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Ogallala Aquifer Program: A Catalyst for Research and Education to Sustain the Ogallala Aquifer on the Southern High Plains (2003-2017)

*David Brauer[1], Dan Devlin[2], Kevin Wagner[3], Mike Ballou[4], Dean Hawkins[5], and Robert Lascano[6]

[1]Ogallala Aquifer Program, USDA-Conservation and Production Research Laboratory - Bushland, TX; [2]Kansas State University, Kansas Center for Agricultural Resources and Environment; [3]Oklahoma Water Resources Center, Oklahoma State University, formerly Texas Water Resources Institute at Texas A&M AgriLife Research and Extension; [4]Texas Tech University College of Agricultural Sciences and Natural Resources; [5]West Texas A&M University, College of Agriculture and Natural Sciences; [6]Cropping Systems Research Laboratory-Agricultural Research Service - USDA
**Corresponding Author*

Abstract: The Ogallala Aquifer Program (OAP) was created in 2003 with support from Congressmen from Kansas and Texas. The OAP is a research-education consortium seeking solutions from problems arising from declining water availability from the Ogallala Aquifer in western Kansas and the Texas High Plains. The consortium is led by the Agricultural Research Service (ARS) laboratories in Bushland and Lubbock, TX, and the university partners are Kansas State University, Texas A&M AgriLife Research and Extension Service, Texas Tech University, and West Texas A&M University. The OAP has provided over $40 million to support research and education activities. About half of these funds were used to support permanent ARS scientists and ARS hired post-docs. The other half were used by university scientists to supplement on-going projects by providing support for supplies, sample analyses, temporary employees, etc. Initially, OAP activities were focused on seven priorities. In 2013, four objectives replaced the original seven priorities. A fifth priority was added in 2017. The current objectives are: 1) Develop and evaluate water management strategies and technologies that could reduce water withdrawals for irrigation by 20% in 2020 compared to 2012; 2) Develop and evaluate management strategies and technologies that would increase the productivity and profitability of dryland cropping systems; 3) Improve the understanding of hydrological and climatic factors that affect water use and agricultural profitability; 4) Determine the impacts of alternative water withdrawal/use policies on the economic viability of the agriculture industry of the Southern Ogallala Aquifer Region; and 5) Develop best management practices for production of high value and alternative crops for both dryland and irrigated systems. The objectives of the program and distribution of resources are decided by an executive committee with a member from each of the four universities, two from ARS, one from Bushland, and the other from Lubbock. Proposed projects that utilize resources from more than one participating institution, leverage existing resources, and address the stated objectives are more likely to be provided support. The impact of the OAP on research directed at agriculture on the High Plains has been recognized by three prestigious awards.

Keywords: *irrigation technology, irrigation scheduling, water conservation, economic impacts*

The objective of this article is to provide an overview of the Ogallala Aquifer Program (OAP) and to examine successes and failures that the program has experienced to date. The OAP was initiated in 2002 to address problems resulting from declining water levels in the Ogallala Aquifer. The program is a research-education consortium consisting of the Agricultural Research Service-U.S. Department of Agriculture (ARS-USDA) locations at Bushland and Lubbock, Texas, and four universities, Kansas State University, Texas A&M University, Texas Tech University, and West Texas A&M University. The alternative titles of the OAP have been modeled after its first Current

Research Information System (CRIS) project title: "Sustaining rural communities through new water technologies."

Background

The Ogallala Aquifer is located in the U.S. Great Plains (Fig. 1) and extends from the southern portion of the Texas High Plains and eastern New Mexico, northward through the panhandle areas of Texas and Oklahoma, into western Kansas and eastern Colorado, to Nebraska and southern South Dakota and eastern Wyoming, covering 173,000 square miles (Zwingle 1993). As such, the Ogallala Aquifer is the largest fresh water aquifer in the U.S. The saturated thickness of the aquifer, which comprises the interval between the water table of the aquifer and the base of the aquifer, ranges from 0 to 1200 feet and averages 200 feet (Fig. 1). The thickest portions of the saturated zone of the aquifer are located in Nebraska, and in the panhandle areas of Texas and Oklahoma into southwestern Kansas. The water-bearing formation of the Ogallala Aquifer is essentially "fossilized water", meaning that there is no longer a connection to the source of the water bearing materials and that recharge is limited to deep percolation and interactions between surface bodies and the aquifer. South of the Kansas-Nebraska state line, there are few rivers that transverse the U.S. Great Plains above the Ogallala Aquifer. Therefore, recharge is limited to deep percolation. Deep percolation rarely occurs because potential evaporation greatly exceeds rainfall (Baumhardt et al. 2010). On the Texas High Plains, there is an on-going debate as to the significance of playas, sites of lower elevation that inundate when heavy rainfall produces runoff, to recharge (Gitz and Brauer 2016). On the Texas High Plains, the best estimates for recharge outside of playas is that rain falling today will reach the

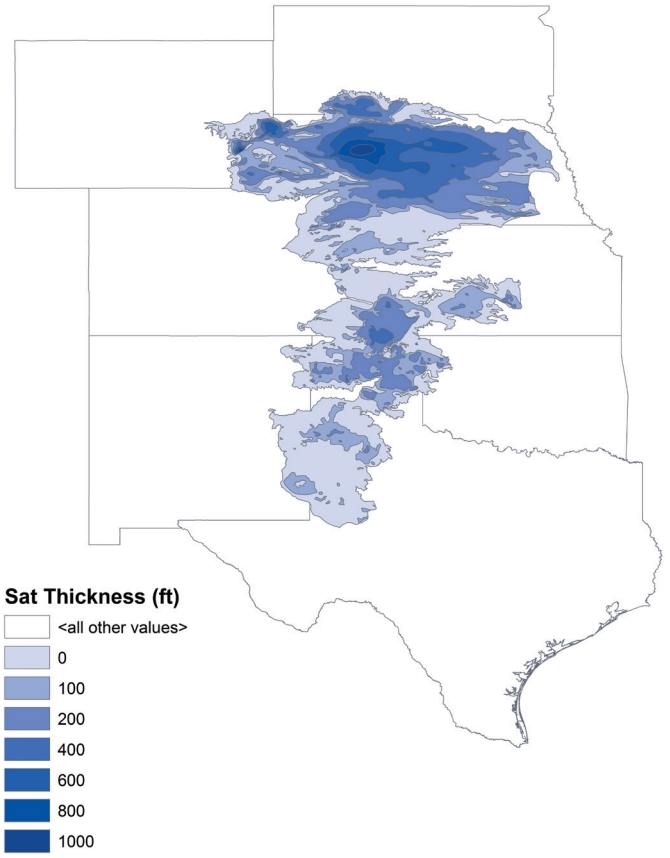


Figure 1. Saturated thickness in the Ogallala Aquifer prior to the development of widespread irrigation. Legend is in the figure. Figure is based on data from McGuire (2009).

aquifer in no sooner than 1,000 years. North of the Kansas-Nebraska border, rivers traversing the Great Plains are more numerous, and the depth to the top of the aquifer tends to be shallower. Therefore, recharge in the northern region of the aquifer is estimated to be at least 10 times faster.

