Water Use and Climate Evaluation Service to Irrigators for Drought Resiliency in Southwest Kansas

Prepared For: US Bureau of Reclamation
WaterSMART – Drought Response Program: Drought Resiliency Projects for Fiscal Year 2021

Applicant: Southwest Kansas Groundwater Management District No. 3

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Table of Contents

Technical Proposal and Evaluation Criteria 3
- Executive Summary 3
- Background Data 3
- Project Location 4
- Technical Project Description 5
- Performance Measures 7
- Evaluation Criteria 7
  - Evaluation Criterion A – Project Benefits 7
  - Evaluation Criterion B – Drought Planning and Preparedness 8
  - Evaluation Criterion C – Severity of Actual or Potential Drought Impacts to be addressed by the Project 9
  - Evaluation Criterion D – Project Implementation 12
  - Evaluation Criterion E – Nexus to Reclamation 16
  - Evaluation Criterion F – Department of the Interior Priorities 17

Project Budget 17
- Funding Plan and Letters of Commitment 17
- Budget Proposal 17
- Budget Narrative 18
  - Contractual/Construction 18
  - Supplies and Materials 19

Environmental and Cultural Resources Compliance 20

Required Permits or Approvals 21

Existing Drought Contingency Plan 21

Letters of Project Support 22

Official Resolution 22

Works Cited 22

Technical Proposal and Evaluation Criteria

Executive Summary

Application Date: August 5, 2020

Applicant Name: Southwest Kansas Groundwater Management District No. 3

City: Garden City

County: Finney County

State: Kansas

Drought affects southwest Kansas frequently, but its onset is subtle, and its impacts develop over time. Local aquifer storage has been used to counter the effects of drought, but as reserves are mined, water supplies become less reliable, and drought resiliency can be lost. This is a proposal to provide irrigators with local water use information that will encourage them to become more drought resilient through better water management. Each water user will receive an annual report detailing their water use compared to other water users within 5 miles that have similar crops, soil, land value, and aquifer characteristics. The report will also include information in five key areas: 1) on remaining saturated thickness of the local aquifer, 2) an analysis detailing the effect in terms of years of additional water supply from a reduction in water use, 3) a drought monitor report for the growing season, 4) the estimated cost per acre-foot of pumping water under local energy and aquifer conditions, and 5) a comparison of the irrigator's total cost of accessing water with water use peers in their area. This project will build long-term resilience to drought and reduce the need for emergency response actions by providing water users with valuable information that will empower them to better manage and conserve water, increase the usable life of the Ogallala/High Plains Aquifer, and increase farm profitability. This project supports drought planning needs identified in the Groundwater Management District 3 Draft Management Program, the Kansas Water Plan Volume III, and the State Water Resources Planning Act.

The proposed project will require 2 years to complete. This is not a construction project. Work on this project will begin in May 2021 and will be completed by December 31, 2022.

This project is not located on a Federal facility.

Background Data

The Southwest Kansas Groundwater Management District Number 3 (GMD3) was formed in 1976 under the State of Kansas's GMD Act (K.S.A. 82a-1020 et. seq.), which grants the right of locally formed districts, acting through their governing body politic and corporate, to determine their destiny regarding water use and conduct the affairs of groundwater management as a public agency. GMD3 is a special district that conducts local activities in water planning, policy development, and use and supply evaluation. GMD3 participates in state administration matters affecting groundwater and economy and represents members in matters concerning groundwater management. GMD3 prepares and adopts the management program for water resources and makes recommendations to members, state and federal officials, the Governor, Kansas Legislature, and to Congress. GMD3 represents water users from 12 counties in Kansas, with water rights amounting to about 3.6 million acre-feet (AF) per year and average use totaling about 1.8 million AF. The management program can be found at http://www.gmd3.org/what-we-do/management-program/. About half of all groundwater pumped annually in Kansas is pumped in GMD3. Most water use is for irrigation. The primary crops grown are corn, alfalfa, wheat, sorghum, soybeans, cotton, and triticale. The primary source of water is the Ogallala/High Plains Aquifer, a critical water resource for Kansas and the High Plains region of the United States. Irrigation use from the Ogallala Aquifer supports high value use animal agriculture and other local industries that are threatened by water level declines. The Ogallala Aquifer within GMD3 has declined significantly since development in the 1950s. It is critical for water users to find ways to use less water.

There are currently 15,108 points of diversion with certified water rights accessing aquifers in GMD3. Uses made of water include irrigation, stock, industrial, municipal, domestic, recreation, thermal exchange, contamination remediation, fire protection, and sedimentation remediation.

