios were simulated with the annual water balance model. The climate scenarios provided river inflows to the project study area and local climatology. A hypothetical extended drought scenario was simulated, which extended the 2011-2014 drought another five years. As expected, reservoir storage and surface water allocations dropped to minimum levels after another two-three years and groundwater pumping increased in response. A pessimistic, 30-year future climate scenario based on global circulation models was simulated. The sensitivity of reservoir storage and surface water allocations to future water demand and minimum reservoir storage constraints was explored, revealing that, over the expected ranges of water demand and minimum reservation storages, reservoir storage and surface water allocations dropped to minimum levels within 5 to 15 years.

We carried out simulations using the MRG Water Balance model to assess near-term scenarios for Elephant Butte Reservoir, considering various climate fluctuations and possible management strategies for controlling evaporation and tradeoffs between fully allocated releases vs. managing to maintain higher reservoir volumes. We quantified the changes to Elephant Butte storage, and downstream surface water releases from Caballo Reservoir, associated with several different reservoir management strategies. We showed that there is an inherent tradeoff between keeping Elephant Butte storage high (which decreases the risk of water shortages in future years), vs. evaporative losses from the greater water surface area of a nearly full reservoir. By far, the most effective strategy for enhancing downstream deliveries is to mitigate reservoir evaporation. In the model, this can be accomplished hypothetically by setting a model parameter, but in reality, evaporative losses go hand in hand with higher water levels and reducing evaporation is not a trivial task for a reservoir the size of Elephant Butte.

We also evaluated three extreme climate scenarios and ten observationally consistent climate scenarios with the SWAT model. The climate scenarios provide river inflows to the project study area and local climatology. The simulated climate scenarios included no release from the Elephant Butte-Caballo reservoir system, and scenarios based on twelve different CMIP5 models that had previously been post-processed by the US Bureau of Reclamation. Climate impact assessments indicated that surface water reservoirs will become a much less reliable water source in the future. As expected, reservoir storage dropped to minimum levels for extended periods of time during the 21<sup>st</sup> century. Under such scenarios, water withdrawals from the regional aquifers would be needed to compensate for declining surface water to maintain current levels of agricultural production, meaning that groundwater sustainability will become the main water resources management challenge in the second half of the 21<sup>st</sup> century.

### **Objective 3. System Dynamics Modelling**

#### **Our Toolbox**

Rather than build a single system dynamics model, we chose to build a “toolbox” of models that can answer important questions about the future of water at multiple scales for multiple types of users. This approach is in fact more flexible, more efficient, and more effective than a single model. Our toolbox includes:

- The MRG Water Balance Model – a basin scale model effective for addressing large scale questions about the water balance as impacted by climate and competing demands in the Middle Rio Grande Basin
- The GAMS Bucket Model – a basin scale hydroeconomic model that optimizes solutions to important questions about the future of water in the Middle Rio Grande Basin
- SWIM – a user interface model that optimizes solutions to important questions about the future of water in a user friendly online format
- SWAT-MF – a spatially explicit modelling framework that integrates surface and groundwater hydrology and provides more fine-grained answers to important questions about the future of water by linking SWAT and MODFLOW; it is more appropriate for research users
- SWAT-Salt – a version of SWAT that includes the sources, fate, and transport of salts in the hydrological system
- A variety of specific models to address specific questions of interest; these are identified above under Obj. 1.

During the last year of the project, we used this toolbox of models to evaluate a number of important stakeholder-identified questions and/or potential interventions that can serve as solutions to the undesirable future of water in the Middle Rio Grande Basin. Some of these important interventions or changes in future policies or management include: a) conjunctive surface water-groundwater management policy alternatives; b) salinity dynamics in the HUC 8 watershed that contains Elephant Butte Irrigation District; c) least-cost provision of water-derived ecosystem services; d) impact of new water technologies (e.g., desalination) on agriculture (water availability and cost); e) aquifer protection methods (e.g., aquifer pumping caps, aquifer recharge)—costs and impacts of implementation; f) estimation of urban evapotranspiration and water consumption in the three cities in the middle Rio Grande basin; g) affordability of urban water in a region with growing water scarcity; h) water footprint for algae cultivation in an arid basin; and i) future water demand and supply scenarios in response to climate change and the impacts on water availability in agriculture and urban users.

As examples of the utility of models in our toolbox, we evaluated a number of interventions and made the following assessments:

- The MRG Water Balance Model was used to (a) simulate reservoir storage for a range of climate change and operational scenarios, (b) simulate groundwater depletion rates for the aforementioned scenarios, and (c) to provide inputs for simulations of water demand associated with algae cultivation.
- A conceptual framework was developed to assess increases in urban water supply costs and their impact on water prices and corresponding impact on livelihoods in El Paso; data were collected to operationalize this line of inquiry.
- Estimates of urban evapotranspiration and water consumption were completed for the three urban centers in the study area.
- A computational framework was developed to optimize scheduling of environment pulse flows in the Caballo to El Paso reach of the Rio Grande.
- Conveyance and other losses involved in transferring water from Rio Grande diversion points to farms were estimated for the three US irrigation districts.

- We evaluated impacts of climate water stress on all major water users in southern New Mexico, west Texas, and northern Mexico and alternative aquifer protection measures and climate-water supply scenarios.
- We completed an analysis of success predictors of alternative water banking structures to smooth adaptive capacity to drought and climate water stress.
- We developed projections of water supply and demand for fifty years into the future under conditions of “business as usual”, using the MRG Water Balance Model.
- We estimated the time to depletion of freshwater in the Hueco Bolson and evaluated the impact of implementing a number of interventions to prolong the life of the aquifer, including their cost.

### **Summary of System Modelling Results:**

#### **Status of Water Resources in the Middle Rio Grande, Now and Into the Future**

##### Surface Water

Over the past 20 years, reduced snowfall and snowmelt in the upper portions of the basin have resulted in much reduced water storage in EB Reservoir and prolonged drought for downstream users. The impact of drought, at times prolonged lasting several consecutive years, has been dramatic on EB Reservoir, resulting in much reduced surface area of the reservoir and a corresponding reduced storage volume for the majority of time.

We evaluated many future climate scenarios ranging from very wet to very dry and developed an innovative technique for adjusting the modeled (natural) flows to account for upstream water management. Looking at what climate scientists consider to be more likely future scenarios (mostly warmer and thus drier), it is clear that the trend of prolonged drought and dwindling supplies of surface water are likely to continue and even worsen into the foreseeable future (the next 50 years). In the future scenarios that we evaluated, EB reservoir will meet demand for only about 20% of the time under the likely warmer, drier scenario, and will not meet demand at any time during the period of simulation (50 years) under the very dry scenario. For irrigators in the Middle Rio Grande Basin (the largest and almost exclusive use of surface water in the region), the deficit in surface water availability will likely be replaced with groundwater.

##### Groundwater

Since irrigators will use groundwater to make up surface water deficits while continuing to expand pecan production, and the large cities in the region, who depend primarily on groundwater, will continue to grow, the Mesilla and Hueco Bolsons will be significantly depleted under the dry and very dry scenarios. Results for the Hueco Bolson show a dropping water level in the aquifer of about 3 ft/yr or 1 m/yr. Similar results were found in Mexico, where the rate of drop or depletion is 1.4 m/yr for “business as usual” and 9.4 m/yr if pumping rates increase by 50%. Furthermore, groundwater will migrate to areas of depletion, causing overall drops in the water elevation in general, and deterioration of water quality due to intrusion of brackish water. Since Ciudad Juárez is the biggest user, net movement of fresh groundwater is currently from the US to MX. It is possible that the freshwater in the Hueco Bolson, (approximately 10 to 15 million ac-ft) will be completely depleted within the next 50 years under



the dry and very dry scenarios that we evaluated. The Mesilla Bolson, with an estimated 50 to 75 million ac-ft, has a longer life but perhaps still within this century.

### Implications

The implications of these results for water management and sustainable agriculture are significant. Pecans, now the predominant and most profitable crop in the region, are perennials and represent a significant capital investment. They require water every year just to keep them alive, much less to optimize production. This makes cropping strategies for the region much less flexible. Our results show that if we were to experience a prolonged drought of 8-10 years, for example, current irrigation methods/limits would fail to meet the needs of pecans unless all other crops are removed from production in order to save pecan orchards. As surface water for irrigation continues to dwindle, more use of groundwater will be required. As the aquifers in the region are depleted and water levels fall, it will become more and more expensive to pump groundwater, and the salinity of the groundwater that is being pumped will increase as saline water encroaches. This is clearly an unsustainable situation.

There are significant implications for urban users as well. The urban centers are the biggest users of groundwater in the region. As groundwater sources are depleted, alternative sources will have to be “tapped” to meet growing demand, resulting in increased cost of water to residents. In 2020, the cost of water for residents in El Paso was on the average only 1.3% of their annual income. In 2070, it is projected to be 4.4%. The greatest consumptive use in the urban environment, and thus the greatest opportunity for conservation, is outdoor vegetation and evaporation from bare soil. Reducing landscaping uses of water would be an effective way to reduce urban demand. Furthermore, urban centers can improve water sustainability and resiliency by reusing municipal wastewater, especially for drinking water supplies. Direct potable reuse of wastewater could reduce the amount of fresh groundwater pumping by cities, though it is a very expensive alternative.

With respect to environmental uses of water, historically almost no surface water has been allocated to serve environmental needs in the region, and environmental uses of water remain one of the greatest deficiencies in water policy. The U.S. Boundary and Water Commission (IBWC) has proposed periodic pulse flows in times of ample supply to flood riparian areas to encourage riparian vegetation. We evaluated the water requirements for pulse flows every 5-10 years. This strategy would require relatively small amounts of water, amounting to generally less than 2% of the total annual flow in any one year.

### **Objective 4. Stakeholder engagement and participation.**

The description of our process for engaging stakeholders and some of the results of our initial stakeholder engagement as a foundation for implementing the project was published in a journal article (Hargrove and Heyman, 2020). We briefly summarize key milestones in stakeholder involvement below.

In the first year of the project, we introduced our project through presentations to various groups and also invited stakeholders to participate in a series of focus group meetings to identify chief concerns of stakeholders and their attitudes about the future of water in the region. We used

these meetings to identify a group of key research questions that could guide our research. We supplemented it with a survey of urban consumers to better understand public opinion beyond organized stakeholders.

In the second year of the project, we followed up with stakeholders to share what was learned in the first round of meetings and to present and discuss the various modeling tools that were being developed and validated for use in the project, including the Bucket Model that we developed and the SWAT and MODFLOW models. In general, stakeholders expressed trust in these models as viable tools for use in the project. Much of Yr 2 was spent “backstage” from the target audiences, preparing and validating the models to be used.

In Yr 3, we convened meetings with stakeholders to present validation results for the Bucket Model and to present the user interface, eventually designated SWIM (Sustainable Water through Integrated Modelling). We were successful in demonstrating the efficacy of the model in simulating the major parts of water supply including the reservoir storage, river flow, and decline of the aquifers as pumping increased. We presented results to stakeholders for a projected 10-yr drought.

In Yr 4, we evaluated a number of climate scenarios, evaluated the impacts of competing demands, and began to simulate the future of surface and groundwater resources under changing climate and changing demands. These were presented to and discussed with stakeholders through group meetings.

In Yr 5, we evaluated interventions to improve the sustainable use of water in the region, including improved irrigation methods, alternative irrigation methods, alternative crops, alternative water supplies, and others. We also evaluated environmental uses of water, and the future cost of water. We hosted a workshop with key stakeholders and identified and discussed interventions to improve the future of water using Serious Games methodology. We hosted a final round of stakeholder meetings to present project results. Participating stakeholders represented agriculture, urban, and environmental uses of water from the private, government, and business sectors.

We identify examples of specific and important activities below. This is not an exhaustive list of all our activities but were chosen to illustrate the depth and breadth of our engagement with stakeholders in the participatory research context.

- A sample of residential consumers in El Paso and Ciudad Juárez was surveyed about water use and perceptions about the future of water. A study of the public policy process related to implementation of direct potable reuse as a technology/policy option by the Public Service Board in El Paso was initiated. We conducted a review of relevant documents and also face-to-face interviews with key actors/informants and residential consumers.
- We conducted one-on-one interviews with farmers to learn more about farmer decision making under conditions of limited water and their understanding of and responses to the future of water. An interview instrument was designed to elicit discussion of on-farm decision making and production history over the past 10-12 years and plans for facing extreme weather events in the future. We worked with them to identify more effective and

meaningful methods for data representation concerning water, with significant findings that were used to improve the SWIM model.