Water from the Ogallala Aquifer has contributed greatly to the agricultural output of the Great Plains. A great increase in irrigation in the Great Plains occurred during the post-World War II era. By 1959, total irrigated cropland acreage was approximately 7 million acres. By 1978, irrigated cropland had increased to approximately 13 million acres. Irrigated acreage declined by approximately 20% by the late 1980s (Kromm and White 1992). Withdrawals greatly exceeding rates of recharge have resulted in lower well yields, deeper water tables, and reduced saturated thickness. Despite declines in irrigated acres, irrigation use still accounts for nearly 90% of the groundwater withdrawals in many areas over the Ogallala Aquifer. Aquifer depletion rates of 1 to 3 feet annually are commonplace in areas of irrigated agriculture. Although it has been estimated that only 10% of the water in the Ogallala Aquifer has been withdrawn (Gollehon and Winston 2013), the depletion is not constant across the aquifer. In many areas of the aquifer, especially in the southern portion of the Texas High Plains, eastern New Mexico, northwestern Kansas, and eastern Colorado, the saturated thickness has been reduced by at least 40% of pre-development levels (National Research Council 1996). Steward and Allen (2015) estimated that peak withdrawal rates for Texas occurred in 1999, and in 2010 for Kansas.

The current state of ground water utilization in the Great Plains is a reflection of economic, social, and political factors. The primary reason that the underground water resources in the Great Plains are being used at a high rate is that the revenues stemming from their current use are greater than the associated cost of extraction. Current withdrawals also increase farm and regional economic stability and reduce producer risks. However, current rates of withdrawals from the aquifer cannot be sustained in many areas of the Great Plains. For this reason, the sustainability of this resource and its associated economic consequences needs to be better understood.

Funding and Congressional Actions

In 2001-2002, representatives from ARS (Dr. Nolan Clark, Laboratory Director at Bushland, TX and Dr. Dan Upchurch, Laboratory Director at Lubbock, TX), Kansas State University (Dr. Bill Hargraves), Texas A&M University (Dr. Alan Jones), and West Texas A&M University (Dr. Jim Clark) drafted an initiative for consideration by the Congressional appropriation committees to provide funding for a research-education consortium that would become the OAP. Simultaneously, Texas Tech University was preparing a similar proposal with Dr. Sukant Misra acting as the point person. When the congressional delegation from Texas learned of the two potentially competing, they instructed the representatives from the two groups to draft a joint proposal, which occurred.

In 2002, reports for the fiscal year (FY) 2003 from both the House and Senate appropriation committees included funds to initiate the OAP. The Director of ARS' Southern High Plain Area, Dr. Chuck Onstad, was so confident that federal funds were forthcoming for the OAP that he provided $300,000 (Fig. 2) so that the organization of the scientists to participate in the OAP could begin. For FY2003, the U.S. Congress provided ARS-USDA with funding "for research into the complex nature of water availability, potential uses, and costs which will help determine future water policy in the Ogallala Aquifer Region". The two major objectives of the program were: "1) develop, evaluate, and disseminate information and technologies for water uses; and 2) provide scientifically sound data to water use planners and policymakers." Initially, Congress provided $670,613 and $223,537 to the Bushland and Lubbock, TX locations, respectively. In FY2004, Congress provided an additional $764,960 for the OAP, increasing the total to approximately $1.76 million (Fig. 2). ARS headquarter staff, under advisement from Congress, directed all of the OAP funds to reside at the Bushland location. However, Bushland was to provide the Lubbock location with sufficient funds for at least a 0.5 full time equivalent (FTE) research scientist. This scientist was to come from re-direction of current staff. ARS headquarters also directed ARS to hire 1.0 FTE research scientist at Bushland to

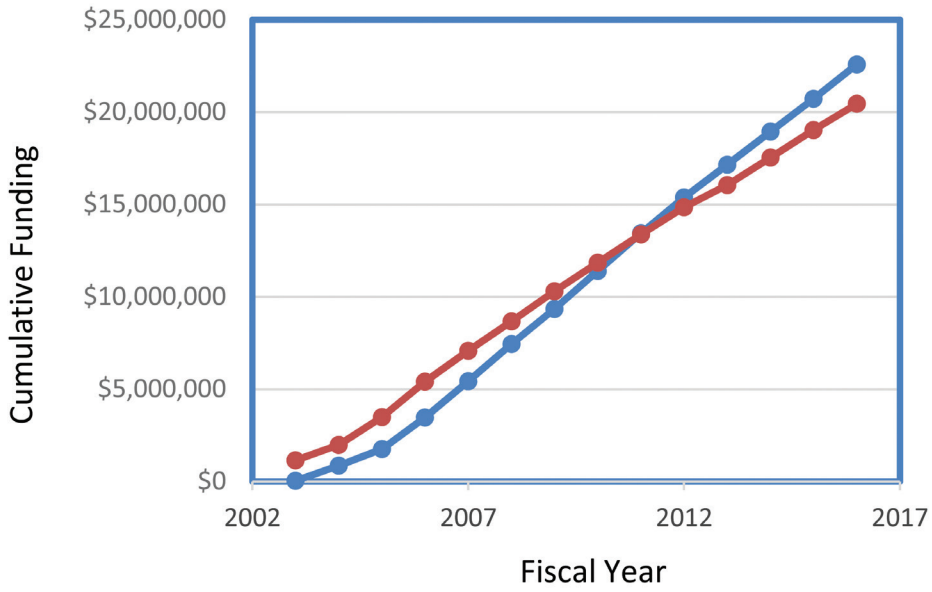


Figure 2. Cumulative funding for ARS (gray) and the sum of funding at four participating universities (black) from FY2003 to FY2016.

provide direct support for the OAP. In FY2005 and FY2006, Congress provided additional funds increasing the total OAP funding to approximately $3.6 million (Fig. 2). From these increased funds, the Bushland location was to hire two additional FTE research scientists, increasing Bushland OAP staff to 3.0 FTE.