Since irrigation use across GMD3 is sourced nearly entirely from groundwater supplies, drought does not have the same type of immediate effect on water availability that it does on surface water supplies. However, drought does have a significant effect on water demands, and increased use increases well-to-well interaction effects, reducing well pumping rates. During severe drought, most dryland crops fail to reach a harvestable stage, and many water users either lack the water right quantity or physical well capacity to access enough water to mitigate drought effects. Since major development of the Ogallala Aquifer began in the 1950s, approximately half of the usable water supply has been exhausted. Average annual water level declines in southwest Kansas during the last severe drought in 2012 were more than 4 ft. It is imperative that local water users find ways to reduce water demands, or stored quantities of groundwater will continue to decline and water users, including irrigators, cities, and other industry, will soon find themselves without any readily available water supply to mitigate drought.

GMD3 has worked with Reclamation on past projects. These projects include a System Optimization Review, completed in 2014, an Upper Arkansas River Basin Public Water Supply Alternatives Viability Analysis, completed in 2014, a Plan of Study: Arkansas Basin Study from John Martin Reservoir to Garden City, Kansas, completed in 2015, and a Water and Energy Efficiency Grant, with a project that is currently underway.

Project Location

This project will give water use information to every irrigator within GMD3, accounting for 9,573 wells. GMD3 covers part or all of 12 counties in southwest Kansas, including Hamilton, Kearny, Finney, Stanton, Grant, Haskell, Gray, Ford, Morton, Stevens, Seward, and Meade Counties. See figure 1 for a map of GMD3, including all irrigation wells within. This map is also attached to this application as a PDF file.