- We hosted a focus group meeting with environmental professionals to discuss ideas for modeling ecosystem services. The environmental stakeholders provided documentation on environmental flow policies for the Caballo-El Paso reach of the Rio Grande. The documentation included a number of specifics related to pulse flows in the Middle Rio Grande aimed at maintaining riparian vegetation, including: a) recommended inter-annual frequencies, b) intra-annual timing (seasonal timing), and c) flow durations (number of hours to days) of environmental flows along the Caballo-El Paso reach. This information was used to impose environmental flow constraints in the MRG Water Balance Model.
- Several “hands on” workshops on SWIM were offered during the course of the project and at various stages of SWIM development. Four workshops were conducted in the U.S. and two in Mexico. Various types of stakeholders attended, including farmers, water officials, and the general public. In all cases, project overviews and modeling outputs were presented, combined with hands-on activities. In Mexico, stakeholders from both farming communities and government offices participated (ie. CONAGUA, CILA, JMAS, JCAS, SAGARPA). SWIM was demonstrated and participants were allowed to manipulate parameters and observe preliminary outputs. At the end of the project, we held two stakeholder workshops that guided users through scenario analysis with the SWIM interface using 1) pre-formulated questions; and 2) questions formulated by the stakeholders themselves. These workshops were targeted towards more technically-savvy stakeholders. We focused on how diverse water users envision the future, using our increasingly refined water scenarios in SWIM. Canned scenarios based on user interests were provided to simplify model options and alternatives. We interviewed farmers with example SWIM output to find out better ways to present and narrate data for users; this was then used to improve the SWIM data representations to make them more understandable and useful. We also conducted simulations of transboundary water management interactions, using our regional water future simulation in SWIM.
- Experimental results showed that irrigation scheduling based on real time in-situ soil moisture conditions in pecan orchards can potentially save 3000 acre-feet of water across the El Paso County irrigation district.
- Results from bioenergy feedstock production on salt affected lands using marginal quality waters indicated potential yield levels of 7.5 dry tons of switchgrass and 8.8 dry tons of energy sorghum per acre. Results from winter canola production with alternative waters irrigation research indicate a seed yield of 1500 lbs/acre.
- Results from on-going research on sulfur burner treatment of irrigation water to manage soil sodicity can contribute to significant reductions salinity management costs. At an estimated cost of \$2 acre-inch, by converting calcium carbonate present in the soil profile to gypsum, this technology can save growers about \$100 to 250 per acre in salinity management costs.
- We compiled and analyzed data to study the impact of costly and difficult future urban water supplies and technologies on the cost of urban water. We have compiled data and developed a data analysis strategy to study the impact of costly and difficult future water supplies and technologies on vulnerable poor consumers. This information is of high interest to urban stakeholders.
- We completed several field-scale studies of issues of importance to stakeholders. We completed two years of evaluation of irrigation water quality (specifically salinity), responses

of crops to elevated salinity, and changes to root zone salinity and sodicity. We evaluated drip and surge irrigation systems and their effects on root zone salinity in pecan orchards. We evaluated the potential for S burner technology to manage salinity in affected cotton fields. We evaluated alternative crops that are more salt tolerant and require less water, such as pomegranate, pistachio, energy sorghum, and canola. These crops are adapted to our area, but are not as profitable as pecans.

- We evaluated an innovative irrigation management scheme referred to as partial root zone drying, a type of deficit irrigation. Preliminary results showed that the amount of irrigation water could be reduced by as much as 25% without significant reductions in yield using this technique. In addition, midday stem water potential (i.e., plant water status) and soil moisture data were collected at the end of three flood irrigation dry-down cycles in a mature ‘Western’ pecan orchard. Plus, comparisons were made between trees at different stages of mechanical pruning re-growth, with the goal of describing how pruning affects pecan tree water requirements. These data were used to fine-tune the application of such water conserving techniques as micro-irrigation, partial rootzone drying, and regulated deficit irrigation.
- During the last year of the project, we developed and conducted a binational workshop using “serious game” methodologies, a simulated decision process involving position-taking and negotiation related to the depletion of the freshwater in the Hueco Bolson, the transboundary aquifer shared by Texas and Chihuahua. Six sessions were held by Zoom with good participation from both countries. While there was no consensus on a single set of actions, there was convergence on the seriousness of the problem, parameters of policy responses, and possible options.

### **Objective 5. Dissemination.**

At the heart of our dissemination efforts is the stakeholder participatory methodology of our project. We conducted at least 40 group activities of various kinds with stakeholders and in various formats. We did presentations to larger groups with discussion (15 or more participants each), focus group meetings (6-12 participants each), interactive workshops (10-20 participants each), and “science fair” types of meetings with poster presentations or live demonstrations and one-on-one interaction (20-60 participants each). Focus group meetings and workshops were most effective in eliciting information from stakeholders, but science fair activities were most effective in disseminating results to stakeholders (as determined from stakeholder participation and evaluation of events). We estimate that about 150 individual stakeholders participated in one or more of these events, with the majority of them participating in multiple events over the course of the project. These 150 stakeholders represent leaders, decision makers, and key managers of water resources in our region.

A major dissemination activity of the project is the project website which can be found at: <https://water.cybershare.utep.edu>. In particular, the user interface, designated SWIM, is available at the site (<https://water.cybershare.utep.edu/swim>) and is accessible to stakeholders to conduct policy experiments or other modelling of the future of water resources in the region. There is also a GIS page on the project website for information dissemination and stakeholder’s training and for downloading products in GIS format. We developed cartographic base products and simulation results that can be represented geographically in a GIS-WEB system for online publication.

Aimed more at dissemination to the academic community, we hosted an annual water resources symposium each year of the project. This symposium, aimed especially at faculty and students from participating universities, but also key stakeholders, included at least one keynote guest speaker from outside the project, presentations of results from the project, and poster papers presented by students supported by the project. We generally had from 20-25 poster papers at each symposium. Attendance at these symposia varied from 50-75 people.

We implemented a number of field research projects in cooperation with farmers which of course also results in dissemination of results, and these are described under the stakeholder engagement objective (Section II. Obj. 4). We also implemented some demonstrations specifically aimed at dissemination. We implemented a total of five rainwater harvesting demonstrations in rural communities, called *colonias*, who lack piped water and who rely on hauled water for their household use. These are primarily rural communities of predominantly Hispanic residents located on the U.S./Mexico border that are remote, isolated, and poor. We implemented rainwater harvesting from rooftops at five homes in three different communities to demonstrate the technique. Residents used the collected rainwater to water landscaping, home gardens, small livestock, and pets, and thus reduced the amount of water that they had to haul by about half on the average. We also produced a written guide to rainwater harvesting from rooftops in English and Spanish, and we produced a training video, also in English and Spanish. These are available at the following website: <https://rainwaterharvestingdemo.weebly.com/guides.html>. Our project received an award for environmental education from the state of Texas for this work.

Another noteworthy dissemination activity in the final months of the project was the organization and implementation of a binational workshop based on Serious Games methodology. This workshop focused on the future of the Hueco Bolson, the major shared aquifer between Texas and Chihuahua and a major source of water for agriculture in Texas and Chihuahua and the cities of El Paso and Juárez. The workshop is described above under Obj. 4, but a key result for dissemination was that the results of the workshop were shared in presentations to a number of stakeholder groups, who showed keen interest in the results from this binational discussion of how to prolong the life of the Hueco Bolson.

Finally, we provide here a list of other noteworthy dissemination activities aimed at different types of stakeholders, not an exhaustive list, but key examples of our efforts to disseminate our results to a relatively wide audience. A more complete list is provided in the Outputs section of the report.

#### Dissemination to Agricultural Stakeholders

Dr. Richard Heerema who participates in our project, worked with Western Pecan Growers Association Board to organize an educational program on water management at their annual conference and tradeshow. Two invited speakers spoke on aspects of irrigation efficiency in pecan orchards: 1) “Hedging and tree water stress”, which led to an experiment conducted in the 2017 as part of the project; and 2) “Considerations in converting flood irrigated pecan orchards to micro-irrigation”. Heerema or his students also made the following presentations or published the following articles:

- Presentation at a pistachio workshop in Otero County, NM on the topic of “Orchard Irrigation”

- Presentation “Salinity Considerations for Pecan Orchards” at an El Paso County Pecan Growers Workshop
- Published article in Pecan South magazine (major trade magazine for pecan industry) on topic of irrigation scheduling
- Presentation "Drip Irrigation Studies (Student Research)", Western Pecan Growers Association Conference and Tradeshow, Las Cruces, NM, March 2, 2020. (slides available online at [https://aces.nmsu.edu/ces/pecans/documents/2020\\_6pierce.pdf](https://aces.nmsu.edu/ces/pecans/documents/2020_6pierce.pdf) )
- Published “Micro-Irrigation versus Flood Irrigation” in Pecan South. 53(6): 14-21
- Published “Your Pecan Tree’s Piggy Bank & Water Budgeting” in Pecan South 53(3): 6-11)
- Published “Revisiting Drip Irrigation for New Mexico Pecans: Recent studies at NMSU look at regulated deficit irrigation regimes in pecan orchards”  
(<http://www.wcngg.com/2020/07/10/revisiting-drip-irrigation-for-new-mexico-pecans/>)

Other presentations to agricultural stakeholders included:

- Stakeholders in southern New Mexico expressed an interest in water banking as a policy alternative to promote water conservation. A PhD student supported by the project delivered a seminar describing options for handling water banking at the NMWRRI water conference in Silver City in 2016
- Drought workshop co-sponsored with USDA Climate Science Hubs and TXAgriLife-El Paso; one-day workshop for stakeholders regarding how to manage under drought

#### Presentations to or Meetings with Government Agencies or Water Utilities

- Meeting with NM State Land Office personnel regarding climate change and land management
- Meeting with NM Bureau of Geology personnel on initial steps in development of a 50-year water plan for New Mexico, Dec 14, 2020 (plan development now underway).
- Presented “Listening to Complex and Diverse Stakeholders in the Paso Del Norte Water Region” at Public Science Day in Santa Fe, NM
- The Project PI and two Co-PIs were invited to attend a statewide planning meeting in Chihuahua City, Mexico hosted by the statewide water utility for professional water managers from all over Chihuahua. The Project Leader was invited to give the keynote address on the future of water in the region, based on project modeling results.
- Report on key findings for small utilities distributed to three utilities that provided interviews, Tornillo, TX; Anthony, TX; and Anthony, NM.

#### Presentations to Academic Audiences

- Presentation (regional water overview) to high school and college students at Water Resources and Conservation Symposium, sponsored by TX State Sen. José Rodríguez.
- Presentation on binational water issues to students from US and Mexico in study abroad exchange, through the 100,000 Strong in the Americas Innovation Fund awarded to UTEP and UNAM.
- A book chapter was published that discussed water issues in the Lower Valle de Juárez, Irrigation District # 9.
- One invited seminar delivered at Oregon State University by Frank A. Ward “Managing the Food-Energy-Water Nexus: An International Look,” November 2017.

- In 2019, our project and the Texas A&M-led project on the Rio Grande delivered a special session at the UCOWR conference in Utah. There were three presentations and a panel discussion about the future of water in the Rio Grande basin. The special session was entitled “Sustainable Water Resources for Irrigated Agriculture.”
- Thirty-three additional presentations were made at professional meetings, eight other kinds of invited presentations, and seven media interviews, all listed in this report under Outputs.

#### Presentations to Other Groups

- Screened a documentary entitled “Last Call at the Oasis” and hosted a panel discussion about global and regional water management challenges at El Paso Convention and Performing Art Center, open to the public. A total of about 60 participants attended the event.

#### **Objective 6. Water resources education and institutional strengthening.**

- New course developed in Yr 1 and offered in Yr 2 at UTEP, “Regional Water Sustainability in a Changing Climate”, at senior undergraduate and Masters graduate levels. The course combined field trips, laboratory techniques, lectures, discussions and data exercises to cover topics such as quality and quantity of freshwater resources in our region and the challenges we are facing. The course was team-taught, and multiple projects were designed to understand and solve local and regional water-related environmental problems. Through hands-on experiences and field trips, students were trained to collect data using state-of-the-art instruments and techniques, analyze their own data as well as larger, more complex datasets, and understand the importance of water resources in the societal stability. The course was offered each year of the project and now continues after the project ended.
- A new graduate seminar course at UNM was developed, entitled Climatic and Hydrologic Forecasting.
- UNM Co-PI Gutzler presented a well-attended (>150 people) departmental colloquium on hydroclimatic forecasting in the Earth & Planetary Sciences auditorium in 2016.
- Two new graduate level courses were developed and offered in 2016-2017 through Civil Engineering: Water Resources Management (CE 6313) and Surface Water Hydrology (CE 5340).
- Our project played a supporting role in water-themed study abroad program 100,000 Strong in the Americas Innovation Fund awarded to UTEP and UNAM based on our ongoing project on the Rio Grande.
- Dr. Pennington conducted a unique, ten-day summer workshop for Ph.D. students around the nation who are conducting research on large, interdisciplinary water resource projects. The workshop included content on regional water sustainability, methods that facilitate systems thinking and participatory modeling, and developed teamwork skills.
- A new graduate seminar course at UNM, entitled Climatic and Hydrologic Forecasting, was offered in 2017. The course evaluations from students were extremely enthusiastic (e.g. in response to the question "How much did you learn?" the average student score was 4.83 on a scale of 1-5).
- The Environmental Science undergraduate major at UNM was significantly revised to incorporate much more curricular structure, instead of just requiring a set number of credits from a wide variety of courses. The restructured major now includes required upper division courses in both Physical Hydrology and Climatology.

- An NMSU seminar series was established in 2016, with an emphasis on connections between water science, management, and policy.
- Educational modules on the Middle Rio Grande system were developed and used in an undergraduate geohydrology class, a graduate hydrology class, and a graduate mathematical modeling course at MTU.
- A Water Resources Seminar series was established at UTEP. On the average, six seminars were presented each year, primarily by speakers from outside of UTEP. Seminars were attended by UTEP, TAMU, and NMSU faculty and students and some local stakeholders.
- After moving from UTEP to Oklahoma State University, Dr. Ali Mirchi developed a graduate level course in Water Resources Management (BAE 6520) at OSU.
- This project significantly influenced UTEP's commitment to water resources education and research. UTEP hired (at its own expense) a Research Assistant Professor in Civil Engineering (Dr. Ali Mirchi) to bolster water resources education and research. After three years, that Dr. Mirchi left UTEP for a tenure track job, but UTEP hired a senior scientist in Civil Engineering. Dr. Alex Mayer, a participant in our project from Michigan Tech. Dr. Mayer led the formation of a water "cluster" of faculty whose interdisciplinary research is to be housed in UTEP's new Interdisciplinary Research Building. At the end of our project, UTEP also committed to hiring a social scientist in water resources in the Sociology Department. This position is under recruitment.

### **III. Project Outcomes/Impacts**

#### **1. Summary of Key Findings**

Our project focused on the future of water in our region, a region which is characterized by water scarcity and worsening conditions as supplies dwindle and demands rise. We took an integrated approach to water resources in our project. This unifies surface and subsurface water; issues of quantity and quality (primarily salt); agricultural, urban and industrial, and ecosystem services sectors; and three states (Texas, New Mexico, and Chihuahua) in two nations (the United States and Mexico). Our products were directed toward issues and questions identified at the start of the project by stakeholders. This has required a large and diverse team from six institutions. Our team was energetic and our work progress steady over the course of the project. In particular, the work of our modeling team culminated in making major models publicly available to stakeholders (SWIM, the GAMS Bucket Model, and the MRG Water Balance Model), as well as developing more computationally demanding models (SWAT-Modflow, SWAT-Salt, a variety of special field scale models, and geospatially explicit land use/land cover change) whose results have been provided to stakeholders.