In 2006, reports for FY2007 budgets from both the House and Senate appropriation committees provided even more funds for the OAP. These increases never came to the OAP. The attitude of Congress toward ear-marks changed during the 2006 congressional year. Congressionally directed ear-marks were defined by the Office of Management and Budget (OMB) as appropriations passed by Congress and approved by the President that directed specific funds to stated locations and for defined purposes. For example, a line item in an appropriation bill "directing $200,000 to Bushland, TX location for research directed towards better management of sorghum" would be an ear-mark. Congress passed and the President signed a continuing resolution for FY2007 providing funding at the FY2006 level so that the OMB could evaluate all line items to determine if they were congressional ear-marks.

The OMB evaluations of line items in previous year's budgets went beyond the language in the congressional appropriation bills. A major factor in the OMB's evaluations was: did the agency have in place sufficient controls to ensure that funds were directed towards federal priorities? The OMB determined that approximately 75% of the line items in ARS budgets were congressional ear-marks and recommended that these funds be re-directed to high priority projects. The OMB determined that funding for the OAP was not a congressional ear-mark because ARS had sufficient controls over the projects being funded to ensure that no cooperator was guaranteed a specific level of funding and that the projects addressed high priorities for the USDA.

From FY2007 to FY2014, funding for the OAP was designated as discretionary and therefore was relatively free from proposed re-directions in the President's proposed budget for the following year. It has been common for the President to propose re-direction of ear-marks and other congressional directed programs in the ARS budget to program areas that the executive branch deem of higher priority. This enables the administration to identify their research priorities with minimum increase in the agency's budget. Funding for the OAP was relatively constant from FY2007 to FY2011, except for minor changes for enhancements to governmental internet technology (IT) and

increases in funds for federal salary to offset directed increases in employee's salaries (cost of living adjustments). In FY2012, the ARS was directed to close 10 locations. Unfortunately, location closure typically results in increased cost for retirements, etc. ARS headquarters ordered an across-the-board 30% reduction in outgoing funds including those OAP funds that supported research at the four participating universities. How that reduction was calculated is still a mystery to ARS OAP leadership. ARS headquarters ordered the outgoing funds to be approximately $1.15 million. The in-house portion of the OAP had to be decreased by $100,000 to reach the total reduction. The estimated cost for closure of the 10 locations was less than that estimated and therefore approximately $280,000 was provided at the end of FY2012 for cooperating universities. In total, the final reduction in OAP funding in FY2012 was approximately $170,000 or 5%.

The OAP did not fare as well in FY2013 when sequestration was imposed (Fig. 2), and OAP funding was reduced by approximately $400,000. In 2014, many recipients of outgoing funds from the ARS, including representatives from at least three of the four cooperating universities within the OAP, petitioned Congress for restoration of outgoing funds to FY2012 levels. The reports from the House and Senate appropriation committee for FY2014 included language for the ARS to restore outgoing funds to FY2012 levels. ARS' budget for FY2014 included an increase of $321,000 for the OAP. ARS' headquarters directions under advisement of Congress set outgoing OAP funding at approximately $1.4 million. Because the funding level was defined, the outgoing funds were designated as congressionally mandated, once again.

Total funding to the four universities was stable between FY2014 and FY2017. During this period, however, there was a change in OAP funding. The two CRIS projects associated with the OAP, one in Lubbock and one Bushland, are a part of ARS' National Program (NP) 211, Water Availability and Watershed Management. As such, both of these research projects developed a five-year research plan that was subjected to peer review in FY2016 and FY2017. To enhance long term research planning by ARS scientists, it was agreed that Bushland would transfer a portion of the in-house OAP to Lubbock. These funds would enable Lubbock scientists to develop long term research plans to meet the objectives of the NP211, as well as the OAP. In 2017, a permanent transfer of $400,000 from Bushland to Lubbock occurred so that Lubbock scientists can conduct their share of OAP research from 2017 to 2022.

In total, the OAP since its inception has provided over $40 million for research and education related to conservation of the Ogallala Aquifer (Fig. 2). Early in the program's history, the universities received more than half of the funds. After ARS hired the three authorized scientists, ARS' share of the funding has exceeded one-half.

Early Program Objectives and Management

Several meetings with potential participants and stakeholders were held in 2003. The six individuals mentioned in the previous section who drafted the appeal to Congress were responsible for identifying participants from the four universities and stakeholders that attended these meetings. These meeting were the basis of developing the initial program priority areas. In 2003, the priority areas were: 1) economic assessment of conservation practices and water policies; 2) region's hydrology and climatology; 3) integrated crop and livestock production; 4) irrigation and precipitation water management; 5) irrigation systems and technologies; and 6) technology transfer. These six areas were the basis of distributing FY2003 funds to research projects.

When funding for the OAP was certain, the six persons that were involved in the drafting of the joint congressional initiative formed what would become the program leadership. Shortly after, the leadership team was expanded to include the Research Leader (RL) of the Soil and Water Management Research Unit, Dr. Terry Howell, because OAP's CRIS project resides in this unit. Later, the leadership team was formally defined as the RLs of the Soil and Water Management Research Unit (ARS-Bushland), the Wind Erosion and Water Management Research Unit (ARS-Lubbock), the Laboratory Director (ARS-Bushland), and the PIs from the four universities. Decisions regarding