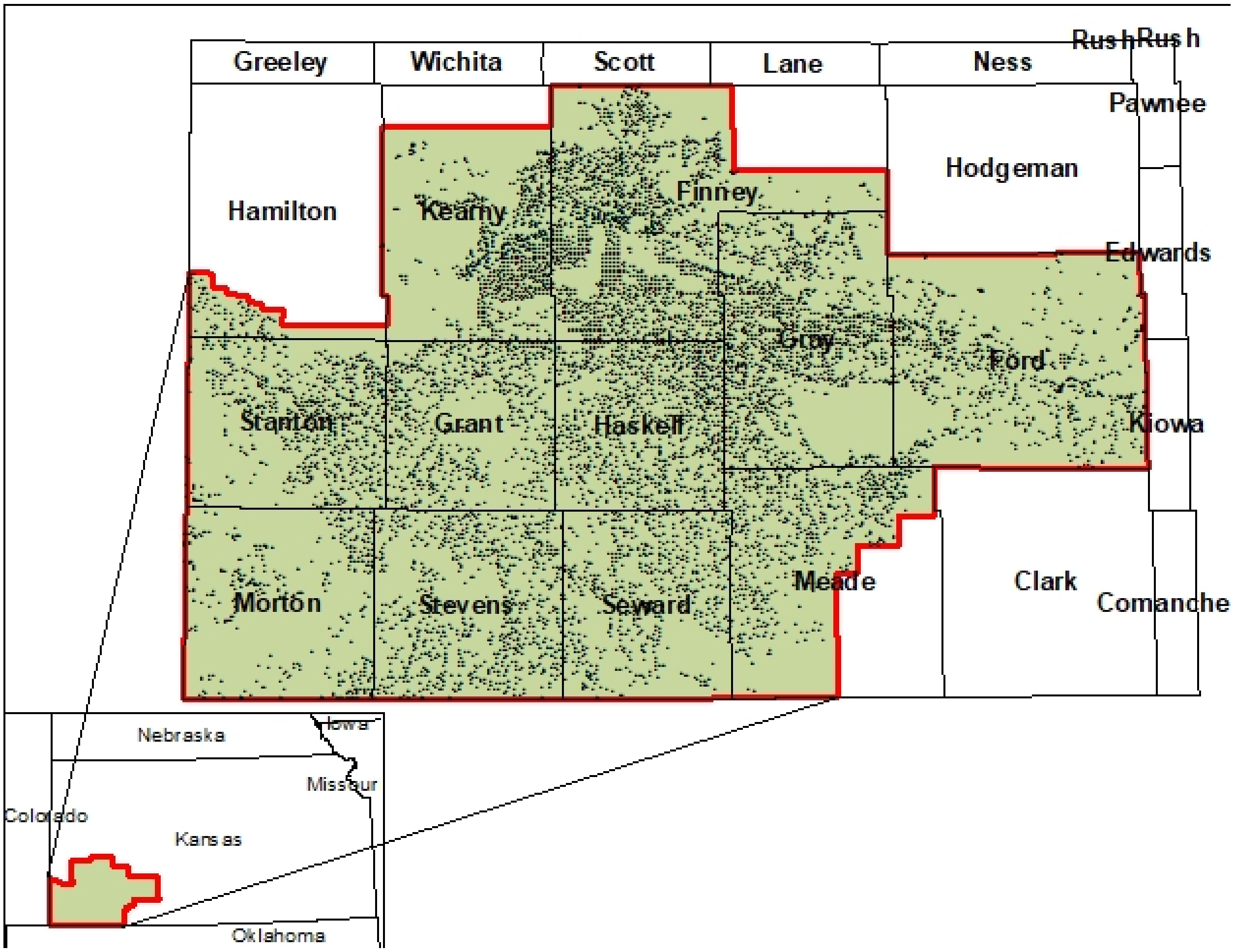


Figure 1. Project area map. Black dots represent irrigation wells.

Technical Project Description

The proposed project will provide annual water management reports to every irrigator in GMD3 detailing their water use compared to their water use peers within a five mile radius, their remaining saturated thickness, an evaluation of the aquifer effect a reduction in use would have in terms of additional years of supply, a monthly overview of the year's drought monitor during irrigation season, and an economic overview describing how much higher or lower costs of accessing water were compared to nearby users with similar project conditions. For project development and quality control, GMD3 will pilot reports to irrigators with wells in Finney County during the first project year. The process will be improved based on results and experience with the pilot report. All irrigators within GMD3 will receive a report during the second project year, and annually after the project has concluded.

Wells will be classified based upon aquifer characteristics at the well site, crop type, soil type, climate, and land valuation. Water use from all wells within 5 miles of the well for which the report is being generated that have similar specific yield and transmissivity, either from the well log or modeled, and irrigate the same crop type will be averaged for comparison in the report. Boundaries where significant operational differences can be expected, such as sand hill regions, areas with poor water quality, and areas where groundwater and surface water use are both authorized, will be created so that wells across boundary lines will not be compared. This helps ensure that water use comparisons will be useful. If no wells have the same crop and aquifer characteristics, the report will compare all wells within 5 miles, but also describe differences in operation.

Reported annual water use and crop type data will be provided by the Kansas Department of Agriculture, Division of Water Resources (DWR). DWR requires all water users in Kansas to submit annual water use reports detailing the quantity and rate of water pumped, the number of acres irrigated, and the type of crop grown. This data will be provided to GMD3 via open records request. Water use data is also made available through the Water Information Management and Analysis System (WIMAS), created by DWR and the KGS. Water level data will be provided by the WIZARD Water Levels Database, a repository of information on freshwater wells drilled into aquifer in Kansas, measured at least annually, and maintained by the Kansas Geological Survey (KGS). This water level data will be used to provide information to water users regarding remaining saturated thickness and estimated pumping costs.

Information from the Kansas Department of Revenue, Property Valuation Division (PVD) will be used to obtain land valuations. PVD assigns values to parcels based on soil type, well depth, access to water supply, and type of irrigation system. Using land values to group wells within a confined five-mile radius will help to ensure that similar operations are being compared in the reports that go to irrigators.

The KGS will work with GMD3 to develop a comparison tool to identify similar wells within 5 miles, based upon the information provided by DWR. The KGS has a wealth of experience in data management and modeling of the Ogallala/High Plains Aquifer in Kansas and are an excellent partner for this task.

The Finney County Economic Development Corporation (FCEDC) will provide support to statistically analyze data provided by the comparison tool and ensure that wells are properly grouped so that useful comparisons can be provided in the report. FCEDC provided similar services to the City of Garden City for their use comparison project.

The City of Garden City will provide support in designing the reports in a way that is concise, informative, and easily understood. They have worked on a similar project comparing water use between household peer groups. They have maintained that program and are currently sending reports annually. This makes them an excellent partner for this project.

Pumping costs will be estimated based upon total dynamic head, fuel type, and price per gallon, MCF, or KWH. Local energy providers will be contacted to provide accurate rates for different geographic regions.