Our key "take home messages" from the project as a whole include:

- There is a high probability of declining surface water inflows due to climate change in the Rio Grande headwaters.
- There is increased risk of prolonged surface water shortages; Elephant Butte (EB) Reservoir will frequently be below 10% and 50% full, under current operation protocols.
- EB Reservoir will meet irrigation demands only 20% of the time under a plausible, drier future climate scenario; relatively low volumes of water would be required for environmental pulse flows and would result in relatively small reductions in the total supply of water for other uses in the region.
- Increased groundwater extraction will be the response to decreased surface water supply.



- Most of groundwater pumped and surface water delivered are consumed via ET.
- There is very little natural aquifer recharge; much more is pumped than is replaced; flood irrigation using surface water does provide some recharge to groundwater, but flood irrigation using groundwater provides only return flow not really recharge; freshwater depletion in the regional aquifers is likely before the end of the century without changes in management, technologies, and/or policies.
- Policy, management, and/or conservation changes could extend the life of freshwater supplies in local aquifers, but not indefinitely, and will come at a high cost. More brackish water is already intruding; this will require difficult and expensive adaptations by cities and agriculture, and could even curtail the practice of agriculture due to lack of affordable water.
- Greater systemic efforts at conservation, use of brackish water (desalination and salt-tolerant crops), increased reuse through water treatment, managed aquifer recharge, and possibly water importation will all be necessary.
- The net result is not that we will “run out” of water, but that water of usable quality will be much more costly in the future; who will bear the cost?

We have identified a number of overarching conclusions and significant recommendations based on these key findings:

- “Business as usual” is not sustainable; if climate actually turns out to be warmer and drier, which is likely, the situation can even be perilous, and if much drier, which is plausible, even catastrophic. Water management across all sectors and jurisdictions must be improved to realize a more sustainable future. Both for agriculture and urban uses, several alternatives are possible, but all are costly, some more than others. Water will become more expensive for all users as these alternatives are implemented.
- On a larger regional and jurisdictional scale, a new approach is called for, one based on “adaptive cooperation”, among sectors and across jurisdictions. Our future as a viable community depends on joint action.
- Adaptive cooperation is needed across four important themes:
  - Information sharing
  - Conservation
  - Greater development and use of alternative water sources
  - New limits to water allocation/withdrawals coupled with more flexibility in uses

In the waning months of the project, we spent time disseminating these findings and recommendations, including potential solutions, to stakeholders, especially in irrigated agriculture, but also across the various sectors and geographies. We have generated considerable interest in our results and anticipate widespread impacts as our project continues to share results and generate interest in actions to ensure a sustainable future for water in our region.

## **2. Summary of Broader Impacts**

The integrated, holistic nature of our approach that combined interdisciplinary team-based science with stakeholder participation resulted in a number of positive impacts listed below:

- We designed and implemented processes and activities within the modeling team that resulted in effective collaboration across disciplines, institutions, and modeling strategies, generating an unusually high-performing large research team.

- We converged on novel, interesting insights about the water socio-environmental system(s) and have conveyed these insights to stakeholders in meaningful ways.
- We facilitated processes for collectively considering actions that could improve water sustainability in this region.
- Our online modeling infrastructure has provided stakeholders with a user-friendly tool to evaluate the future of water in the region on their own. We know that we have more than 200 registered users, and the map visualization has been accessed more than 61,000 times.
- Our students have demonstrated excellence in their ability to grasp complex water sustainability issues and collaborate across disciplines to address such issues.
- Project results have been used in local decision making by a variety of groups and stakeholders, including the state water utility in the state of Chihuahua in Mexico, the irrigation district in Chihuahua, the utility in Ciudad Juárez, El Paso Water, the New Mexico Office of the State Engineer, New Mexico farmers, and the governments of Costa Rica and Kenya. Research methods and results are informing a PEER funded project on water conservation in Tunisia.
- We have strengthened bonds of mutual trust between U.S. and Mexican water managers and scientists. This includes shared data, models, and meetings. We laid a foundation for building improved transboundary water cooperation and are building toward binational actions to prolong the life of our shared aquifer.
- Our work in rural communities who lack access to water (*colonias*) includes pilot testing rainwater harvesting systems for residents to collect water for outdoor uses like gardens, landscaping, and small livestock. Our work in Las Pampas resulted in reducing the amount of water that residents have to haul by about one half. Work in Cochran Mobile Home Park resulted in plans for collaboration with the Lower Valley Water District to promote “soft path to water” strategies for *colonias* for which piped water might not be a financial reality.

The broad impacts of our project, though not complete, have ranged from very local to international. We anticipate even greater impacts as we continue to disseminate final results and facilitate discussions of a variety of interventions to improve the future of water in our region. We provide more detail on some of these impacts below.

### **3. Impacts Resulting from Collaboration with Mexico**

The direct participation of the Universidad Autónoma de Ciudad Juárez (UACJ) as a full partner in our consortium resulted in a level of participation and collaboration that is rare, if not unique, in water resources research in the portion of the Rio Grande basin centered in the El Paso/Ciudad Juárez region. Through this project, we made great strides in removing what is commonly referred to as the “white map syndrome” in water resources research, a focus in each country on only their portion of the basin resulting in blank space for the other country’s portion on the opposite side of the river. Our modeling results includes both sides of the border in every respect, not an easy feat considering unequal and dissimilar sources, categories, and levels of data available to support models. The result is unique modeling products that include the total area of the basin in our study area. This resulted in a number of significant outcomes and impacts for our team in Mexico.

- UACJ team members were invited to participate in the II Water Governance Forum of the Rio Bravo Basin Council and the Regional Forum for the Construction of a New National Water Law.
- Both UACJ and UTEP team members were invited to participate in a planning meeting for the state of Chihuahua organized by the Junta Central del Agua de Chihuahua; the project PI was invited to present the keynote address.
- UACJ team members were invited to participate in the State Water Plan Workshop organized by the Junta Central de Agua y Saneamiento of Chihuahua.
- UACJ team members were invited to participate in the round table discussions of Rural Development and Public Policies 2020. This event was organized by Congressmen Francisco Humberto Chavez, President of the Water Commission in the Chihuahua Congress.
- Three UACJ students supported by the project were invited to participate in the meeting of Young Researchers of the State of Chihuahua in 2019; the students were members of the UACJ SWAT modeling team.
- Research focused on the analysis of the water balance and the impacts of water recharge under different irrigation efficiencies and crop changes, using SWAT in Irrigation District 09 in the Valle de Juárez Valley, resulted in a technical report of high value to the irrigation district (CONSTRUCTION OF THE FLOW MODEL OF THE JUÁREZ VALLEY AQUIFER).
- Several peer reviewed papers were published jointly by U.S. and Mexican colleagues and students (Alger et al., 2020; Hargrove et al., 2020; Sotos Ontiveros et al., 2019; Granados et al., 2019).

#### **4. Use of project results in local decision-making**

Chihuahua. Discussion of published results of rainfall shortages in short-term climate scenarios supported the decision of the State of Chihuahua Water Utility (JCAS) to implement executive projects for the use of green infrastructure as a strategy to capture more water while reducing flooding in 24 sectors of Ciudad Juárez. Also, the UACJ team collaborated with the Irrigation District 009 Valle de Juárez CONAGUA officer to provide modeling information and are evaluating how the resulting integrated hydrological data will support decision making to enhance irrigation water efficiency in the district. The groundwater model for the urban area of Ciudad Juárez has been shared with state and local water agencies (JCAS-JMAS) so that they can evaluate future urban water demands.

Texas. El Paso Water is using modeling results to consider the impact of irrigation on the total water budget for the region. El Paso Water is implementing conservation measures for surface water and groundwater using estimated amount of water demand in terms of time, location, and quantity from modeling results.

New Mexico. NMSU team members held several stakeholder meetings to inform policy debates in the region from which behavior could be altered in light of information on drought and climate water stress.

The New Mexico Office of the State Engineer has asked NMSU participants on the USDA project to conduct a study on economic impacts of drought in New Mexico to guide their behavior in formulating drought mitigation plans.

About 55 stakeholders attended a project demonstration meeting held in Las Cruces in 2019. One of the attendees asked for a documentation of our work in order that he could conduct policy experiments using our SWIM model as it would affect his pecan farming operations.

The New Mexico Office of the State Engineer requested project team members to develop an economic model of water use in southwest New Mexico to assess the economic performance of in proposed new reservoir storage to be used for urban and agricultural water use.

UNM Co-PI Gutzler incorporated project results into testimony he gave as an expert witness at a New Mexico District Court hearing on water rights in Albuquerque in March 2018. At issue was the need to include climate change information in regulatory assessments of future water availability in New Mexico before allocating new rights to pump groundwater. Gutzler cited climate projections that indicate pronounced future declines in snowpack and increases in evaporative losses; both processes strongly affect recharge at the location of the proposed pumping site. The judge at the hearing denied the application in January 2019, citing (among other reasons) that "Applicant did not consider climate change in preparing its water demand or hydrologic analyses. The data surrounding climate change indicate that the availability of surface water will decline during the life of this proposed development. Applicant's failure to include this in its analysis, suggests a lack of long-term planning regarding conservation. Application is denied as it is not consistent with conservation." To our knowledge this is the first explicit decision by regulatory authorities in New Mexico affirming that ongoing climate change must be an integral component of water rights allocation and decision-making under existing New Mexico state law.

## **5. Global outcomes**

Our project fostered international collaborations between project team members and Tunisian scientists through a research project funded by the US Agency for International Development's (USAID) Partnership for Enhanced Engagement in Research (PEER) program ("The use of modeling, monitoring and smart metering for sustainable groundwater management in a Tunisian coastal aquifer"). Ali Mirchi, who represents our team as the U.S.-Sponsored partner on the PEER project, developed a partnership with Tunisian counterparts following presenting agricultural water management research results from our USDA-funded project at the National Academy of Sciences' fifth Arab-American Frontiers Symposium in Morocco. The project in Tunisia leverages farm-level water-energy nexus to support sustainable agriculture by piloting a stakeholder-centered groundwater management network in a coastal region that faces groundwater depletion and seawater intrusion. The research team is investigating the potential of smart agricultural water management as an innovative strategy for creating new agribusiness opportunities in a rural developing country setting while addressing water sustainability challenges. The project facilitates the transfer of smart energy and water metering (SEWM) technology to Tunisia in order to develop an innovative cost-effective strategy to mitigate groundwater depletion by building local capacity to implement data-driven water resources

management. More about this project can be found at:

<https://content.govdelivery.com/accounts/USDANIFA/bulletins/25c041c>

Also, project team members from NMSU advised governments of Costa Rica and Kenya on measures to promote water conservation, using principles and methods developed from this project.

#### **IV. Project Outputs**

We summarize project outputs as follows:

Peer-Reviewed Publications	74
Non-Peer Reviewed Documents/Publications	8
Invited Presentations	10
Presentations at Professional Meetings	58
Poster papers presented by our students	89
Public presentations/media interviews	15
Hosted Symposia	4
Hosted Special Seminars with Invited Speakers	20

Specific outputs are listed in the following sections for each output type.

##### **A. Peer-Reviewed Publications (by year)**

###### 2015-2016, Yr1

(None)

###### 2016-2017, Yr 2

1. Eastoe, Christopher, Alfredo Granados-Olivas and Barry Hibbs, 2016. Tracers of Groundwater Mixing in the Hueco Bolson Aquifer, Ciudad Juárez, Mexico. *Environmental & Engineering Geoscience*, Vol. XXII, No. 3, August 2016, pp. 195–207
2. Granados-Olivas, Alfredo, Luis Carlos Alatorre-Cejudo, David Adams, Yolande L. Serra, Víctor Hugo Esquivel-Ceballos, Felipe Adrián Vázquez-Gálvez, Maria Elena Giner, and Chris Eastoe, 2016. Runoff Modeling to Inform Policy Regarding Development of Green Infrastructure for Flood Risk Management and Groundwater Recharge Augmentation along an Urban Subcatchment, Ciudad Juárez, Mexico, *Journal of Contemporary Water Research & Education*, Special Issue: Groundwater in Urban Areas. Issue No. 159, December 2016. Pag. 50-61. ISSN 1936-7031
3. Jones, S., and D.S. Gutzler, 2016: Spatial and seasonal variations in aridification across Southwest North America. *Journal of Climate*, v 29, 4637-4649.
4. Ramírez-Villazana, O., A. Granados-Olivas, A. Pinales-Munguía. 2016. Clasificación geoespacial de los indicadores del medio físico para la recarga del acuífero Palomas-Guadalupe Victoria, Chihuahua, México. *TECNOCENCIA Chihuahua* 10(1): 32-38.
5. Ward, F. A., Crawford, T. L. (2016). Economic performance of irrigation capacity development to adapt to climate in the American Southwest. *Journal of Hydrology*, 540 (September 2016), 757-773.
6. Ward, F. A. (2016). Policy Challenges Facing Agricultural Water Use: An International Look. *Water Economics and Policy*, 3(2), 14.