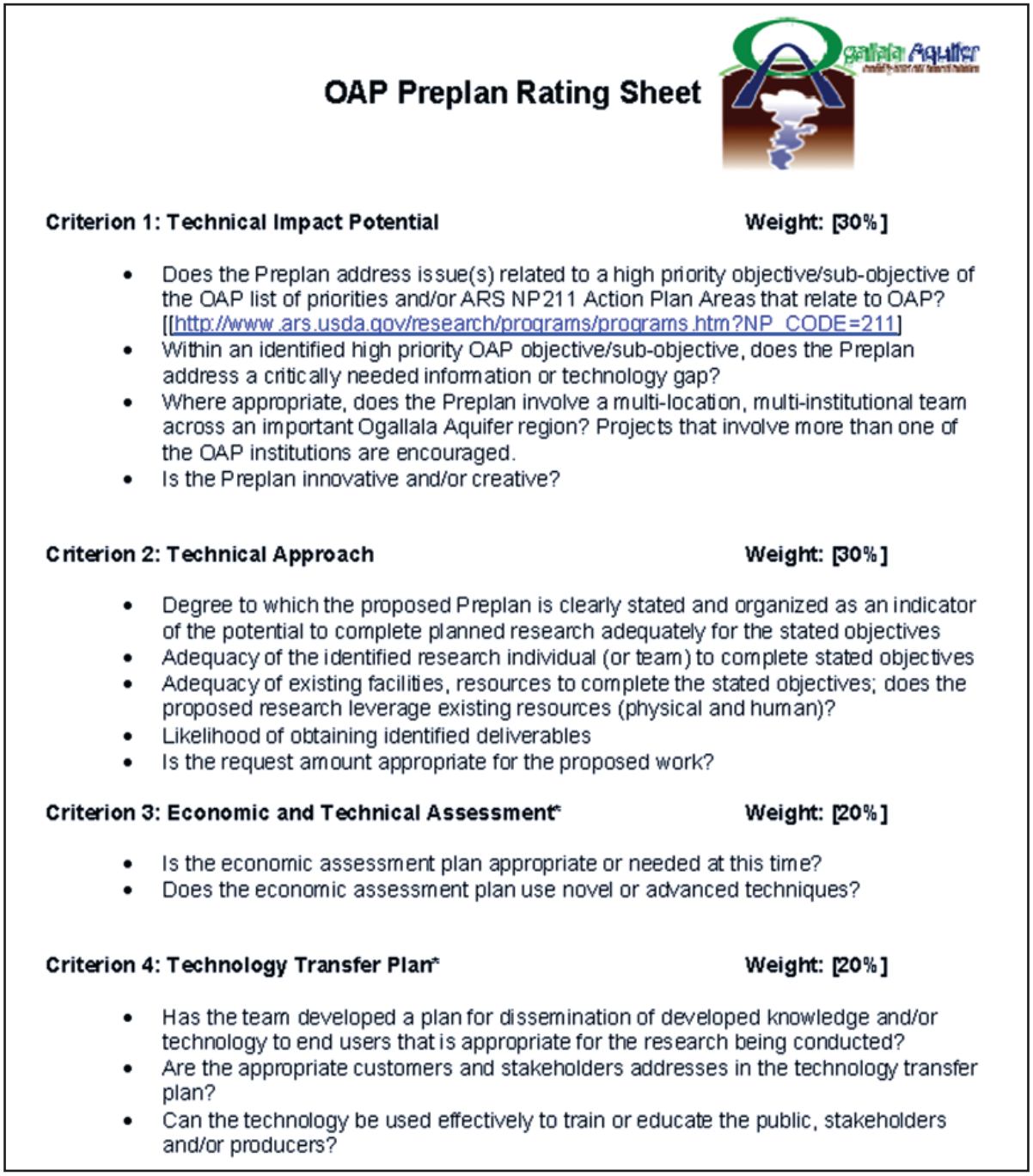
program direction, etc. would be determined by consensus of the leadership team. The leadership team also included non-voting adjunct members, individuals either impacting the program or impacted by it. These members included Residence Directors of university research sites likely to be involved in the OAP including the Texas A&M AgriLife locations in Lubbock and Amarillo, the Director for agricultural experiment stations of the Kansas State University in western Kansas, and ARS' Area Director for Texas.

The program objectives were changed slightly in FY2004 by refining the objectives and adding a seventh objective. The revised objectives included: 1) estimate the economic impacts of water management activities; 2) improve water management, both irrigation and precipitation; 3) improve irrigation systems and technologies; 4) reduce the dependence on groundwater resources by developing integrated cropping systems; 5) develop methodologies for assessing groundwater resources of the Ogallala Aquifer (hydrology-climatology); 6) evaluate water use by concentrated animal feeding operations (CAFOs) and agricultural processing industries; and 7) develop information programs/technology transfer. These remained the priority areas until FY2014.

In FY2003, no official OAP Manager position existed, but the day-to-day management of the OAP was the responsibility of Dr. Nolan Clark, who also served as the Laboratory Director of the Bushland location, RL of the Renewable Energy and Manure Management Research unit, and as the primary scientist in the Renewable Energy Program. In FY2003 and FY2004, the program objectives for the OAP were clearly defined. The OAP leadership team approved a mechanism by which each priority area would have a team with a designated leader and two to three advisers. The OAP leadership would designate a target funding level for each priority area and the priority area team would recommend projects for support with the final decision being made by the leadership team. Priority teams would serve for one year. This process had weaknesses that became more apparent with time. Competition among competing interests of scientists within some priority areas led to abrupt changes in program direction from year to year. In time, animosity among priority area participating scientists started to occur. OAP leadership had hoped that interactions would lead to inter-institutional teams, and in some areas just the opposite occurred.

In 2008, the senior author of this article (Dr. Brauer) was selected as OAP Manager. Dr. Brauer had for the prior 10 years managed two large outgoing research efforts as the RL of the ARS-Booneville, AR location so he had substantial experience working with university bureaucracies and scientists. A priority after the hiring of the OAP Manager in 2008 was to change the mechanism by which projects were selected for support. The Leadership Team determined an approximate funding level for each of the seven priority areas. An evaluation matrix for proposed activities was developed and approved by the Leadership Team (Fig. 3). Each research plan was reviewed by at least four peers: a leadership team member, a representative from the OAP manager, a representative from the RL in Lubbock, and one to two other scientists that may or may not have been participants in the OAP. An average score was determined from the peer reviews and the plans were ranked according to average score within the priority area. The ranking versus funding levels were initially reviewed by the OAP Manager and the RL-Lubbock, and these two individuals adjusted the plans recommended for support by slight changes in the funding per priority area. These recommendations were then presented to the entire leadership who by consensus determined final support. This selection process removed some of the conflict among participating scientists within a priority area.