GMD3 will help provide quality control to the project by inspecting installed flowmeters. Approximately 1,850 flowmeters, ¼ of all irrigation flowmeters, will be inspected by GMD3 each year. Inspections will ensure that meters are properly installed and functioning and ensure that reporting is accurate. Funding for the meter inspection program is already budgeted and secured. This funding will be used to provide the required cost share to this grant. In addition to flowmeter inspections, GMD3 will also verify flow rates with an unobtrusive meter when requested, and measure the conductivity, pH, and total dissolved solids of water supplies where water quality is in question.

Performance Measures

A database will be created to track which irrigators use more water than their peers, which use less, and how their use changes over time. GMD3 will use the database to track the percentage of users who pump above their peer average whose use moves closer to the average over time and quantify savings based upon average quantities pumped. A survey will also be included with each report to facilitate user feedback and aid in evaluating the success of the project. The overall effectiveness of the project will be determined based upon quantified water savings and qualitative feedback. The project will be deemed a success if disparities in water use between producers improve by a statistically significant margin while overall water use also declines over a ten-year period. Water savings will indicate reduced overall water demand and ensure a greater water supply is available for irrigators to better mitigate drought conditions.

Evaluation Criteria

Evaluation Criterion A – Project Benefits

This project will provide information that helps water users reduce water demand. Irrigators will be made aware of their water use compared to other nearby irrigators under similar operating conditions. Information will also notify irrigators of their remaining water supply and estimate irrigation cost per acre-inch. This will encourage users to collaborate on their successes to manage water, improve productivity, and gain drought resiliency more efficiently. Improved management will reduce overall water demand, making more water available during future drought years. This project will continue to provide benefits to irrigators for as long as GMD3 funds the program. GMD3 currently has no plans to discontinue the program. Once the tools are developed, sustaining the program will have a significantly lower budget impact.

This project will provide information that will allow water users to improve management of more than 1.8 million acre-feet of irrigation water annually, accounting for 96% of the overall annual water use within GMD3. This number is based on the average irrigation water use within GMD3. Every irrigator in GMD3 will receive annual reports on water use, supply, and economics in their local area.

Recent research conducted by Stephen Lauer and Matthew Sanderson on behalf of the Ogallala Water Coordinated Agriculture Project (OWCAP) finds that the overwhelming majority of irrigators in the Ogallala Aquifer region of Kansas and other states believe that groundwater should be conserved and that this problem is more of a community problem than a personal problem. Most producers also believe that they personally are already doing all that they can to conserve water. Only 7% of producers believe that they can conserve more water. 84% of producers are open to the possibility that voluntary group efforts can solve water resource problems, but only 7% of producers are currently involved in organizing group efforts. This project will provide data to similar water users within their communities. The comparative data will demonstrate to many water users that they can do more to conserve water. The primary motivations for groundwater conservation identified by survey participants were securing a way of life for future generations, supporting local communities, and preparing for droughts. See https://ogallalawater.org/producer-attitudes/# for more information on OWCAP research and survey results. The reports provided by this project fall directly in line with those motivations. Producers will get an update on their remaining water supply, with information detailing how long a reduction in use will extend supply. They will get information on how their local water use community is using water in comparison to them. They will also get valuable weather information detailing how they and their community are mitigating drought effects.

Water users within GMD3 currently have three programs available that can provide water use flexibility to carry over unused water allocations during wet years to be applied later during drought years without increasing overall consumption. These programs are Water Conservation Areas (WCA), Local Enhanced Management Areas (LEMA), and Multi-Year Flex Accounts (MYFA). The MYFA program is designed to allow producers to pump extra water in drought years without increasing overall use, and the WCA and LEMA programs may allow some water use flexibilities in exchange for overall water conservation. The WCA and LEMA programs allow for marketing of water between different users enrolled in the same designated conservation area, should the GMD and/or DWR choose to implement that flexibility. This project will allow producers to better manage their water supply, making more water available for marketing and drought mitigation tools. It will also provide valuable information to GMD3 and DWR to help determine which specific flexibilities and marketing within a conservation area can occur to ensure that water use authority is not shifted in a way that might enable producers to potentially pump more water than they would otherwise.

Evaluation Criterion B – Drought Planning and Preparedness

The Drought Resiliency Program section of the GMD3 Draft Management Program identifies the need to "develop water use, climate, and conservation feedback to members utilizing annual water use report, site visits, and other data to inform and assist members in their decisions affecting their drought resiliency." This project is specifically identified as a key component of the drought resiliency program planned by GMD3. The draft management program is currently under legal review by DWR and is expected to be formally adopted in 2021, after completing a formal review process with GMD3 membership. The GMD3 draft management program is available at http://www.gmd3.org/wp-content/uploads/2020/07/Management-Program-June-Draft.pdf. See Page 48 for the GMD3 Drought Resiliency Program. Relevant pages are attached to this document.