#### 2017-2018, Yr 3

1. Acquah, Sarah, and Frank A. Ward, “Optimizing Adjustments to Transboundary Water Sharing Plans: A Multi Basin Approach,” Water Resources Management, DOI 10.1007/s11269-017-1794-3, August 2017.
2. Chavarria, S.B, and D.S. Gutzler, 2018: Observed changes in climate and streamflow in the upper Rio Grande basin. *J. American Water Resources Assn.*, accepted for publication.
3. Cox, C., L. Jin, G. K. Ganjegunte, D. Borrok, V. Loughheed, and L. Ma. 2018. Soil Quality changes due to flood-irrigation in agricultural fields along the Rio Grande in western Texas. *Applied Geochemistry* 90:87-100.
4. Ganjegunte, G.K. and J.A. Clark. 2017. Improved Irrigation Scheduling for Freshwater Conservation in the Desert Southwest U.S. *Irrigation Science* 35: 315-326.
5. Ganjegunte, G.K., A. Ulery, G. Niu, Y. Wu. 2017. Effects of Treated Municipal Wastewater Irrigation on Soil properties, Switchgrass Biomass Production and Quality under Arid Climate. *Industrial Crops and Products* 99:60-69.
6. Ganjegunte, G.K., B. Leinauer, E. Sevostianova, M. Serena and R. Sallenave. 2017. Soil salinity of an urban park after long-term irrigation with saline groundwater. *Agronomy Journal* 109:3011-3018.
7. Ganjegunte, G.K., G. Niu, A. Ulery, and Y. Wu. 2018. Treated urban wastewater irrigation effects on bioenergy sorghum biomass, quality and soil salinity in an arid environment. *Land Degradation & Development* 29:534–542.
8. Ganjegunte, G.K., G. Niu, A. Ulery, Y. Wu. 2018. Organic carbon, nutrient, and salt dynamics in saline soil and switchgrass (*Panicum virgatum* L.) irrigated with treated municipal wastewater. *Land Degradation & Development* 29: 80-90.
9. Granados Olivas, Alfredo, Arturo Soto Ontiveros y Ana Cristina García Vásquez, 2017. Agua del Valle de Juárez: caso localidad de Práxedes. El Valle de Juárez: su historia, economía y ambiente para el uso de energía fotovoltaica. El Colegio de Chihuahua, Esmeralda Cervantes Rendón / Coordinadora. Primera edición 2017. Pag 37-79. ISBN: 978-607-8214-43-3
10. Habteyes, Befekadu, and Frank A. Ward, “Economic Performance of Water Conservation and Storage Capacity Development to Adapt to Climate in the American Southwest,” New Mexico Water Resources Research Institute Technical Report, July 2017.
11. Villanueva-Rosales, N., Chavira, L.G., Tamrakar, S.R., Pennington, D., Vargas-Acosta, R. A., Ward, F., and Mayer, A.S. (2017). Capturing scientific knowledge for water resources sustainability in the Rio Grande area. *Proceedings of the Second International Workshop on Capturing Scientific Knowledge*, D. Garijo and M. de Vos, Editors, December 4, 2017, Austin, Texas.

#### 2018-2019, Yr 4

1. Mirchi, A., Heyman, J., Tchobanoglous, G., Minakata, D., Walker, S., Samimi, M., Guerrero, B., Handler, R. 2019. Community implementation of potable reuse of treated wastewater. In: Halvorsen, K.E., Schelly, C., Handler, R., and Knowlton, J.L. (Eds.). *A Research Agenda for Environmental Management*, 169–181. Cheltenham, UK: Edward Elgar Publishing. DOI:10.4337/9781788115193.00025
2. Mubako, Stanley, Omar Belhaj, Josiah Heyman, William Hargrove, and Carlos Reyes. 2018. Monitoring of Land Use/Land-Cover Changes in the Arid Transboundary Middle Rio Grande Basin Using Remote Sensing. *Remote Sensing* 10(12): 2005;

<https://doi.org/10.3390/rs10122005>

3. Chavarria, S.B., and D.S. Gutzler, 2018. Observed changes in climate and streamflow in the upper Rio Grande basin. *J. American Water Resources Assn. (JAWRA)*, 54:644–659.
4. Ward, F.A., A.S. Mayer, L.A. Garnica, N.T. Townsend and D.S. Gutzler, 2019. The economics of aquifer protection plans under climate-water stress: New insights from hydroeconomic modeling. *J. Hydrology*, 576:667-684.
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4. Samimi, M., Mirchi, A., Townsend, N.T., Gutzler, D.S., Daggubati, S.†, Ahn, S., Sheng, Z., Moriasi, D., Granados-Olivas, A., Alian, S., Mayer, A., and Hargrove, W.L. Climate change impacts on water availability in a semi-arid, agriculture-dominated basin in the US Southwest. JAWRA Journal of the American Water Resources Association. 2021.
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7. Chaganti, V.N., G.K. Ganjegunte, G. Niu, A. Ulery, R. Flynn, J.M. Enciso, M.N. Meki, and J. Kiniry. 2020. Effects of treated urban wastewater irrigation on bioenergy sorghum and soil quality. *Agricultural Water Management*, 105894
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13. Mayer, A., Tavakoli, H., Fessel Doan, C., Heidari, A. and Handler, R., 2020. Modeling water-energy tradeoffs for cultivating algae for biofuels in a semi-arid region with fresh and brackish water supplies. *Biofuels, Bioproducts and Biorefining*, 14(6), pp.1254-1269.
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15. Hargrove, William L., and Josiah M. Heyman. 2020. “A Comprehensive Process for Stakeholder Identification and Engagement in Addressing Wicked Water Resources Problems,” *Land* 9(4): 119.
16. Granados Olivas, Alfredo; Luis Carlos Alatorre Cejudo; Josiah M. Heyman; Arturo Soto Ontiveros; Adán Pinales Munguia; Sergio Saúl Solís; Hugo Luis Rojas Villalobos, Adrián Vázquez Gálvez, María Elena Torres Olave; Luis Carlos Bravo Peña; Oscar Ibañez; William L. Hargrove; Alex Mayer y Zhuping Sheng. 2019. “Las oportunidades para la sustentabilidad hídrica en las Cuencas de Chihuahua: Estrategias para compensar las demandas socioeconómicas y ambientales ante los retos del cambio climático (Agua-Energía-Alimentación),” in Germán Eduardo Dévora Isiordia and Esmeralda Cervantes Rendón, coords. *Problemáticas del agua y medidas sustentables en estados desérticos de México, caso Chihuahua*, pp. 34-49. Ciudad Obregon, Son., Mexico: Instituto Tecnológico de Sonora ITSON.

17. Soto Ontiveros, A., Granados Olivas, A., Pinales Munguía, A., Saúl Solís, S., & Heyman, J. 2019. "Evolución temporal del flujo del agua subterránea en Ciudad Juárez, Chihuahua aplicando modelación geoespacial," *TECNOCIENCIA Chihuahua*, 12(2), 103-113.  
<https://vocero.uach.mx/index.php/tecnociencia/article/view/150>
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19. Alatorre Cejudo, Luis Carlos, Alfredo Granados-Olivas, Luis Carlos Bravo, Maria Elena Torres, Lara Cecilia Wiebe, Mario Ivan Uc, Manuel Octavio Gonzalez, Erick Sanchez, Victor Manuel Salas, 2019. Agricultural furrow irrigation inefficiency in the basin of the Laguna de Bustillos, Chihuahua, Mexico: Geometric characteristics of agricultural plots and aquifer depletion. *Tecnología y Ciencias del Agua*, 2019. Accepted for publication. ISSN electrónico: 2007-2422 ISSN impreso: 0187-8336 DOI: 10.24850/j-tyca-imta
20. Application of a calibrated model for calculating the concentration of chlorine in the drinking water network of the Colonia Anapra , in Cd. Juárez, Chih., México, 2019 (in edition). LUIS IGNACIO PRIETO-ARMENDARIZ; ALFREDO GRANADOS-OLIVAS; RANULFO LEMUS-SÁNCHEZ; OSCAR F. IBAÑEZ-HERNANDEZ. *Tecnociencia*, Chihuahua.
21. Adán Pinales Munguía, Alfredo Granados Olivas, Arturo Soto Ontiveros, William L. Hargrove, Josiah M. Heyman, Zhuping Sheng, Humberto Silva Hidalgo, María Socorro Espino Valdés, 2020. SIMULATION OF GROUNDWATER IN AQUIFERS WHOSE MAIN USE IS URBAN PUBLIC SUPPLY. CASE STUDY: VALLE DE JUAREZ AQUIFER. Mexican Geophysical Union. Reunión Anual UGM 2019,  
<https://www.raugm.org.mx/2019/>
22. Townsend, N.T., and D.S. Gutzler, 2020: Adaptation of climate model projections of streamflow to account for upstream anthropogenic impairments. *Journal of the American Water Resources Association*, v 56, p 586–598. doi.org/10.1111/1752-1688.12851.
23. Poulouse, Thomas, Saurav Kumar, and Girisha K. Ganjegunte. 2020. "Robust crop water simulation using system dynamic approach for participatory modeling." *Environmental Modelling & Software* 135 (2021): 104899.

#### 2021, No Cost Extension and Post-Project

1. Capt, T., Mirchi, A., Kumar, S., Walker, W. S. (2021). Urban water demand forecasting: A statistical modeling approach. *Journal of Water Resources Planning and Management*, 147(2): 04020105.
2. Chaganti, V., G.K. Ganjegunte, A. Somenahally, W. Hargrove, A. Ulery, J. Enciso, and R. Flynn. 2021. Response of soil organic carbon and emerging soil health indicators to treated wastewater irrigation in bioenergy sorghum production on an arid soil. *Land Degradation and Development* (Accepted, <https://doi.org/10.1002/ldr.3888>).

## **B. Other Documents, Non-Peer Reviewed**

1. Tippin, Chilton. Securing water for an unserved El Paso County community: A report on water needs, economic hardships, and potential solutions for Cochran Mobile Park. [Also translated to Spanish]. Document provided to community and policy makers.
2. Tippin, Chilton, What are the benefits of water infrastructure? A case study of Socorro and San Elizario, Texas. One page fact sheet for policy makers.
3. Miguel Duran Rangel *et al.* (2019). *Modelación hidrológica de recarga al acuífero Bolsón del Hueco, simulando efectos por inclusión de políticas de administración del agua*. Congreso Jóvenes Investigadores, UACJ.
4. Katya Esquivel *et al.* (2019). Modelación hidrológica de la recarga del valle de Juárez de 1995 al 2040, incorporando un modelo de cambio climático RCP 4.5 Congreso Jóvenes Investigadores, UACJ.
5. Lowe, Kiah S, Hormat Shadgou, Jennifer Randall, Richard J. Heerema, Rolston, St. Hilaire, “Molecular Approaches to Decipher Alternate Bearing in Pecans,” Hortscience, Volume 54, Issue 9, pages, Abstract, S330-S331.
6. Pierce, Curt A., Blair L. Stringam, and Richard J. Heerema, “Assessing Water Use Efficiency in Field-Grown Pecans Under a Partial Root Zone Drying Irrigation Regime,” Abstract, Hortscience, Volume 54, Issue 9, pages S329-S330.
7. Ganjegunte, G. and G. Lucas. 2019. Managing salt loading through irrigation practices. Ag Mag 32 (Nov-Dec), 12-13.
8. Executive summary of Water Banking Workshop, 2017 (partial credit; co-hosted with NM Water Resources Research Institute); see <http://waterbank.nmsu.edu/speaker-slides/>

## **C. Invited Presentations**

1. Gutzler, D.S., S.B. Chavarria and N.R. Bjarke. 2020. “Water supply predictions in a changing climate” [invited keynote address] Texas Weather Conference, (online, based in Lubbock TX).
2. Mirchi, A. “Future Climate Impacts in the Middle Rio Grande”, Fall Science Meeting 2020, South Central Climate Adaptation Science Center. October 2020.
3. “Diminished snowmelt runoff in western rivers” [invited presentation and panelist] Gutzler, D.S., N.R. Bjarke and N.T. Townsend GSA Annual Meeting, Pardee Symposium on Challenges and Solutions for a Changing Climate, (online, based in Montreal), Oct 30 2020.
4. Mirchi, A. Transboundary water management in the Middle Section of the Rio Grande River and PEER Tunisia, 2019 PEER Forum - Transboundary Water Research in Central Asia, Tashkent, Uzbekistan, October 2019.
5. Mirchi, A. Implications of future climate scenarios for water availability in the Middle Rio Grande Basin, Southern Plains Climate Science Seminar Series, Norman, Oklahoma (broadcast webinar), June 2019.
6. Gutzler, D.S. (2018). Drought and future water supplies for southern New Mexico, Las Cruces Public Library, Mar 1, 2018.
7. Gutzler, D.S. (2018). Climate change, 21st Century droughts, and the looming water resource crisis in southwestern United States”, invited presentation, Instituto Mora, Mexico City, Oct 12, 2018.
8. Gutzler, D.S. (2018). Climate Change and the Future of the Rio Grande.Southwest Seminar series, Santa Fe, Nov 19, 2018.

9. Gutzler, D.S. (2019). Climate change and New Mexico water resources. Testimony presented to NM House of Representatives Energy, Minerals and Natural Resources Committee, Santa Fe, Jan 17, 2019. (media coverage of this presentation appeared the next day in the *Santa Fe New Mexican* and *Las Cruces Sun-Times* newspapers)
10. Gutzler, D.S. (2019). Drought in New Mexico - Yes it's still here. Invited presentation to Rotary Club of Albuquerque, Feb 4, 2019.
11. Townsend, N.T. (2019). Adaptation of climate model projections of streamflow to account for anthropogenic flow impairments. Invited presentation to US Bureau of Reclamation, Albuquerque office, Feb 22, 2019.
12. Ganjgunte, G.K. 2020. Water Resources and Salinity Management in the Middle Rio Grande Basin. Department of Soil & Crop sciences seminar, Texas A&M University, October 7, 2020, Virtual.
13. Ganjgunte, G.K., V.N. Chaganti, B. Leinauer, and S. Kumar. 2019. Managing soil salinity and sodicity in a west Texas golf course irrigated with treated wastewater. Global Forum on Innovations for Marginal Environments, November 20-21, 2019, Dubai, UAE.