From FY2003 to FY2013, funding by priority area varied substantially (Fig. 4). Funding for projects in the priority area related to water use by CAFOs and agricultural industries was the least, reaching approximately 4% of the funds provided by priority area. Projects supporting objectives related to precipitation and irrigation water use priority areas received the greatest portion of funding, exceeding 25% of the total funds. The assignment of funds to priority areas prior to the review of plans created a situation in which the possibility for support was greater in some priority areas than others. During the time frame that the



OAP Preplan Rating Sheet

Criterion 1: Technical Impact Potential **Weight: [30%]**

- Does the Preplan address issue(s) related to a high priority objective/sub-objective of the OAP list of priorities and/or ARS NP211 Action Plan Areas that relate to OAP? [[http://www.ars.usda.gov/research/programs/programs.htm?NP_CODE=211]
- Within an identified high priority OAP objective/sub-objective, does the Preplan address a critically needed information or technology gap?
- Where appropriate, does the Preplan involve a multi-location, multi-institutional team across an important Ogallala Aquifer region? Projects that involve more than one of the OAP institutions are encouraged.
- Is the Preplan innovative and/or creative?

Criterion 2: Technical Approach **Weight: [30%]**

- Degree to which the proposed Preplan is clearly stated and organized as an indicator of the potential to complete planned research adequately for the stated objectives
- Adequacy of the identified research individual (or team) to complete stated objectives
- Adequacy of existing facilities, resources to complete the stated objectives; does the proposed research leverage existing resources (physical and human)?
- Likelihood of obtaining identified deliverables
- Is the request amount appropriate for the proposed work?

Criterion 3: Economic and Technical Assessment* **Weight: [20%]**

- Is the economic assessment plan appropriate or needed at this time?
- Does the economic assessment plan use novel or advanced techniques?

Criterion 4: Technology Transfer Plan* **Weight: [20%]**

- Has the team developed a plan for dissemination of developed knowledge and/or technology to end users that is appropriate for the research being conducted?
- Are the appropriate customers and stakeholders addresses in the technology transfer plan?
- Can the technology be used effectively to train or educate the public, stakeholders and/or producers?

Figure 3. Preplan evaluation matrix (2010).

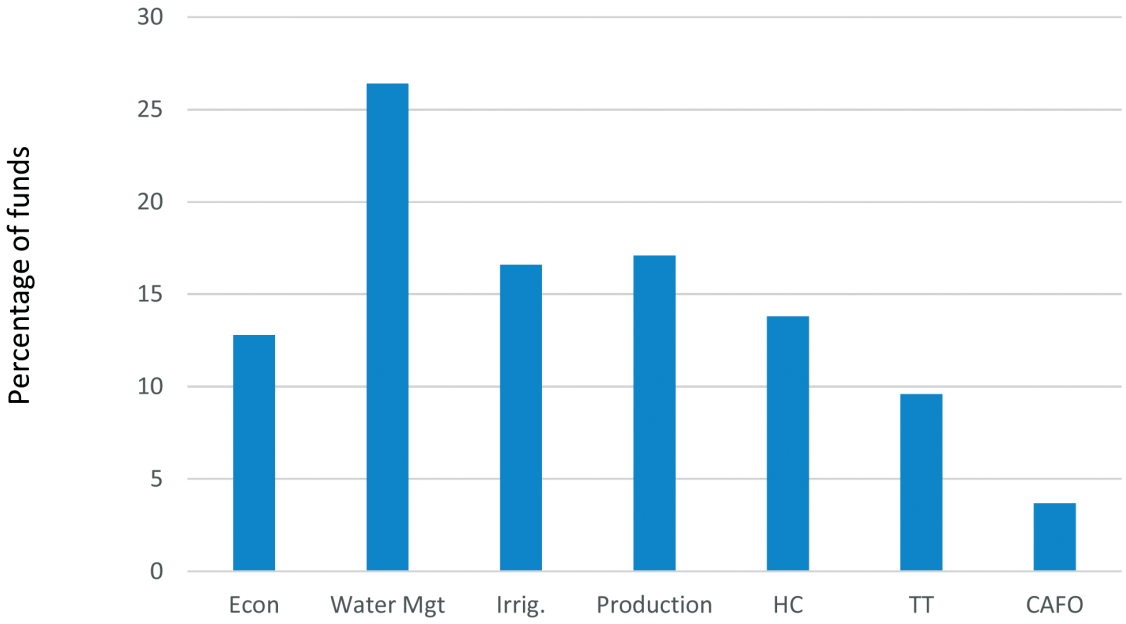


Figure 4. Percentage of the total OAP funding among the seven prioirty areas from FY2003 to FY2013. Priority areas are abbreviated: 1) Econ: Economic Assessment and Impact; 2) Water Mgt: Irrigation and Preciptation Management; 3) Irrig.: Irrigation Systems and Technologies; 4) Production: Integrated Crop and Livestock Systems; 5) HC: Hydrology and Climatology; 6) TT: Technology Transfer; and 7) CAFO: Water use by CAFO and Agricultural Industries.

OAP had seven priority areas, the probability for support was about one out of three. However, there was great disparity between the priority areas. For instance, no suitable plan was submitted in the priority area for evaluating water use by CAFOs and agricultural processing industries and therefore the probability for support was zero. Plans in the economic assessment and impact priority area tend to have a higher success rate than in any of the other six areas.

From FY2005 to FY2007, substantial increases in funds for ARS' portion of the OAP was provided by Congress but ARS was unable to fully utilize these funds because personnel needed to be hired. ARS members of the Leadership Team offered to make $2,000,000 available over three years for two large multi-location and multidisciplinary efforts and the overall Leadership agreed to support two such projects: 1) integration of hydrological and economic data and models to assess economic impacts of water policy scenarios; and 2) investigations into the plant physiological basis for drought tolerance in four major crops of the Southern High Plains, cotton, wheat, sorghum, and corn. The economic-hydrological team made substantial progress on the development of an economic-hydrological model to predict changes in crop acreages and returns at the county level, though a model to predict such trends at a farm level was not realized. The plant physiology project produced numerous journal publications, but no unifying theories on the underlying mechanism of drought tolerance were put forth.