This project is consistent with the Kansas Water Plan Volume III – Guiding Principles: Reducing our Vulnerability to Extreme Events, attached to this document. The full Water Plan can be found at https://kwo.ks.gov/water-vision-water-plan/water-plan. The Kansas Water Plan is developed with input from the Kansas Water Authority, a body representing multiple stakeholders from the public and private sectors across the state of Kansas. The Kansas Water Office is tasked with creating and regularly updating the Water Plan, which must be approved by the Water Authority. The Water Plan includes consideration of climate change impacts to water resources due to more frequent droughts and floods. The Water Plan describes the need for identification of key needs and indicators to reduce extreme impacts of drought. The document also mentions the need for decision support tools for agriculture, such as the tools proposed, to help manage risk. Producers will gain access to information describing their irrigation performance each year, along with the drought index for each month of the growing season. GMD3 will be able to identify which water users are best equipped to handle drought in localized and regional areas and determine the most effective drought mitigation practices and technologies.

This project further implements the State Water Resources Planning Act (K.S.A. 82a-901 to 82a-945), where K.S.A. 82a-927 states goals and K.S.A. 82a-928 states policies for achieving long-range goals. These statutes are attached to this document. These goals include the sound management, both public and private, of the atmospheric, surface, and groundwater supplies of the state, the efficient, economic distribution of the water supplies of the state, and the protection of the public interest through the conservation of the water resources of the state in a technologically and economically feasible manner. Policies to achieve these goals include the management of the groundwaters of the state as provided by the Kansas water appropriation act and the provisions of the GMD Act (K.S.A. 82a-1020 et. seq.) and the provision of financial and technical assistance to public corporations concerned with management, conservation, and development of water resources. This project will help mitigate drought by improving the management of more than 1.8 million acre-feet of irrigation water used annually in GMD3 by providing vital information to producers that allows them to better prepare for and mitigate drought.

Evaluation Criterion C – Severity of Actual or Potential Drought Impacts to be addressed by the Project

The project area covers Southwest Kansas GMD3, a typically dry region that receives less than 20 inches of rainfall on average. The last severe drought in the region lasted 248 weeks from November 2010 through August 2015. The most severe year of this drought was 2012. Nearly all GMD3 was classified as D4 Exceptional Drought during 2012. D4 classification includes the following effects:

- All crops are severely impacted/not harvested; ground is cracking
- Wildfires and large dust storms occur
- All aquatic species and food chains are affected; fish kills occur
- Negative impact on economy is noted
- Irrigation is turned off; river has dried up

Figure 2 shows the drought monitor for Kansas on August 21, 2012. Note the project area boundary from Figure 1.