#### **D. Conference and Other Presentations (by year)**

##### **2018**

1. Gutzler, D.S. (2018). Drought and the Rio Grande. Two Nations One Water Border Water Summit, El Paso, Mar 1, 2018.
1. Samimi, M., Mirchi, A., Hargrove, W., Heyman, J., Townsend, N, Gutzler, D., Ahn, S.R. and Sheng, Z. (2018). Stakeholder driven watershed modeling to inform drought-adaptive water management in the Rio Grande Project Area. International Congress on Environmental Modelling and Software, Ft Collins CO, June 25, 2018.
3. Mirchi, A., Samimi, M., Townsend, N., Gutzler, D., and Hargrove, W. (2018). Adaptive agricultural water management in a desert river basin facing drought and competing demands. International Congress on Environmental Modelling and Software, Ft Collins CO, June 26, 2018.
4. Gutzler, D.S. (2018). Climate change and snow-fed rivers in the southwestern United States. Octavo Congreso Nacional de Investigación en Cambio Climático, Mexico City, Oct 11, 2018.
5. Mayer, A.S., Ward, F.A., Gutzler, D.S., and Townsend, N.T. (2018). Economics of aquifer protection plans under climate-water stress uncertainty: New insights from hydroeconomic modeling. American Geophysical Union Fall Meeting, Washington DC, Dec 10, 2018.
6. Leister, S.D., and Gutzler, D.S. (2018). Analysis of observed and projected interannual variability of North American Monsoon precipitation. American Geophysical Union Fall Meeting, Washington DC. Dec 10, 2018.
7. Townsend, N.T., and Gutzler, D.S. (2018). Are southwestern rivers sustainable? Impacts of climate change and severe drought on water availability along the Rio Grande. American Geophysical Union Fall Meeting, Washington DC. Dec 14, 2018.
8. Samimi, M., Mirchi, A., Ahn, S., Moriasi, D., Sheng, Z., Tahneen Jahan, N., Alian, S. Challenges of calibrating SWAT for arid/semiarid agricultural regions. American Geophysical Union Fall Meeting 2018, Washington, D.C.
9. Mirchi, A., Samimi, M. Water resources modeling to inform adaptive water management in the Middle Rio Grande Basin. Oklahoma Governor's Water Conference 2018. Midwest City, Oklahoma.

10. Samimi, M., Mirchi, A., Hargrove, W., Heyman, J., Townsend, N., Gutzler, D., Ahn, A., Sheng, Z. Stakeholder driven watershed modeling to inform drought-adaptive water management in the Rio Grande Project Area. 9th International Congress on Environmental Modelling and Software 2018: Modelling for Sustainable Food-Energy-Water Systems, The International Environmental Modelling & Software Society (iEMSs), Fort Collins, Colorado.
11. Capt, T., Walker, S., Mirchi, A. Arid region urban water demand: A flexible predictive model for five-year forecast on daily timescale. 9th International Congress on Environmental Modelling and Software 2018: Modelling for Sustainable Food-Energy-Water Systems, The International Environmental Modelling & Software Society (iEMSs), Fort Collins, Colorado.
12. Tahneen Jahan, N., Samimi, M., Kumar, S., and Mirchi, A. Assessing the compounding impact of precipitation and land use change on runoff in a semiarid watershed. World Environmental and Water Resources Congress 2018, Minneapolis, Minnesota.
13. Samimi, M., Tahneen Jahan, N., and Mirchi, A. Assessment of climate change impacts on surface water hydrologic processes in New Mexico-Texas-Mexico border region. World Environmental and Water Resources Congress 2018, Minneapolis, Minnesota.
14. Bahaddin, B., Mirchi, A., Watkins Jr., D.W., Ahmad, S., Rich, E., Madani, K. System archetypes in water resources management. World Environmental and Water Resources Congress 2018, Minneapolis, Minnesota.
15. Mirchi, A., Samimi, M., Townsend, N., Gutzler, G., Hargrove, W. Adaptive agricultural water management in a desert river basin facing drought and competing demands. 6th International Water Forum Conference 2018, Hammamet, Tunisia.
16. Mayer, A., "Coping with uncertainty: Water tales from the Wild West and elsewhere, Michigan Technological University Inaugural University Professor Research Forum, "Houghton, Michigan, October 2018.
17. Townsend, N.T., Gutzler, D.S., Mayer, A., and Thiemann, K. "Impacts of climate change and severe drought on water availability along the Rio Grande Basin," American Geophysical Union Meeting, Washington, DC, December 2018.
18. Ward, F., Mayer, A., Garnica, L., Townsend, N., Gutzler, D. "Economics of Aquifer Protection Plans under Climate-Water Stress Uncertainty: New Insights from Hydro-Economic Modeling," American Geophysical Union Meeting, Washington, DC, December 2018.
19. Hargrove, W. and A. Mayer, "Sustainable Water Resources for Irrigated Agriculture in a Desert River Facing Drought and Competing Demands: From Characterization to Solutions," USDA NIFA Project Meeting, Newark, Delaware, October 2018.

## 2019

1. Pierce, C. (Presenter), Heerema, R., Stringam, B. "Does a partial root zone drying irrigation regime increase water use efficiency in field-grown pecans?". International Conference on Irrigation and Drainage, United States Committee on Irrigation and Drainage, Reno, NV, November 6, 2019.
2. Sheng, Z., Ahn, S., Jung, C., Park, S., Bailey, R., Granados-Olivas, A., Mirchi, A., Samimi, M.\*, Hargrove, W.L. Coupled SWAT-MODFLOW modeling for determining groundwater sustainability under climate and pumping scenarios in a semi-arid agricultural watershed. American Geophysical Union Fall Meeting 2019, San Francisco, California.

3. Bailey, R., Samimi, M., Mirchi, A., Ma, L. Assessing salt ion fate and transport in arid regions using SWAT-Salt. International Soil and Water Assessment Tool (SWAT) Conference, July 15-19, 2019, Vienna, Austria.
4. Samimi, M., Mirchi, A., Townsend, N.T., Gutzler, D.S., Ahn, S., Moriasi, D., Granados-Olivas, Mayer, A., Alian, S., Hargrove, W.L. Climate change impact assessment for an agricultural watershed in the US Desert Southwest. American Geophysical Union Fall Meeting 2019, San Francisco, CA.
5. Koushki, R., Mirchi, A., Alian, S. Urban water management outlook in the Southwestern and South Central United States. American Geophysical Union Fall Meeting 2019, San Francisco, CA.
6. Mirchi, A., Samimi, M., Bailey, R., Ma, L. Modeling salinity in a semi-arid agricultural watershed using SWAT-Salt. American Geophysical Union Fall Meeting 2019, San Francisco, CA.
7. Mirchi, A., Using models to address stakeholder concerns, assess management and/or policy interventions, and evaluate water futures using scenarios, Panel held in session entitled Sustainable Water Resources for Irrigated Agriculture at the Universities Council on Water Resources (UCOWR) conference 2019, Snowbird, Utah, June 2019.
8. Mirchi, A., Adaptive water management in the Middle Rio Grande Basin: Insights from watershed modeling, Annual Meeting of the Oklahoma Section of ASABE, February 2019.
9. Ganjegunte, G.K. Kumar, S., C. E. Cisneros, Z. Sheng, and **G. K. Ganjegunte**. 2019. Exploring Field Scale Heterogeneity in Agroecosystem Modeling with Aerial Evapotranspiration Estimates. AGU Fall Meeting, December 9-13, 2019, San Francisco, CA.
10. G. K. Ganjegunte, V.N. Chaganti, and A. Somenahally. 2019. SOC, N, P and K Dynamics in Saline Soils Irrigated with Treated Municipal Wastewater to Produce Energy Sorghum in Arid West Texas. ASA, CSSA and SSSA International Annual Meeting: "Embracing the Digital Environment", November 10-13, 2019, San Antonio, TX.
11. Flynn, R. P., G. K. Ganjegunte, L. M. Lauriault, and A.L. Ulery 2019. Demonstration of Bioenergy Crop Growth in New Mexico Under Saltwater Irrigation. International Annual Meetings of ASA, CSSA and SSSA: "Embracing the Digital Environment", November 10-13, 2019, San Antonio, TX.
12. Chaganti, V.N., G. K. Ganjegunte, and W.L. Hargrove. 2019. Evaluating the Phytoremediation Potential of Barley Grown on Salt-Affected Soils. ASA, CSSA and SSSA International Annual Meeting: "Embracing the Digital Environment", November 10-13, 2019, San Antonio, TX.
13. Torres, D.S., W. L. Hargrove, S. Kumar, V. N. Chaganti, R. J. Heerema, and G. K. Ganjegunte. 2019. Water Evaporation from the Soil Surface in Flood-Irrigated Pecans. ASA, CSSA and SSSA International Annual Meeting: "Embracing the Digital Environment", November 10-13, 2019, San Antonio, TX.
14. The Political Ecology of New Technologies, Practices, and Allocations of Water. Session at the Political Ecology Society 2019 meeting, in conjunction with the Society for Applied Anthropology meeting, Portland, OR, March 19-23, 2019. Organized by Josiah Heyman.
15. Heyman, Josiah. The Political Ecology of Direct Potable Reuse in El Paso, Texas. Political Ecology Society 2019 meeting, in conjunction with the Society for Applied Anthropology meeting, Portland, OR, March 19-23, 2019.
16. Gutzler, D.S. (2019). How climate change is affecting the Rio Grande. Two Nations One Water US-Mexico Border Water Summit, Las Cruces NM, Apr 24, 2019.

17. Townsend, N.T., and Gutzler, D.S. (2019). Impacts of climate change and severe drought on water availability in the upper Rio Grande. Two Nations One Water US-Mexico Border Water Summit, Las Cruces NM, Apr 24, 2019.
18. Samimi, M., Mirchi, A., Townsend, N.T., Gutzler, D.S., Ahn, S.R., Sheng, Z., Moriasi, D., Granados-Olivas, A., and Hargrove, W. (2019). Climate change impact assessment for an agricultural watershed in the U.S. desert Southwest. American Geophysical Union Fall Meeting, San Francisco CA, Dec. 11, 2019.
19. Alger, J., Mayer, A. and S. Kumar, "Urban Evapotranspiration in Water Scarce Regions – Estimates for the Middle Rio Grande Region, United States and Mexico," Urban Evapotranspiration in Water Scarce Regions – Estimates for the Middle Rio Grande Region, United States and Mexico, Pittsburgh, Pennsylvania, May 2019.
20. Monfarad, M. and A. Mayer, "Development of a numerical model for estimating the impacts of alluvial aquifer pumping on surface water flows in the middle Rio Grande basin," Urban Evapotranspiration in Water Scarce Regions – Estimates for the Middle Rio Grande Region, United States and Mexico, Pittsburgh, Pennsylvania, May 2019.
21. Mayer, A. Gutzler, D., Pennington, D.D., Ward, F., "Evaluating water scarcity under climate change with a basin scale model," Universities Council on Water Resources/NIWR Annual Water Resources Conference, Snowbird, Utah, June 2019.
22. Heyman, J., Mayer, A., Hargrove, W., Granados, A., Pennington, D., "Lifetimes for a Trans-Boundary Aquifer: Drivers of Change and Proposals for Response," Chapman Conference on the Quest for Sustainability of Heavily Stressed Aquifers at Regional to Global Scales, Valencia, Spain, October 2019.
23. Gutzler, D.S. (2019). Regional climate change, observed and projected. American Institute of Architects, Albuquerque, Apr 18, 2019.
24. Gutzler, D.S. (2019). Managing a water future without precedent. Water Law Continuing Legal Education Conference, Santa Fe, Oct 4., 2019.

## 2020

1. Samimi, M., Mirchi, A., Bailey, R., Ma, L. SWAT-Salt simulation of salinity in Elephant Butte Irrigation District. 2020 Annual International Meeting of the American Society of Agricultural and Biological Engineers (ASABE).
2. Samimi, S., Mirchi, A., Taghvaeian, S., Moriasi, D., Sheng, Z., Gutzler, D. (2020). Adaptive agricultural water management to cope with warm-dry future in the US Desert Southwest. American Geophysical Union Fall Meeting 2020.
3. Mirchi, A., Research Highlight Presentation at Oklahoma State Science and Engineering Fair (OSSEF) Teacher Workshop, Oklahoma State University, October 2020.
4. Mirchi, A., Future Climate Impacts in the Middle Rio Grande, Fall Science Meeting 2020, South Central Climate Adaptation Science Center. October 2020.
5. Mirchi, A., Water resources systems modeling for sustainable resource planning, management, and decision making. Graduate Seminar (BAE 5501), Dept. of Biosystems and Agricultural Engineering, Oklahoma State University, Stillwater, OK, March 2020.
6. Mirchi, A., Water futures in the Middle Rio Grande Basin: Insights from SWAT-MODFLOW. Symposium on Sustainable Water Resources Management in the Rio Grande/Rio Bravo Basin, UTEP, El Paso, TX, January 2020.
7. Hooks, T., G. Niu, X. Wang, **G. K. Ganjgunte**, 2020. Relative Salt Tolerance of Eight Pecan Rootstocks 2020 ASHS Annual Conference.



8. Chaganti, V.N. and **G.K. Ganjegunte**. 2020. Changes in Soil Health Indicators and Organic Carbon Under Treated Urban Wastewater Irrigation for Bioenergy Sorghum Production on an Arid Soil. 2020 ASA-CSSA-SSSA International Annual Meeting, <https://scisoc.confex.com/scisoc/2020am/2020>
9. Flynn, R.P., **G.K. Ganjegunte**, L.M. Lauriault, and A. Ulery. 2020. Performance of Irrigated Bio-Energy Crops Under Groundwater and Salinized Water. 2020 ASA-CSSA-SSSA International Annual Meeting. <https://scisoc.confex.com/scisoc/2020am/2020>
10. Gutzler, D.S., Bjarke, N.R., and Townsend, N.T. (2020). Diminished flows in southwestern snow-fed rivers: Assessing climate change projections for use in heavily managed hydrologic systems. American Meteorological Society 33rd Conference on Climate Variability and Change, Boston MA, Jan 2020.
11. Gutzler, D.S., N.R. Bjarke and N.T. Townsend. 2020. “Diminished flows in southwestern snowfed rivers: Adjusting climate change projections to describe heavily managed hydrologic systems” American Meteorological Society Annual Meeting, Boston, Jan 14 2020.

