Ogallala Aquifer
Funded by USDA ARS Research Initiative
A research consortium between USDA-Agricultural Research Service, Kansas State University, Texas AgriLife Research and Extension, Texas Tech University, and West Texas A&M University

Project Plan from FY2016
(Crop Years 2017-2019)

1. Title: Landscape-scale crop water productivity model supporting multi-year water management decisions.

2. Investigator(s)

Principle Investigator:	Robert M. Aiken (KSU, Colby); Xiaomao Lin (KSU, Manhattan)
Co-Investigator(s):	Paul Colaizzi (ARS, Bushland)
Cooperator(s):	Dan O'Brien (KSU, Colby) R. Louis Baumhardt (ARS, Bushland)

3. Summary/abstract

Groundwater management districts with Local Enhanced Management Areas (LEMA) are developing multi-year water management plans which can result in 20% or more reductions in irrigation withdrawals. Maintaining farm profitability with reduced irrigation can be supported by knowledge and management of risks associated with inter-annual and multi-year water management decisions. Current decision-support tools provide reliable information for specific irrigated fields under standard conditions. However, macro- and micro-scale weather conditions can increase the normal crop water requirement by 100% or more. Increased understanding of global circulation patterns, such as the El Nino/Southern Oscillation dynamic can guide crop selection to mitigate climate-related risk. A working knowledge of landscape- and regional scale-effects on water dynamics can build on this success and identify opportunities to exploit climate-informed water management synergisms at landscape scales. Knowledge supporting regional evapotranspiration (ET) mapping and associated crop productivity is available, however knowledge of large scale turbulence effects on crop water requirements is incomplete. This project will synthesize current knowledge of ET mapping and working hypotheses of turbulent transfer into a physically-based modeling tool which can be scaled (30 m — 10 km region) to provide information regarding consumptive water use, net primary productivity, and yield formation for multi-year crop systems ranging from dryland to full irrigation. Successful implementation of this tool will support analysis of water management policies on net economic returns at farm and regional levels.

4. Project narrative
a) Objectives

1) Develop a landscape-scale crop water productivity model which simulates land-atmosphere exchange processes for dryland and irrigated crop production in water management regions such as GMD4 of Northwest Kansas.
2) Utilize available data to determine the predictive accuracy of model algorithms at site and landscape scales.
3) Evaluate suitability of the landscape-scale crop water productivity model for analysis of multi-year water management decision-support.

The proposed work will support three OAP objectives:

1) support a 20% reduction in water withdrawal,
2) increase the water productivity of dryland cropping systems, and
3) improve understanding of hydrologic and climatic factors.

b) Rationale

Multi-year water allocation policies pose new opportunities and challenges to irrigation management. District policies which permit flexible use of a fixed allocation (e.g. 60" over a five year period, LEMA's in Kansas' GMD4) can reduce water withdrawal by 20%. However, climate-related risk becomes a more significant consideration. For example, if drought is reliably forecast for year three of a five-year plan, can water productivity be maximized by shifting limited water allocation to fields and years with more favorable production potential?

Available decision-support tools (Crop Water Allocator, KanSched) provide reliable information about in-season crop water requirements and alternatives for limited capacity irrigation systems—under normal environmental conditions. Current efforts to develop a multi-year planning feature will enhance decision-support capabilities (O'Brien, pers. comm). However, under extreme advective or drought conditions sensible heat can contribute up to 60% of the energy associated with water use of irrigated alfalfa (Tolk et al. (2006)). This 'imposed' heat load results from local and regional advection—turbulent transfer associated with large-scales eddies (Prueger et al., 2012) which is incompletely represented in standard crop ET equations.

Baumhardt et al. (2016) found that wheat productivity in the N. Texas High Plains was positively related to the El Nino phase of the El Nino/Southern Oscillation (ENSO) cycle. Models for ENSO phases (Salisbury and Wimbush, 2002; Galenti and Tziperman, 2000) provide a basis for forecasting muti-year weather conditions. Landscape-scale approaches to water management, which consider multi-year weather forecasts, require new conceptual and analytic tools for effective design and application.

Knowledge of canopy surface temperatures has long been recognized as an indicator of soil and plant water status (Idso et al., 1975, Jackson, 1982, Moran et al., 1994). A two-source energy balance model (TSEB, Norman et al., 1995) provides a means of mapping ET at regional (Anderson et al., 2003) and seasonal (Anderson et al., 2012) scales. Albertson et al (2001) combined a TSEB model with a Large Eddy Simulation (LES) model of turbulent transfer in the atmospheric boundary layer to quantify local and regional advective effects. Bertoldi et al. (2008) used this model to develop a procedure to quantify local advection effects.

Application of these remote sensing techniques are limited by availability of clear-sky imagery. Functional soil water balance algorithms (e.g. Kansas Water Budget, KSWB; Stone et al., 2006; Moberly, 2016), which support current decision-support tools (Klocke et al., 2006), can be linked with TSEB and LES models at the landscape scale to quantify ET with daily time steps.

c) How the objective will be met

We envision a landscape-scale crop water productivity model which would quantify energy and water balance components as well as net primary productivity and yield formation for dryland and irrigated cropland. The control volume will extend from the root zone through the surface boundary layer for a region approximately 10 km x 10 km with spatial resolution of 30 m. Components of the model would include a functional soil water balance (Stone et al. 2006); a two-layer surface energy balance (Colaizzi et al. 2012), coupled with a physiological model of canopy conductance (Aiken and Klocke, 2013); a LES turbulent transfer model (Albertson et al. 2001; Bertoldi et al., 2008); and established crop growth and development algorithms (APSIM). Satellite imagery would be used to evaluate and identify opportunities to modify system parameters (e.g. available water capacity) and boundary conditions (e.g. precipitation and soil water deficit).