The accomplishments of both large projects were limited, due to a lack of leadership. The OAP Leadership Team expected someone from within each of the large project's team to emerge as the leader, but this did not occur. The Leadership Team did not provide incentives and support for a project member to encourage coordination and leadership roles. As a reminder, these large projects occurred prior to the hiring of an ARS program leader. If there had been an OAP manager, that individual could have provided that coordination and leadership for these large projects. Team members were chosen in large part by the Leadership Team to ensure that the funds were distributed among the different participating entities, rather than considering team

members' expertise and probably more important, team members' ability to act synergistically.

During this period of time, the OAP had a formal annual and final project reporting process. A progress report was due 18 months after funding was provided and a final report was due 30 months after funding was provided. Participating scientists were encouraged several times a year to report journal articles that had resulted from OAP funding. These articles were included in the project's annual report.

Current Program Objectives and Management

In large part due to the leadership of the ARS' Southern Plains Area Director, Dr. Dan Upchurch, the objectives of the OAP changed in FY2014. Dr. Upchurch's primary concern was that the objectives of the OAP be related to measureable outcomes. Another concern he had was that after 10 years, a level of complacency had developed among participating scientists. Dr. Upchurch invited the OAP Leadership Team to College Station, Texas in November 2013 and charged the group with defining a handful of objectives to replace the seven priority areas. Four objectives emerged from this meeting: 1) Develop and evaluate water management strategies and technologies that could reduce water withdrawals for irrigation by 20% in 2020 compared to 2012, while maintaining and/or enhancing the economic viability of the agriculture industry and the vitality of the Southern Ogallala Aquifer Region; 2) Develop and evaluate management strategies and technologies that would increase the productivity and profitability of dryland cropping systems; 3) Improve the understanding of hydrological and climatic factors that affect water use and economic profitability, and provide estimates of the climatic, hydrologic, cropping, and profitability conditions that are likely to occur on the Southern High Plains over the next 50 years; and 4) Determine the impacts of alternative water withdrawal/use policies on the economic viability of the agriculture industry and the vitality of the Southern Ogallala Aquifer Region. Starting in FY2014, submitted plans were evaluated by a peer review process similar to that described earlier, but with regard to the above four objectives. A fifth objective was added in FY2017: 5) Develop best management practices for alternative dryland and high value irrigated crops that can sustain farm level income and profitability as pumping from the Ogallala Aquifer declines. By and large, stand-alone technology transfer activities were not encouraged under these objectives but PrePlans with strong technology transfer and economic assessment aspects were more likely to be supported because of the evaluation matrix. In 2016, a stand-alone technology transfer activity related to 40 years of sprinkler irrigation research on the High Plains was selected for support. The evaluation process and matrix remained as before. However, no target funding levels were designated for the objectives.

Collaborative activities are facilitated by an annual workshop in which program scientists participate. The annual workshop is also a forum in which research priorities from stakeholder groups are presented. Attendance varies from 80 to 150 participating scientists, graduate students, and stakeholders. The annual workshop is held at different venues with typical rotations involving Lubbock and Amarillo, TX and Garden City, KS; however, the workshop has been held in Manhattan, KS as well.

In 2014, the manager of the OAP assumed additional responsibilities as the Research Leader of the Soil and Water Management Research Unit. Then later, in 2016, the manager also assumed responsibilities of Acting Laboratory Director for the Center for Public Research and Leadership (CPRL). These increased duties necessitated changes on the workload for the OAP manager duties. Scientists were provided the option of making an oral or poster presentation at the annual workshop rather than submitting a report. As such, since 2014, a poster session has become a standard feature of the program's annual workshop. These changes were implemented in part to reduce the work load of the OAP Manager after he became RL of the Soil-Water unit.

Awards and Outcomes

The OAP has been recognized several times for its accomplishments related to production agriculture, irrigation technologies, and water

conservation. These awards document the outcomes of the OAP to date and therefore are worthy of examination.

Irrigation Symposium (2009)

Every ten years the Irrigation Association sponsors at its national annual meeting a symposium summarizing the recent advances in irrigation research. In 2009, the Fifth National Decennial Irrigation Symposium features advances arising from the support by the OAP. The symposium featured 18 presentations from OAP researchers. The presentations were the basis of proceeding articles that were published in 2010 in the Transactions of the American Society of Agricultural and Biological Engineers.

Exemplary Example of Cooperative Agricultural Related Research Program (2011)

In the fall of 2010, there was a call for nominations from a consortium of agricultural related organizations including Farm Foundation, Charles Valentine Riley Memorial Foundation, and others, for Exemplary Examples of Cooperative Research and Development Programs to be presented at the Agriculture, Food, Nutrition, and Natural Resources R&D Round Table in the spring of 2011. There were over 50 nominations and eight were selected. The OAP was the only group selected that conducted research related to production agriculture.

The nomination material indicated that a major accomplishment of the OAP from 2003 to 2010 was its impact on water conservation, that is, management practices to reduce withdrawals from the aquifer and thus sustain economic benefits derived from its use in Texas. The Texas Legislature, through the Texas Water Development Board, has divided the state into 16 water planning regions, two of which are located above the Ogallala Aquifer. These water planning regions must create 50-year water plans that are updated every five years. In Region A (Panhandle portion of Texas), the 2011 water plan (Panhandle Water Planning Group 2011) indicates that the demand for water will exceed the supply in most counties in which irrigation is occurring for most of the next 50 years (2010-2060) if the status quo is maintained. However, the region's 2011 water plan indicates that this supply deficit can be turned into modest supply surplus by the adoption of OAP research results in the areas of best cropping practices, improved irrigation scheduling to better match crop needs with water applications, and continued adoption of efficient irrigation systems. Research activities of the OAP produced over 20 peer reviewed journal articles annually since 2005. In 2010, the OAP maintained a public web site: http://www.ogallala.ars.usda.gov/. The web site provided access to research projects' final reports, annual accomplishment statements, news items related to the Ogallala Aquifer and the OAP, and calendar of events. However, due to internet security issues the site was taken down in 2014. A new site that is hosted by Texas A&M AgriLife's Texas Water Resource Institute went online in June 2017 (http://ogallala.tamu.edu/). Archived material from the original site (2010-2012) is available at: http://web.archive.org/web/20130217193538/http://www.ogallala.ars.usda.gov/index.php.