## 2021

1. Samimi, M., Mirchi, A., Taghvaeian, S., Moriasi, D., Sheng, Z., Gutzler, D., Alian, S., Hargrove, W. Evaluating Irrigation Interventions for Agricultural Resiliency under Future Water Scarcity in a Desert River Basin. 2021 Annual International Meeting of the American Society of Agricultural and Biological Engineers (ASABE).
2. Chaganti, V.N., and Ganjegunte, G. 2021. Switchgrass biomass yield and composition and soil quality as affected by treated wastewater irrigation in Rio Grande Basin. Water and Waste Management, 3rd International Conference & Expo. (virtual). February 24 – 26, 2021.
3. Mirchi, A., Zghibi, A., Chekirbane, A., Alibakhshian, K. (2021, Accepted). Using smart energy and water meters to inform agricultural groundwater use in Cap Bon Peninsula, Tunisia. The Universities Council on Water Resources (UCOWR) conference 2021, Online.

## **E. Media Interviews**

Southwestern drought and regional water resources, New York Times, May 26, 2018.

Future projections of the Rio Grande, quartz.com, Aug 16, 2018.

Drought and Rio Grande streamflow, Texas Observer, Aug 22, 2018.

Drought on Rio Grande and the water future of the Rio Grande Valley, CNN, Nov 30, 2018.

Climate change and community-engaged reseach, KUNM Radio (Albuquerque) University Showcase program, Dec 21, 2018.

Water conflicts along the Rio Grande, ARD German radio network (Arbeitsgemeinschaft der öffentlich-rechtlichen Rundfunkanstalten der Bundesrepublik Deutschland), Mar 21, 2019.

Climate change and the Rio Grande, CBS News, Apr 22, 2019.

## **F. Modeling Outputs**

Model development and products are identified and described under Accomplishments, Objective 1 (Section II. Obj. 1).

### **G. Other Dissemination Products to the Academic Community**

**A Water Symposium** was held each year in January from 2017-2020. The programs included guest speakers, presentations of progress on the project and from 20-30 poster papers presented mostly by students.

**Twenty special seminars** were presented in the Water Resources Seminar Series at UTEP over the course of the project. These special seminars were presented primarily by guest speakers from outside the project on topics of high interest to the project. Four additional seminars were delivered at NMSU.

### **V. Training**

A major impact of our project that cannot be overstated is the effect that the project has had on undergraduate and graduate students through research projects and experiences and the effect the students have had on research outcomes from the project. We have sponsored or supported between 32 and 74 students per year over the past five years. These students have been enrolled at the University of Texas at El Paso, New Mexico State University, University of New Mexico, Michigan Tech, and Oklahoma State University and have also conducted research with Texas A&M AgriLife Research in El Paso. Through these partnerships, we now have updated on-going courses, developed new courses, and enabled our students to conduct research for their theses and dissertations and as part of internships and research experiences for undergraduates. Below is a robust list of outputs from these efforts, all of which were mentored by faculty from the partner organizations, a point that should not be overlooked.

External evaluation reports prepared during the last year of the project punctuate the impact of the project on students and the impact of students on the project. These reports focused on the knowledge gained, skills acquired, and abilities developed from the points of view of the students and their mentors. Following are some key findings from their combined perspectives that merit highlighting in this end-of-project report.

1. The students experienced a transdisciplinary research enterprise that will enable them to develop and undertake future research in a different way than what is evident in many multidisciplinary and multi-institutional projects. This was made possible by student participation in periodic meetings of project leaders and annual meetings and conferences that facilitated an understanding of the inextricable relationships between the wide array of disciplines that affect water quality, availability, and sustainability.
2. The students experienced a unique and unusual project management approach that promoted open and harmonious discussions among scientists and practitioners from two countries and two states to address current and future water sustainability issues of the region, many of which are extant in other parts of the world.
3. The students developed specific unique and timely research skills that they can now use in their roles as future water professionals in academia, government, non-government, and the private sector, e.g., the development, use, and interpretation of data from computer-generated models.
4. The students improved their abilities to not only conduct research but also synthesize it, write about it, and present it to the scientific community and the general public, as is evident from the list below.

5. The students developed or enhanced leadership skills, as evidenced by their abilities to collaborate across disciplines, oftentimes playing leading roles in developing relationships with academics, other students, and water stakeholders in the region.

The answers to the following four questions, posed to the students and their mentors by the project evaluator, summarize the impact of the project.

From the students' perspectives:

1. What are ways in which you feel the project impacted YOU?
  - a. My career development
  - b. My understanding of the complexity of water issues
  - c. My ability to communicate
  - d. My potential for networking
  - e. My capacity for working in teams
  - f. My computer skills.
2. In what ways do you feel that YOU have impacted the project?
  - a. By disseminating information about the project
  - b. By analyzing data from different perspectives
  - c. By assisting with data presentation
  - d. By participating in model development
  - e. By publishing papers and manuals

From the mentors' perspectives:

3. What are ways in which you feel this project has impacted the students?
  - a. Students have interacted with each other in a friendly collegial way
  - b. Students have developed and practiced a 2<sup>nd</sup> language
  - c. Students have developed team work and organization abilities
  - d. Students have networked across institutions
  - e. Students have gained important academic credentials
  - f. Students have learned about transdisciplinary research
  - g. Student have developed communication and analytical problem solving
  - h. Students have learned to translate cutting edge research to stakeholders

The individuals who participated in the project are identified below by institution and year.

**UTEP**

**2015-2016**

Omar Sulaiman Belhaj, Ph.D. student, Env Sci & Eng (ESE) program – reviewed and summarized literature; collected and collated model input data

Paul Brian Guerrero, M.A. student, Sociology – reviewed literature and co-designed household consumer interview questionnaire, performed household consumer interviews, assisted with stakeholder meetings, researched direct potable reuse; Josiah Heyman, Advisor

Izel Barraza, M.A. student, Latin America & Border Studies – reviewed literature and co-designed household consumer interview questionnaire, Josiah Heyman, Advisor

Estrella Molina, Ph.D. Student, ESE Program – reviewed Riverware model; described data needs; contributed data

Luis Chavez Garnica, M.S. student, Comp Sci. – enhanced web portal to capture provenance of data and additional metadata for models

Armando Reyes, M.S. student, Comp. Sci. - worked on web portal

Erick Garcia, B.S., Computer Science – worked on definition of metadata for the web portal

#### 2016-2017

Brian Guerrero, MA in Sociology (completed), thesis research on El Paso Water's new program of direct potable reuse, Josiah Heyman, Advisor.

Marlene Flores, MA in Latin American and Border Studies; research on small utilities, especially accomplishments and challenges in serving geographically and socially marginalized rural communities, Josiah Heyman, Advisor.

William Vallee, M.A. in Political Science; thesis research on governance of transnational groundwater.

Diego Sanchez, M.A. in Sociology; thesis research on household water consumption, Josiah Heyman, Advisor.

Omar Sulaiman Belhaj, Ph.D. student, ESE Program; received hands on training on land use land cover classification, reviewed and summarized literature, acquired and processed satellite imagery, prepared and presented a poster at the USDA project symposium at UTEP.

Carlos S. Reyes, Undergraduate Intern, B.S. Environmental Science; classified satellite imagery for the study region; searched for research articles and summarized literature.

Jose Caballero, B.S., Computer Science. Mr. Caballero received training in the use of General Algebraic Modeling System (GAMS) to apply his work on model integration funded by NSF Grant HRD-1242122 (Cyber-ShARE Center).

Oscar Ricaud, B.S., Computer Science; enhanced web portal to capture and generate aggregate data for project evaluation.

Smriti Rajkarnikar, M.S., Computer Science; received training in the automated generation of models, inputs and outputs to apply her work on developing a generic provenance pattern to trace back model execution and data sources for the online modeling platform funded by NSF Grant HRD-1242122 (Cyber-ShARE Center).

Raul Vargas, Ph.D., Computer Science; received training on visualization requirements for the project's web portal to enable the graphical visualization for provenance data of the models generated as part of his work on knowledge representation funded by NSF Grant HRD-1242122 (Cyber-ShARE Center).

Neelam Tahneed Jahan, M.S., Civil Engineering; collected and organized model input data, developed a basic SWAT model.

Maryam Samimi, PhD student, Civil Engineering; reviewed literature; collected and organized model input data, helped with SWAT model design.

Majid Alahmoradi, M.S., Civil Engineering; worked on system dynamics modeling.

Tallen Capt, Ph.D., Civil Engineering – developed mathematical model for predicting daily water demand for El Paso as a function of average daily temperature, population, and several other factors.

### Summer Research Interns

Anna Piña. MS, Environmental Science Program. Examined water quality, groundwater depth and aquatic macroinvertebrate communities at the Rio Bosque wetland.

Carlos Reyes, B.S. Geology. Study of urbanization using remote sensing.

Joe Candelaria, B.S. Civil Engineering; EPWU wastewater treatment system and potential biogas production.

Gabby Porras, B.S. Civil Engineering. Urban water use modeling and fieldwork on water quality and water treatment.

### 2017-2018

Brian Guerrero, MA in Sociology (thesis completed), research on El Paso Water's new program of direct potable reuse, Josiah Heyman, Advisor.

Marlene Flores, MA in Latin American and Border Studies (non-thesis degree completed); research on small utilities, especially accomplishments and challenges in serving geographically and socially marginalized rural communities, Josiah Heyman, Advisor.

Diego Sanchez, MA in Sociology (thesis completed); thesis research on attitudes and behaviors to water among El Paso household consumers, Josiah Heyman, Advisor.

Karen De Anda, MA in Latin American and Border Studies; research on impact of water sustainability issues on alternative agriculture, Josiah Heyman, Advisor.

Evan Lopez, MA in Latin American and Border Studies; literature review on transboundary water on the U.S.-Mexico border, Josiah Heyman, Advisor.

Alondra Soltero, BS in Geological Sciences (completed); data compilation in ArcGIS on social variables in project study area.

Jose Caballero, MS in Software Engineering; research and development on the automated data exchange between the Water Modeling User Interface and the modeling system GAMS.

Omar Sulaiman Belhaj, Ph.D. student, ESE Program, UTEP – land use/land cover classification, acquired and processed satellite imagery.

Carlos S. Reyes, undergraduate research assistant, B.S. Environmental Science; classified satellite imagery for the study region. Graduated from UTEP with undergraduate degree.

Andrew Ellerson, M.S. in Civil Engineering; working on system dynamic modeling for field scale salinity and SWAT-MODFLOW-RT3D connection for salinity assessment.

Yohtaro Kobayashi, B.S. in Civil Engineering; working on developing a graphical model, based on Bayesian Networks, that can categorize the impacts of irrigation method on salinity.

Neelam Tahneed Jahan, M.S., Civil Engineering; collected and organized model input data, developed a basic SWAT model.

Maryam Samimi, PhD student, Civil Engineering; developed a SWAT watershed model and a reservoir simulation model for climate change impact assessment.

Tallen Capt, Ph.D. (completed), Civil Engineering – predictive modeling for municipal water consumption and wastewater production as a function of climate parameters.

Alahmoradi, M., M.S.Civil Engineering; Graduated 2017; Thesis: Developing a system dynamics model of the El Paso water resources system.

#### Summer Research Interns

Lisa Baughman, M.S., Environmental Science – “Wetland Vegetation Monitoring at the Rio Bosque Wetlands Park”

Anna Ortiz, Ph.D. Environmental Science and Engineering – “Reactive Transport Modeling of CO<sub>2</sub> Emission and Calcite Precipitation Kinetics in Dryland Agriculture”

Ivy Trevizo, M.S., Environmental Science – “Climate Change Communication”

Gerardo Montero, B.S., Civil Engineering – “Estimating Evaporation in the Middle Rio Grande Irrigation Delivery System”

#### 2018-2019

Karen De Anda, MA Latin American and Border Studies, non-thesis option completed (manuscript produced for publication as an article on alternative agriculture)

Chilton Tippin, MA Latin American and Border Studies in progress, research on access to water in two colonias, thesis defense scheduled Dec. 2019, Josiah Heyman, Advisor

Rebeka Issac MA Latin American and Border Studies in progress (first stages of thesis), Josiah Heyman, Advisor

Karla Janet Madriles, Undergraduate Research Assistant, Civil Engineering, Dr. Suarav Kumar, Supervisor

Katalina Salas, PhD Student, Environmental Science and Engineering, Dr. Deana Pennington, Advisor

Tom Poulouse, M.S. Student in Civil Engineering, Dr. Suarav Kumar, Advisor

Carlos Reyes, M. S. Student in Environmental Science, Dr. Deana Pennington, Advisor

Daniel Torres, Undergraduate Research Assistant, Mechanical Engineering, Dr. W.L. Hargrove, Supervisor

Yohtaro Koayashi, M.S. Student in Civil Engineering, Dr. Suarav Kumar, Advisor

Omar Belhaj, Ph.D. in Environmental Science and Engineering, Dr. Stanley Mubako, Advisor

#### 2019-20

Chilton Tippin, MA Latin American and Border Studies thesis completed on access to water in two colonias (UTEP Graduate School Banner Bearer, top distinction for a graduate student), Josiah Heyman advisor

Katalina Salas, PhD Student, Environmental Science and Engineering, Dr. Deana Pennington, Advisor

Carlos Reyes, M. S. Student in Environmental Science, Dr. Deana Pennington, Advisor

Rebeka Issac MA Latin American and Border Studies, thesis completed and graduation in early 2021, Josiah Heyman, Advisor.

Janette Rodriguez, MA Latin American and Border Studies, Josiah Heyman, Advisor

#### 2020-2021

Rebeka Issac MA Latin American and Border Studies thesis completed, Josiah Heyman advisor

Janette Rodriguez, MA Latin American and Border Studies non-thesis option completed, Josiah Heyman advisor

#### NMSU

##### 2015-2016

Cody Runyan, M.S., Water Science & Management Program – reviewed pecan orchard irrigation and water conservation literature; learned experimental techniques and equipment, planned irrigation experiments.

Margie Vela, Ph.D. student, Water Science & Management Program - reviewed literature, formulated water education plans

Sarah Sayles, Ph.D. Student, Water Science & Management Program - took notes at stakeholder meetings, built prototype farm income optimization model, reviewed and developed irrigator survey questions.