Lin has completed algorithm development and testing for 30m by 30m ET mapping. Aiken and Lin supervised algorithm development and evaluation for a multi-year crop water use and yield formation model, based on KSWB. Colaizzi has published extensively on the TSEB model algorithm and field evaluations.

The proposed workflow is structured in three phases, corresponding to objectives of model development, testing and application. Within each phase, tasks involve identifying, assembling and evaluating critical information.

Aiken and Lin will take lead identifying key algorithms, model design and structure of supporting databases. Aiken will advise on canopy conductance model and soil water balance component; Lin will advise on LES turbulent transfer model and remote sensing application; Colaizzi will advise on two-source surface energy balance and remote sensing application; Baumhardt will advise on climate-informed decision-support and soil water balance component. O'Brien will advise on risk assessment and decision-support.

Step 1: Identify key algorithms for model development, critical datasets for model evaluation or critical decision factors required for suitability analysis.

Step 2: Assemble the required information as needed to implement the model, construct the performance test or structure the decision-support evaluation.

Step 3: Evaluate the results, make the revisions and document the lessons learned.

Timeline of activities:

Table 1: Project Schedule, Target Dates and Milestones (M)

Objectives	Year 1				Year 2				Year 3			
1. Develop landscape-scale crop water productivity model												
Step 1: Identify key algorithms, model design		X										
Step 2: Assemble databases, boundary conditions			X									
Step 3: Evaluate and revise model design				X								
M: Operational model for testing					X							
2. Determine predictive accuracy of model algorithms												
Step 1: Identify key datasets					X							
Step 2: Assemble databases, boundary conditions						X						
Step 3: Evaluate and revise model implementation							X	X				
M: Evaluation of predictive accuracy								X				
3. Evaluate suitability for multi-year water decision-support												
Step 1: Identify key decision factors							X					
Step 2: Assemble databases, boundary conditions									X			
Step 3: Evaluate and revise model implementation										X	X	
M: Evaluation of decision-support:												X
Reporting					1,2				1,2			2,3

1 = Annual Progress Report, by March 31; 2 = Annual meeting; 3 = Final Technical Report

d) Expected outcomes

Publications and technology transfer activities:

Presentations at OAP meetings, workshop for GMD4 staff and board.
A minimum of one manuscript for submission for peer-reviewed publication.
Working landscape-scale multi-year crop water use and productivity model, suitable for replication for additional sites and supporting analysis of alternative water management scenarios.

5. Relevant publications

1. Aiken, R.M., D. M. O'Brien, B. L. Olson and L. Murray. 2013. Replacing fallow with continuous cropping reduces crop water productivity of semiarid wheat. Agronomy Journal 2013 105:199-207
2. Aiken, R.M. and N.L. Klocke. 2012. Inferring transpiration control from sap flow heat gauges and the Penman-Monteith equation. Transactions of the ASABE. 55(2):543-549.
3. Baumhardt, R.L., S.A. Mauget, R.C. Schwartz and O.R. Jones. 2016. El Niño Southern Oscillation Effects on Dryland Crop Production in the Texas High Plains Agron. J. 108(2):*736-744*
4. Colaizzi, P.D., W.P. Kustas, M.C. Anderson, N. Agam, J.A. Tolk, S.R. Evett, T.A. Howell, P.H. Gowda and S.A. O'Shaughnessy. 2012. Two-source energy balance model estimates of evapotranspiration using component and composite surface temperatures. Adv. In Water Resources 50:134-151.
5. Narayanan, S., R.M. Aiken, P.V.V. Prasad, Z. Xin and J. Yu. 2013. Water and Radiation Use Efficiencies in Sorghum. Agron. J. 105:649-656.

6. Paul, G., Gowda, P.H., Vara Prasad, P.V., Howell, T.A., Aiken, R.M., Neale, C.M.U., 2014. Investigating the influence of roughness length for heat transport (Z_{oh}) on the performance of SEBAL in semi-arid irrigated and dryland agricultural systems. Journal of Hydrology, 509:231-244. http://dx.doi.org/10.1016/j.jhydrol.2013.11.040.
7. Lin, X., R.A. Pielke Sr., R. Mahmood, C.A. Fiebrich and R. Aiken. 2015. Observational evidence of temperature trends at two levels in the surface layer. Atmos. Chem. Phys. Discuss. 15:1-32. Doi:10.5194/acpd-15-1-2015.

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Bertoldi, G., W.P. Kustas and J.D. Albertson. 2008. Estimating spatial variability in atmospheric properties over remotely sensed land surface conditions. AMS 47:2147- 2165.

Colaizzi, P.D., W.P. Kustas, M.C. Anderson, N. Agam, J.A. Tolk, S.R. Evett, T.A. Howell, P.H. Gowda and S.A. O'Shaughnessy. 2012. Two-source energy balance model estimates of evapotranspiration using component and composite surface temperatures. Adv. In Water Resources 50:134-151.

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