The eight selected groups made presentations at the Association for the Advancement of American Science (AAAS). The presentations were distributed over the internet to over 100 locations.

Blue Legacy Award for Agriculture (2012)

The Water Conservation Advisory Council of Texas presents annually the Blue Legacy Award(s) for Agriculture to individuals and groups that have promoted water conservation in Texas. In 2012, the OAP was presented with one of the 2012's Blue Legacy Awards.

The nomination materials included the following accomplishments. Since the 2000s, the 16 water planning regions in Texas have been charged with the development of a water plan that determined water supply shortages and means to overcome those shortages. The 2011 Region A (Texas Panhandle) Water Plan identified at least five counties in which the demand for irrigation water from the Ogallala Aquifer will exceed supply under current practices. This difference between irrigation demand and water supply is expected to grow between 2010 and 2040, and then decrease between 2040 and 2060 due to the conversion of irrigated acres to dryland farming. Under such a scenario, the region is expected to lose nearly $1 billion in annual agricultural sales.

The regional water planners examined the impact of implementation of water conservation practices based on OAP research: 1) Continued adoption of water efficient irrigation systems, like low pressure center pivot systems, and subsurface drip; 2) Irrigation scheduling based on crop needs, using real time sensors that detect crop water stress, and/or the integration of weather data with patterns of crop water use; and 3) Use of crop species and varieties that have lower water requirements, including support for the development of drought and heat tolerant germplasm for sorghum, corn, peanuts, and wheat. Adoption of these water conservation practices is projected to reduce the difference in the water demand for irrigation and water supply to the extent that supply will exceed demand from 2050 to 2060. Such conservation efforts are expected to maintain the $4 billion agricultural economy of the Texas Panhandle.

Water conservation practices currently being researched that will facilitate future water savings include: 1) Development of technology and management practices for the use of variable rate irrigation controls and supervisory control and data acquisition (SCADA) to improve the efficiency of irrigation applications; 2) Management practices that better match water needs to cropping practices that integrate whole farm operations, both in terms of time (multiple years) and different fields and/or irrigation systems; and 3) Development of soil moisture sensors that can provide real time, accurate information on total soil water availability.

Although water use by CAFOs and animal processing facilities represent a small part of the water use in the Texas High Plains, high water use by these entities can significantly affect their profitability. Research conducted by OAP participating scientists has provided sound estimates of water use by these industries and means of which water can be used more efficiently (Guerrero and Amosson 2013a; 2013b). This information is needed by water policy makers to understand their contribution to the regional economy.

The OAP has supported educational activities to facilitate the transfer of information to end users. These activities include but are not limited to: 1) Development and support for hands-on training sessions and/or self-help on-line resources available through Texas A&M AgriLife or Kansas State University; 2) Development of software that helps farmers and irrigators allocate their water resources to different crops and fields to optimize water use and returns; 3) Hosting an annual workshop in which participating scientists and stakeholders exchange information; and 4) Support for farm days and demonstration projects including support for the scientists and extension agents who were involved in the North Plains Groundwater Conservation District 200 bushels with 12 inches challenge, recognized in 2011 with a Blue Legacy Award in Agriculture.

The activities of the OAP have been instrumental in the development of mass media stories on water conservation and the importance of the Ogallala Aquifer to world food production in such outlets as CNN and National Public Radio's Marketplace. Participants in the OAP tend to be leaders in their local communities with respect to water conservation. Many of the program participants in the Amarillo area have been involved in the development of Region A water plans.

The OAP is a regional project that has significant efforts directed towards water conservation in western Kansas. The OAP had a significant impact on water policies in western Kansas over the last two years. In 2011, Governor Brownback of Kansas spearheaded an effort to change water policies that will help sustain the economic activity derived from the Ogallala Aquifer. A Governor's Economic Summit for the Future of the Ogallala Aquifer was held in July 2011, and led to the creation of the Ogallala Aquifer Advisory Committee (OAAC). The OAAC's recommendations for changes in state water policies were largely based on investigations supported by the OAP. New state legislation passed during the spring of 2012 was described above.

Honor Award for Excellence from the Secretary of Agriculture (2013)

In 2013, the OAP received an Honor Award from the U.S. Secretary of Agriculture for its effort "Sustaining rural prosperity on the drought prone Southern High Plains by finding solutions to problems arising from declining water in the Ogallala Aquifer". Outcomes from this project that conserve water and promote agriculture include:

1) Irrigation scheduling using evapotranspiration demand has reduced water application by 15% over the past 10 years, saving farmers approximately $200 million in production costs; 2) Advances in the design and management of subsurface drip irrigation has led to the doubling of the acres using this water conserving technology since 2003; 3) New irrigation automation systems could benefit 6 million acres by reducing labor costs by $7 per acre while maintaining crop yields; 4) Development of drought and heat resistant crop varieties has been advanced for corn, cotton, sorghum, wheat, and peanuts; 5) Thousands of farmers have been educated in water conservation practices through extension programs and millions have been exposed to the importance of the Ogallala Aquifer to national and world food and fiber supply via public media stories.

The OAP supported water policy changes in Kansas. In 2011, Governor Brownback of Kansas spearheaded an effort to change water policies that will help sustain the economic activity derived from the Ogallala Aquifer. State legislation passed during the spring of 2012 included: 1) repeal of "use it or lose it" for groundwater rights; 2) creation of Local Enhancement Management Plans; 3) creation of water banks for market-based reallocation of water use and conservation, and repeal of the 10% set aside for deposited water; and 4) amendments to the multi-year flex accounts to provide irrigators with flexibility while eliminating the 10% conservation penalty. Research from the OAP indicated that enactment of these four initiatives will not increase groundwater withdrawals while helping to sustain farm and regional economies. Additional research by the OAP provides the tools and knowledge that irrigators and farmers need to take full advantage of these changes in state and local water policies.