Befekadu Habteyes, Ph.D. Student, Water Science & Management Program - assembled data and developed basin scale water economics optimization model

Sarah Acquah, Ph.D. Student, Water Science & Management Program - assembled data and developed basin scale infrastructure expansion model

Dina Salman, Ph.D. Student, Water Science & Management Program - developed prototype groundwater economic optimization model

Miranda Cisneros, B.S. student, Agricultural Economics & Agricultural Business Program - entered water supply and use data into spreadsheets.

Hugo Luis Rojas Villalobos, PhD candidate, Water Science & Management Program - administration of GIS data

Olga Rodriguez, M.S. student, Water Science & Management Program – data compilation and analyses for model inputs

#### 2016-2017

Sarah Sayles, Ph.D. Water Science & Management Program; built prototype farm income optimization model for assessing water banking options in Rio Grande basin for adapting to future water supply shortages.

Befekadu Habteyes, Ph.D. Water Science and Management Program: calibrated bucket model for the Elephant Butte and Caballo Rio Grande Project region.

Sarah Acquah, Ph.D., Water Science and Management Program; identified and developed future hydrologic and policy scenario impacts to be evaluated by Bucket model.

Dina Salman, Ph.D., Water Science and Management Program; working with NMSU engineering professor to assemble crop ET data for New Mexico, Texas, and Mexico.

Carlos Silva, Ph.D., Water Science and Management Program; working on groundwater-surface water models to support policy analysis as well as optimization models for irrigated agriculture in southern New Mexico.

Hugo Luis Rojas Villalobos, PhD, Water Science & Management Program; administration of GIS data.

Olga Rodriguez, M.S., Water Science & Management Program; data compilation and analyses for model inputs.

#### 2017-2018

Sarah Sayles, Ph.D. Student, Water Science & Management Program - built prototype farm income management model for assessing water banking options in Rio Grande basin for adapting to future water supply shortages.



Befekadu Habteyes, Ph.D. Student, Water Science and Management Program - calibrated bucket model for the Elephant Butte and Caballo Rio Grande Project region.

Sarah Acquah, Ph.D. Student, Water Science and Management Program – assembled poster for project symposium meeting January 4, 2017, describing future hydrologic and policy scenario impacts for bucket model. Completed dissertation in December 2017.

Dina Salman, Ph.D. Student, Water Science and Management Program – working with NMSU engineering professor to assemble crop ET data for New Mexico, Texas, and Mexico. Completed dissertation in May 2017.

Carlos Silva, Ph.D. Student, Water Science and Management Program – working on groundwater-surface water models to support policy analysis as well as optimization models for irrigated agriculture in southern New Mexico.

Hugo Luis Rojas Villalobos, PhD Student, Water Science & Management Program - administration of GIS data

Bernard Bah Kuma, PhD Student, Water Science & Management Program – economic optimization of water use patterns in a river basin with competing and complementary uses.

Olga Rodriguez, M.S. student, Water Science & Management Program – data compilation and analyses for model inputs.

Curt Pierce, M.S. student, Water Science & Management Program/Plant & Environmental Sciences Department—design and installation of drip irrigation system for pecan orchard experiments, data collection and analysis, assisting course instructor/co-teaching undergraduate-level irrigation and drainage course.

Alfredo Aragon (major: Horticulture) and Daniel Ibañez (major: Geography), undergraduate students—assist with installation and running of micro/drip irrigation systems, assist graduate student and faculty with data collection/entry.

#### 2018-19

Sarah Sayles, Ph.D. Student, Water Science & Management Program – investigated water banking success predictors for western US water banks. Completed dissertation, Fall 2019.

Shanelle Trail, Ph.D. Student, Water Science & Management Program – investigating drought adaptation measures affecting farms and ranches in New Mexico, 2019-2020.

Leila Shadabi, Ph.D. Student, Water Science & Management Program – investigating economic costs of drought in New Mexico, 2019-2020.

Bryana Getchell, M.S. Student, Agricultural Economics and Agricultural Business – investigating economic costs and benefits of aquifer protection for New Mexico and elsewhere.

Ana Garcia, PhD student, Water Science and Management, measuring of crop water use for drip, flood, and center pivot irrigation in southern New Mexico and West Texas.

Befekadu Habteyes, Ph.D. Student, Water Science and Management Program - calibrated bucket model for the Rio Grande Project region. Developed poster paper describing future hydrologic and policy scenario impacts; Completed dissertation July 2018.

Sarah Acquah, Ph.D. Student, Water Science and Management Program – assembled poster for project symposium meeting January 4, 2017, describing future hydrologic and policy scenario impacts for bucket model. Completed dissertation in December 2017.

Dina Salman, Ph.D. Student, Water Science and Management Program – working with NMSU engineering faculty to assemble crop ET data for New Mexico, Texas, and Mexico. Completed dissertation in May 2017.

Carlos Silva, Ph.D. Student, Water Science and Management Program – working on groundwater-surface water models to support policy analysis as well as optimization models for irrigated agriculture in southern New Mexico and elsewhere.

Hugo Luis Rojas Villalobos, PhD Student, Water Science & Management Program - administration of GIS data. Completed dissertation fall 2019.

Bernard Bah Kuma, PhD Student, Water Science & Management Program – economic optimization of water use patterns in a river basin with competing and complementary uses.

Olga Rodriguez, M.S. student, Water Science & Management Program – data compilation and analyses for model inputs.

Curt Pierce, Ph.D. student, Water Science & Management Program/Plant & Environmental Sciences Dept. - design and installation of drip irrigation system for pecan orchard experiments, data collection and analysis, co-teaching undergraduate irrigation and drainage course.

Alfredo Aragon (major: Horticulture) and Daniel Ibañez (major: Geography), undergraduate students—assist with installation and running of micro/drip irrigation systems, assist graduate student and faculty with data collection/entry.

#### 2019-2020

Curt Pierce, Ph.D. Plant and Environmental Sciences Department, Horticulture major; expected defense August, 2021

Isaiah Apodaca, B.S., Animal Science major

Daniel Ibañez, B.S. Biology major, microbiology, chemistry, and biochemistry minor

#### TAMU

#### 2015-2016

Shalamu Abudu, Postdoctoral Research Associate - conducted modeling research on hydrological aspects

Carlos Castro, B.S. student - analyzed baseline properties of pecan field soils, installed irrigation sensors and data loggers, collected sensor data during the irrigation season.

Nesa Serrano, B.S. student - analyzed baseline properties of pecan field soils, installed irrigation sensors and data loggers, collected sensor data during the irrigation season.

Monique Ontiveros, B.S. student - analyzed baseline properties of pecan field soils, installed irrigation sensors and data loggers, collected sensor data during the irrigation season.

John Clark, Research Technician – managed data collected from field experiments.

#### 2016-2017

Shalamu Abudu, Postdoctoral Research Associate, Agricultural Engineering; conducted modeling research on hydrological aspects (RiverWare, MODFLOW).

Sora Ahn, Asst. Research Scientist; conducted SWAT modeling research on hydrological aspects

Erick Reynoso, Research Tech II – GIS and project area delineation.

Darlina Prieto, Work-Study Student (UTEP), B.S. in Biological Sciences; Compile river flow and diversion data.

Jacqueline Alfaro, B.S. Environmental Science: analyzed baseline properties of pecan field soils, installed irrigation sensors and data loggers, collected sensor data during the irrigation season.

John Clark, Research Technician – Helped in implementing and data management of laboratory, greenhouse and field experiments.

#### 2017-2018

Minki Hong, Ph.D., Agricultural and Biological Engineering (TAMU), research on interaction of groundwater and surface water.

Olga Rodriguez, M. Eng., Civil Engineering (NMSU), thesis research on water consumptive uses of pecan with Eddy Covariance observation.

David Ruiz, B.Eng., Civil Engineering (UTEP), flow data compilation and analysis.

Jeff Downey, PhD, Agribusiness and Managerial Economics. Examined water-energy nexus for electricity production and hydro-fracking.

JhamnDas Suthar, an exchange student from Pakistan, has initiated a greenhouse study to evaluate salinity tolerance of cluster bean (*Cyamopsis tetragonoloba* L).

John Clark (Technican), Carlos Castro (UTEP), Monique Ontiveros (UTEP) and Priscilla Reyes (UTEP) have been getting on the job training on field and laboratory protocols related to irrigation water use efficiencies, water reuse and salinity management practices.

#### Summer Research Interns

Carolina V. Solis, B.S. Environmental Sciences – Geoscience (UTEP), compilation and analysis of groundwater data.

Paola I. Soto-Montero, B.S. Environmental Sciences – Geoscience (UTEP), compilation and analysis of groundwater data, continued working at the Center after the summer intern.

#### Visiting Students

Mingyi Huang, Ph.D. Water Conservancy and Hydropower Engineering (Hohai University), SWAT simulations and hydrological assessment.

Xiaole Kong, Ph.D. Urban and Rural Planning and Management & Resources Environment (Chinese Academy of Sciences), Hydrological model simulation of flow and salt loading.

#### 2018-2019

Minki Hong, Ph.D., Agricultural and Biological Engineering (TAMU), research on interaction of groundwater and surface water.

Olga Rodriguez, M. Eng., Civil Engineering (NMSU), thesis research on water consumptive uses of pecan with Eddy Covariance observation.

David Ruiz, B.Eng., Civil Engineering (UTEP), flow data compilation and analysis.

Sebastian Morales, B. Eng., Civil Engineering (UTEP), field work, data processing and analysis

Michelle Rivera, B. Mechanical Eng. (UTEP), flow data processing and analysis.

Cynthia Sanchez, B. Biology (UTEP), Field work on ET monitoring and data processing.

#### Summer Research Interns

Carolina V. Solis, B.S. Environmental Sciences – Geoscience (UTEP), compilation and analysis of groundwater data.

Paola I. Soto-Montero, B.S. Environmental Sciences – Geoscience (UTEP), compilation and analysis of groundwater data, continued working at the Center after the summer intern.

#### Visiting Students

Mingyi Huang, Ph.D. Water Conservancy and Hydropower Engineering (Hohai University), SWAT simulations and hydrological assessment.

Xiaole Kong, Ph.D. Urban and Rural Planning and Management & Resources Environment (Chinese Academy of Sciences), Hydrological model simulation of flow and salt loading.

Peirong Lu, Ph.D. Agricultural Soil and Water Engineering (Hohai University), Hydrological model simulation and hydrological assessment.

Dongshuang Li, Ph.D. College of Agriculture (Yangzhou University), mathematical modeling and analysis of geographic spatio-temporal data.

#### Undergraduate Students

Mariana Munoz, Health Sciences; Andres Gomez, Biomedical Engineering; Kenneth Cazarez, Agronomy (06/2018-Present); Priscilla Reyes, Biological and Health Sciences; Monique Ontiveros, Biological Sciences; Carlos Castro-Lopez, Ecological Sciences; Nessa Serrano, Biological Sciences- Undergraduate students working in lab, greenhouse and field studies related to water reuse, freshwater conservation and salinity management.

#### 2019-2020

Minki Hong, Ph.D., Texas A&M University, Agricultural Engineering

Michelle Rivera, UTEP, B. Sci, Environmental Sciences

Cynthia Sanchez, UTEP, B. Sci, Environmental Sciences

Alfredo Gomez, El Paso Community College

Jacqueline Alfaro, Biological Sciences

Mariana Munoz, Computer Sciences

Andres Gomez, Biomedical Engineering

Priscilla Reyes, Biological and Health Sciences

#### **UACJ**

#### 2015-2016

Victor Hugo Esquivel Ceballos, PhD candidate, Urban Planning Doctoral Program – collected and processed hydrometeorological data from regional weather stations

Arturo Soto Ontiveros, PhD candidate, Urban Planning Doctoral Program - collected and processed groundwater data from official sources and evaluating ModFlow

Ana Cristina Garcia Vasquez, M.S. student, Environmental Engineering – collected and analyzed groundwater quality data

Oscar Ramirez Villazana, M.S. student - Environmental Engineering – Defined number of aquifer layers for the project through aquifer characterization using geophysics

Alexis Gabriel Rodriguez Sanchez, B.S. student, Environmental Engineering – reviewed literature and reviewed SWAT model

Angel Rafael Chavez Rodriguez, B.S. student, Geoinformatics – analyzed LULC geodata

#### 2016-2017

#### Undergraduate students:

Mariela Rascón Castillo, Bachelor in Geoinformatics, Department of Architecture, UACJ-Geospatial analysis.

Mónica Quiñonez González, Bachelor in Geoinformatics, Department of Architecture, UACJ, ModFlow Modeling.

Obed Alejandro Márquez Barraza, Bachelor in Geoinformatics, Department of Architecture, UACJ, ModFlow Modeling.

Alfredo Jaquez Granados, Bachelor in Environmental Engineering (Ag Engineering Exchange student from UADHE) Precision Ag and eBee Drone mapping.

Ana Laura Ruiz Aragonéz, Bachelor in Physics, Department of Physics, UACJ, Spectral analysis of imagery under SEQUOIA camera with eBee Drone.

Alexis Rodriguez Sanchez, Bachelor in Environmental Engineering at the Department of Civil and Environmental Engineering, UACJ, SWAT geodata integration and modeling.

#### Graduate Students:

Oscar Ramirez Villazana, graduated from the M.S. Environmental Engineering program – He accomplished the first phase on the delineation of aquifer layers for the project through aquifer characterization using geophysics. Presently he has received an offer to work at the state level in Junta Central de Agua participating on an interdisciplinary team to apply these technologies to the planning and infrastructure development for new groundwater wells in the state of Chihuahua.

Víctor Hugo Esquivel Ceballos, PhD Candidate at the Urban Studies Program, Department of Architecture, UACJ, Urban Growth, population and groundwater use in Ciudad Juárez, Chih.

Arturo Soto, PhD Candidate at the Urban Studies Program, Department of Architecture, UACJ, ModFlow modeling at study area in Mexico.

Hugo Luis Rojas Villalobos, PhD Candidate Water Science & Management Program at NMSU - administration of GIS data.

Ana Cristina Garcia, MS Student at the Environmental Engineering Program, Department of Civil and Environmental Engineering, UACJ, Isotopic signature of groundwater samples at the Conejos Médanos-Mesilla Aquifer.

#### 2017-2018

##### Undergraduate students:

Sergio Granados González and Gabriela Veleta Jáquez, Geoinformatics Bachelor Program at UACJ (Cuauhtémoc Extension). LULC development and geospatial analysis.

Ana Laura Ruiz Aragonéz, Physics Bachelor Program at UACJ. ETP analysis and Crop spectral signature using eBee Drone.

Katya Esquivel Herrera, Geoscience Bachelor Program at UACJ. SWAT modeling

##### Graduate Students:

Arturo Soto Ontiveros, PhD Program on Urban Studies; MODFLOW modeling.

Hugo Luis Rojas Villalobos, PhD Program on Water Science and Management at NMSU. GIS Master and project web page.

Ana Cristina Garcia, MS Environmental Engineering Program. Groundwater quality.

#### 2018-2019

Mariela Rascón Castillo - Grado: Geoinformática; Lugar: UACJ Cuauhtémoc, Chihuahua, México. Año: 2017; Tesis: Análisis del crecimiento urbano en Ciudad Juárez y su impacto en las coberturas y uso de suelo urbano y del territorio 1985 – 2002, 2002 – 2015.

Gabriela Veleta Jáquez – Grado: Geoinformática; Lugar: UACJ Cuauhtémoc, Chihuahua, México. Año: DIC-2019; Tesis: Determinación de la Cobertura y Uso de Suelo del Rio Bravo (1994-2015). Proceso de Cambios y Evolución del NDVI.

Víctor Hugo Esquivel Ceballos - Grado: Ph D en Estudios Urbanos; Lugar: UACJ- Juárez. Año: DIC-2019; Tesis: Análisis del crecimiento urbano de Ciudad Juárez, Chihuahua, México: repercusiones sobre la demanda y disponibilidad hídrica, y abatimiento del acuífero.

Alfredo Jaquez Granados - Degree: Bachelor on Agribusiness; Place: UACJ- Casas Grandes. Year: DEC-2021; Thesis: Changes on NDVI values on pecan orchards using SEQUOIA camera.

Katya Esquivel - Degree: Bachelor in Geosciences; Place: UACJ- Juárez; Year: DEC-2020; Thesis: *Development of Hydrological Variables from the Hueco Bolson – Valle de Juárez basin, Using the Soil and Water Assessment Tool (SWAT) program.*

Carolina Salazar - Degree: Bachelor on Environmental Engineering; Place: UACJ- Juárez. Year: DEC-2020; Thesis: *On the integration and refinement of land use cover and agricultural parameters, for the modeling of Hydrological Variables of the Hueco Bolson Basin.*

Arturo Soto Ontiveros - Degree: Ph D in Urban Studies; Place: UACJ- Juárez. Year: May-2019; Thesis: “Disponibilidad de Agua Subterránea y su relación con el Desarrollo Urbano en Ciudad Juárez, Chihuahua: Un análisis retrospectivo y prospectivo durante el periodo 2008 al 2030”.

Rogelio Alvarado - Degree: Bachelor on Environmental Engineering; Place: UACJ- Juárez. Year: DEC-2022; Thesis: “Monitoring the influence of atmospheric water vapor fields on the Paso del Norte water basin”

Student: Miguel Duran Rangel - Degree: Master on Environmental Engineering; Place: UACJ- Juárez. Year: DEC-2022; Thesis *Modelación hidrológica de recarga al acuífero Bolsón del Hueco, simulando efectos por inclusión de políticas de administración del agua.*

#### 2019-2020

Alma Beatriz Palacios Valenzuela, 2021 (in progress). Characterization of a Biofertilizer based on various biochemical treatments. Master's Degree in Environmental Studies and Management. Civil and Environmental Engineering Department -IIT-UACJ.

Carlo Ivan Romero Gameros, 2022. Study of the Geomorphological Landscape Units (UPG's) and their relationship with Groundwater recharge in the Palomas-Guadalupe Victoria Aquifer (0812) at the Lower Casas Grandes River Basin. Master's Degree in Environmental Studies and Management. Civil and Environmental Engineering Department -IIT-UACJ.

Frida Karina Koelig Escobedo, 2022. Physicochemical and bacteriological evaluation of biofertilizer with respect to soil fertility and crop productivity. Master's Degree, Environmental Studies and Management. Civil and Environmental Engineering Department -IIT-UACJ.

Carlos Alfonso Moreno Rojas, 2020. Hydraulic modeling for the solution of a street intersection in Ciudad Juarez, Chih., Mexico. Bachelor of Civil Engineering. Civil and Environmental Engineering Department IIT-UACJ.

Rogelio Alvarado Hernández, 2021 (in progress). "Assessment of the impact of climate change and water shortages on the deficit of green areas in Ciudad Juarez, using the SWIM model to a future 2030". Bachelor of Environmental Engineering. Civil and Environmental Engineering Department IIT-UACJ.

Luis Ignacio Prieto González, 2019. Evaluation of wastewater treatment potential using geospatial models in Cd. Juárez, Chih. Master's Degree in Environmental Studies and Management, Civil and Environmental Engineering Department-IIT-UACJ.

### **UNM**

#### **2015-2016**

Fawn Brooks, PhD student, Earth & Planetary Sci (EPS) Department - reviewed literature on intermittent streams in the project study area; collected streamflow data.

Shaleene Chavarria, MS student, EPS Department - collected streamflow data and analyzed snowpack and seasonal streamflow forecasts on the upper Rio Grande.

John Carilli, B.S. student, Physics Department - processed surface hydrologic data for bucket model development

#### **2016-2017**

Shaleene Chavarria, MS, Earth and Planetary Science Department; collected streamflow and snowpack data, analyzed seasonal streamflow forecasts on the upper Rio Grande, presented results at NM State Water Conference and Fall AGU meeting.

John Carilli, B.S., Physics Department - processed surface hydrologic data for bucket model development.

Justin Norris, B.S., Earth and Planetary Science Department; analyzed climate model projections of Rio Grande streamflow.

Yu Jin Sung, undergraduate exchange student from South Korea; analyzed surface hydrologic data as part of bucket model development.



Justin O'Shea, B.S., Earth and Planetary Science Department; analyzed summer season precipitation and streamflow upstream from Elephant Butte Reservoir and defended a senior undergraduate thesis on this work in December.

#### 2017-2018

Nolan Townsend, M.S. student, EPS Department - worked on development of climate change scenarios, including the normalization of naturalized flow projections to make projected flows appropriate for use in models developed by the project.

John Carilli, B.S. student, Physics Department - processed surface hydrologic data for bucket model development; decoded daily precipitation and evapotranspiration data for use in environmental flow assessments.

Justin Norris, B.S. student, EPS Department - analyzed climate model projections of Rio Grande streamflow

Sean Leister, B.S. student, EPS Department - analyzed relationships between temperature, precipitation and streamflow in the study area.

#### 2018-2019

Nolan Townsend, M.S. student, EPS Department - worked on development of climate change scenarios, including the normalization of naturalized flow projections to make projected flows appropriate for use in models developed by the project. Defended his M.S. thesis based on project-supported research and completed degree in July 2019.

Sean Leister, B.S. student, EPS Department - analyzed projected future temperature and precipitation in the study area. Defended his B.S. honors thesis based on project-supported research and completed degree in December 2018.

Indumati Roychowdhury, B.S. student, Geography Department - analyzed projected temperature and precipitation in the study area and related those climate variables to projected streamflow.

#### 2019-2020

Indu Roychowdhury (undergraduate), Nov 2019-May 2020.

Indu graduated from UNM in May 2020, has been working in Albuquerque, and just accepted admission to the PhD program in Geography at UC Davis beginning this Fall.

### **OSU**

#### 2018-2020

Neelam Tahneed Jahan, M.S., Civil Engineering; Graduated 2018; Thesis: Assessing the Hydrologic Impacts of Extreme Rainfall and Land Use Change on a Semiarid Watershed.

Maryam Samimi, PhD student, Civil Engineering; completed the calibration of a SWAT watershed model, developed SWAT-MODFLOW simulation model, conducted climate change impact assessment.

#### Visiting Scholars

Dr. Adel Zghibi, Faculty of Sciences of Tunis, University Tunis El Manar, Tunisia (March 2019)

Dr. Anis Chekirbane, Water Research and Technologies Center, Tunisia (March 2019)

## **MTU**

### **2015-2016**

Lauren Mancewicz, B.S. student, Environmental Engineering, - reviewed literature on water withdrawals, collected input data.

Leila Saberi, PhD student, Environmental Engineering - assisted in conceptualization of models.

### **2016-2017**

Lauren Mancewicz, B.S., Environmental Engineering, Intern; defined study area boundaries, including sub-watershed and aquifer boundaries and accompanying spatial database, collected input data for the bucket model.

Leslie Hamar, B.S., Environmental Science, Intern; identified spatially distributed water withdrawal data for the US portion of the study area.

Ken Thiemann, Ph.D , Environmental Engineering; processing NASA datasets to obtain local climate inputs and output fluxes an accompanying local runoff; compilation of gauged flows along the study area Rio Grande reach; assembly of geodatabase for Bucket Model.

### **2017-2018**

Jessica Alger, MS Environmental Engineering started as an hourly research assistant and is now an MS student working on reservoir evaporation and urban evapotranspiration modeling.

Ken Thiemann, PhD Environmental Engineering is the lead graduate on the development of the water balance model.

Azad Heidari, PhD Civil Engineering assisted in the development of irrigated agriculture evapotranspiration sub-models.

Marjan Monfarednasab, MS Environmental Engineering started as an hourly research assistant and is now an MS student working on groundwater-surface water exchange modeling.

Hannah Weeks, BS Geological Engineering assisted in the processing of data for the water balance model and the urban evapotranspiration model.

Tristan Odekirk, MS Environmental Engineering worked as an hourly research assistant on processing the groundwater elevation data and collecting literature on local groundwater aquifers.

Huiling Piao, BS Environmental Engineering assisted in the processing of data for the water balance model.

### **2018-2019**

Luyao Li, BS Environmental Engineering- estimates of conveyance and other losses involved in transferring water from Rio Grande diversion points to farms for the three US irrigation districts.

Ceily Fessel Doan, BS Environmental Engineering- simulations of algae cultivation in the middle Rio Grande basin.

Jessica Alger, MS Environmental Engineering student- estimates of urban evapotranspiration and water consumption for the three urban centers in the study area (graduated August 2019).

Marjan Monfarad, MS Environmental Engineering student- development of groundwater-surface water model for estimating impacts of irrigation efficiency on Rio Grande channel losses.

Robyn Holmes, MS Environmental Engineering student- refinement of water balance model to (a) simulate seasonal flows, (b) include alternative groundwater demand schemes, (c) include alternative surface water-groundwater interaction models.

Azad Heidari, PhD Civil Engineering student- GIS analysis of land use and climate in the study area to support other students' work (completed PhD in November 2019)

Isabel Manson, BS Environmental Engineering - developing database of crop acreages and production for the three US irrigation districts.

Ken Thiemann, PhD Environmental - water balance modeling.

#### 2019-2020

Robyn Holmes (Michigan Tech MS student)

Marjan Monfarednasab (former Michigan Tech MS student)

Jessica Alger (former Michigan Tech MS student)

Ceily Fessel Doan (Michigan Tech undergrad student)

### **Professional Development**

#### 2015-2016

Dr. Stanley Mubako, UTEP, successfully completed a one-week training course in Statistical Downscaling of Global Climate Models using the SDSM 5.2 model under support provided by this project, from December 7-11, 2015 at the Smithsonian-Mason School of Conservation, Front Royal, Virginia. The training focused on the use and application of this decision support tool for assessing local level climate change impacts and was led by facilitators from the University of Prince Edward Island and University of Toronto in Canada, and Loughborough University in the United Kingdom. Capacity building accomplishments from the course include the ability to (1) access, carry out quality control, and statistically analyze climate data; (2) prepare scenarios of future climate change through ensemble and validation techniques; (3) download and use the SDSM 5.2 software to create a statistical model of climate observations for a region of interest; (4) create site-specific high-resolution scenarios of future climate change; and (5) understand applications of statistically-downscaled model results.

Two students from UACJ in Mexico were trained in how to map cultivated areas using drones.

One faculty member at UACJ in Mexico received Water Harvesting Design Certification.

#### 2016-2017

Dr. Shalamu Abudu, TAMU, successfully completed a one-week training course on SWAT in January, which will help him configure and/or integrate SWAT and RiverWare model for water operations within the project area.

Dr. Ali Mirchi spent one week in El Reno, OK at USDA-ARS lab to be trained on SWATmf by Dr. Daniel Moriasi.

Professors and students involved in the project from UACJ were certified by SenseFly Inc as technical experts on Drone flight missions for Precision Ag Technology.

Special training during the Fall semester 2016 for MS Student Ana Cristina Garcia from UACJ, at the Mexican Institute of Water Technology (IMTA) in Cuernavaca Mexico, specializing in isotopic analysis to evaluate groundwater quality and age.

Dr. Sergio Solis, responsible for the UACJ SWAT modeling team, had a summer internship at the University of Warwick in England to evaluate and calibrate surface water modeling.

Dr. Luis Carlos Alatorre from UACJ participated at the XVII SELPER International Symposium celebrated at Puerto Iguazu, Argentina in Nov, 2016.

Dr. Alfredo Granados from UACJ took a sabbatical leave at UTEP during 2016 to manage and administer the project and coordinate Mexican team efforts.

#### 2019-2020

Sora Ahn and Chunggil Jung, Associate Research Scientist and Post-Doc at TAMU-El Paso, attended a two-day training program on Decision Support Modeling with PEST and PEST++; Making Modeling Great Again at Colorado School of Mines, Golden, Colorado, June 6-7, 2019.

Maryam Samimi, Ph.D. student at UTEP, and SoRa Ahn, Post-Doc at TAMU-El Paso, attended week-long training program on SWAT-MODFLOW coupling at Colorado State Univ., 2019.

Dr. Dave Gutzler (UNM) sabbatical visit to UTEP Center for Environmental Resource Management, Feb 12-Mar 14, 2020 (cut short by pandemic).