The accomplishments of the OAP directly support several of the USDA's priorities. For example, the OAP supports the USDA Strategic Goal 1: Assist rural communities to create prosperity so they are self-sustaining, repopulating, and economically thriving (USDA 2014). A conservative estimate of the value of agricultural production in western Texas and Kansas is $10 billion in 2012. The multiplier effect of irrigated crop production to regional economy is greater than that of dryland farming because irrigated agriculture requires more inputs and services. Therefore, agricultural production in this region may have an economic impact exceeding $20 billion. A significant portion of this agricultural economy is at risk for declining water availability from the Ogallala Aquifer. Localized areas where irrigated agriculture has declined sharply because of severe depletion of the Ogallala Aquifer have already experienced economic decreases and depopulation, for examples, Happy, TX and Greely County, KS. Widespread occurrence of decreased economic activity and depopulation could occur without the accomplishments of the OAP creating information and technologies to increase water conservation and sustain economic activity generated by the water withdrawn from the aquifer.

The OAP is also supporting other USDA goals, such as Pillar 2 of Objective 1.1, facilitating sustainable renewable energy development (USDA 2014). Research results from the program are leading to the development of management practices that enhance both the dryland and irrigated production of feedstock for biofuel production. Economic analyses that support the Ogallala Aquifer Program indicate that per unit of water pumped from the aquifer a biofuel plant supports over 10 times the number of jobs as irrigated crop production (Guerrero et al. 2011). Additionally, the OAP is helping the USDA meet Performance Measure 1.3.6 (Increasing the number of students enrolled in agriculture related degrees by 20%) by training an average of 18 undergraduates, 22 master degree students, and 10 Ph.D. students between FY2010 and FY2013. Increasing the number of people graduating with professional degrees related to agriculture and natural resources has been a long standing goal of the USDA (USDA-REE 2012).

A unique outcome of OAP activities has been the forming of teams that probably would not have developed independently. An Economic Impact and Assessment Team has emerged under the program's umbrella. This team, with at least one representative from each of the four universities, has become prolific in impactful research output, providing insights into the possible outcomes of different water conservation strategies. A team from Kansas State University and Texas A&M University hosted a multi-day multi-location

outreach effort summarizing 20 years of research regarding the installation and management of sub-surface drip irrigation. A broader team has formed to celebrate 40 years of sprinkler irrigation on the High Plains with several technology transfer events in 2018. The usefulness of decision support tools that Kanas State University was developing for Kansas irrigators was extended by the adaptation for use by Texas irrigators. During this process the team developed a means by which these irrigation tools could efficiently and quickly be adapted to anywhere in the world.

Conclusion

Since 2013, the OAP has continued to be productive and serve the needs of the Southern Ogallala Aquifer Region. In 2016, leaders in the OAP in conjunction with prestigious water conservation researchers from Colorado State University, Oklahoma State University, New Mexico State University, and University of Nebraska were granted an USDA-NIFA CAP grant to further the understanding of the resiliency of the Ogallala Aquifer in light of climate change and changes in production systems. In 2017, leaders within the OAP and the NIFA CAP grant presented a special symposium within the Universities Council on Water Resources (UCOWR) 2017 Annual Conference on management practices to sustain aquifers that have been decreasing in water availability. This article is drawn from that symposium.

At the time of writing this article (spring 2017), there is uncertainty how the new Trump administration will affect the OAP. President Trump's initial budget for FY2018 had only passing comments regarding ARS. It is hard to believe that continued support for the OAP is not a high priority since the Ogallala Aquifer Region is one of the most productive crop and livestock production areas in the U.S. (Gollehon and Winston 2013). The current hiring freeze and the administration's stated intentions to reduce the federal workforce may affect the OAP. It is unfortunate that restrictions resulting from the administration goal of reducing the federal workforce may create barriers to the USDA's goal related to the development of next generation agricultural related professionals.

Although there are uncertainties arising from a new Presidential administration, there is hope that the future for the OAP is bright. Through continued research and technology transfer activities the OAP has been successful in providing knowledge that will sustain rural economies in the Southern Great Plains as water available for irrigation from the Ogallala Aquifer decreases. In accomplishing this mission, OAP researchers have contributed significantly to the research and technology transfer activities related to irrigation technology and irrigation best management practices. In addition, the OAP addresses knowledge and technology related to subjects other than irrigation, including dryland farming, hydrology, climatology, etc. Research results will facilitate efficient use of the Ogallala Aquifer, increase the sustainability of dryland farming, and provide water use planners and policymakers with valuable knowledge and tools. The outcomes that Congress intended when it provided the initial funding in 2003 are bearing fruit.

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Author Bio and Contact Information

Dr. David Brauer (corresponding author) has been the Manager of the Ogallala Aquifer Program (OAP) since 2008 and an employee of ARS-USDA since 1986. Dr. Brauer is also a Supervisory Research Leader and Research Leader of the Soil and Water Management Research Unit at the Conservation and Production Research Laboratory in Bushland, Texas. He may be contacted at David.brauer@ars.usda.gov.

Dr. Dan Devlin is a member of the Executive Leader Team of the OAP. Dr. Devlin is also the Director of the Kansas Center for Agricultural Resources and the Environment and the Kansas Water Resources Institute at Kansas State University. He may be contacted at ddevlin@ksu.edu.

Dr. Kevin L. Wagner is the Director of the Oklahoma Water Resources Center and holds the Thomas E. Berry Professorship in Integrated Water Research

and Management. He provides leadership and administration of the Center's water programs, leads Center efforts to increase engagement with the water resources community across Oklahoma and the nation, and facilitates development of inter-disciplinary teams to address high priority water resources issues. Wagner has more than 20 years of experience in watershed assessment and planning, stakeholder engagement and conservation practice research and education. He may be contacted at kevin.wagner@okstate.edu.

Dr. Mike Ballou is a member of the Executive Leader Team of the OAP. Dr. Ballou is also Associate Professor in the Department of Animal and Food Sciences at Texas Tech University and Associate Dean of the College of Agriculture Sciences and Natural Resources. He may be contacted at michael.ballou@ttu.edu.

Dr. Dean Hawkins is a member of the Executive Leader Team of the OAP. Dr. Hawkins is also the Dean of the Paul Engler College of Agriculture and Natural Sciences at West Texas A&M University. He may be contacted at dhawkins@mail.wtamu.edu.

Dr. Robert Lascano is a member of the Executive Leader Team of the OAP. Dr. Lascano is a Supervisory Soil Scientist and Research Leader of USDA-ARS Wind Erosion and Water Conservation Research Unit at the Cropping Systems Research Laboratory in Lubbock, Texas. He may be contacted at Robert.lascano@ars.usda.gov.

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