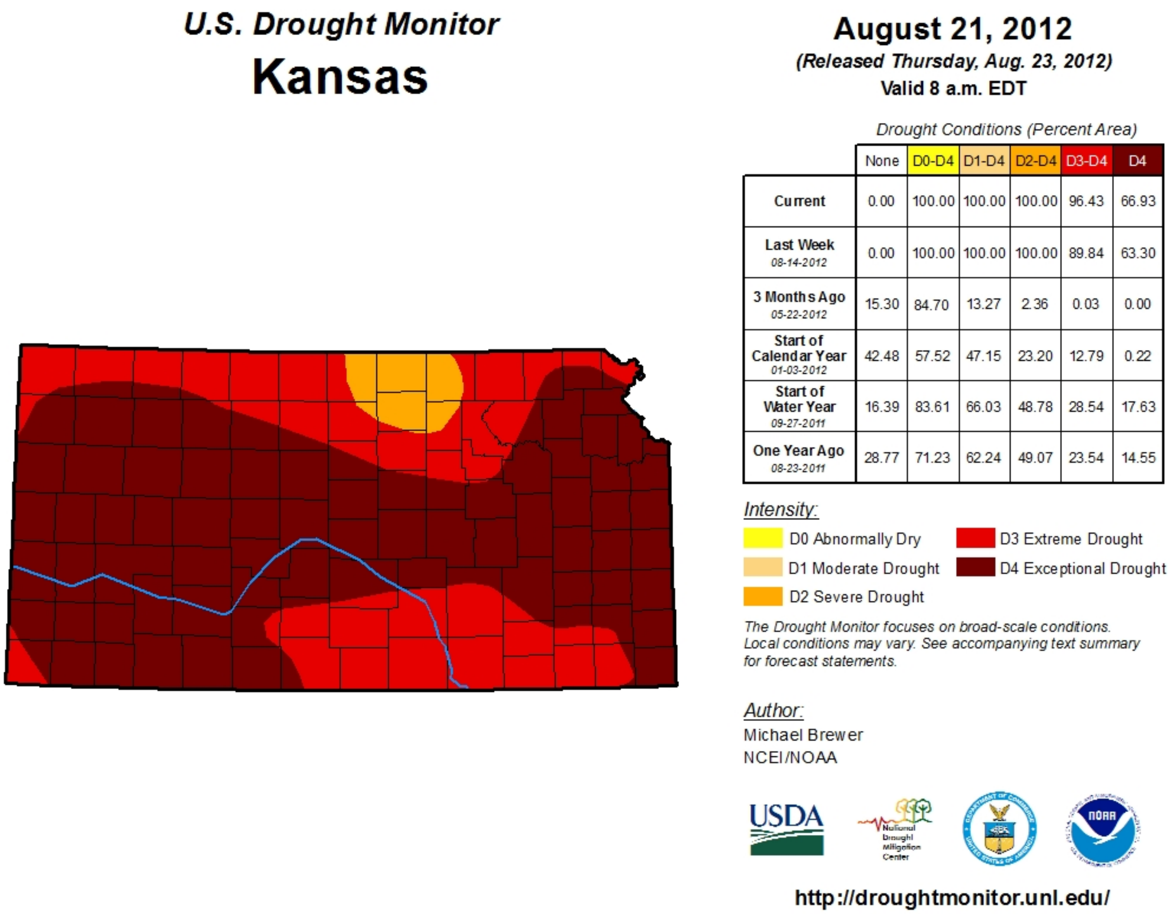


Figure 2. Kansas Drought Monitor, August 21, 2012.

Table 2 shows 2012 precipitation totals compared to average precipitation totals for each county located within the project area.

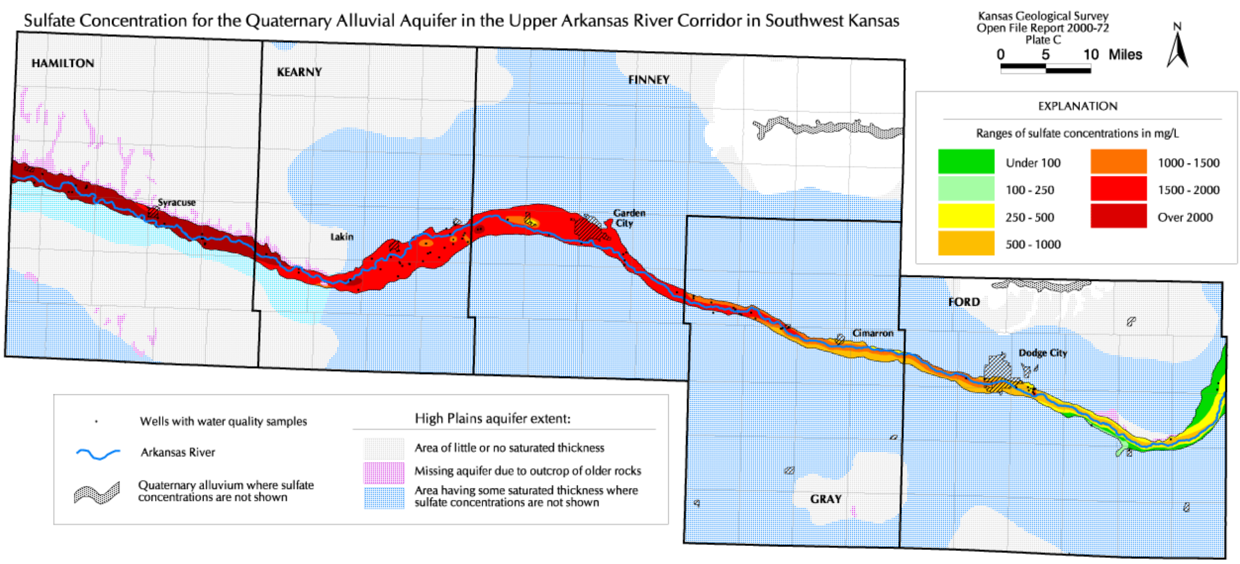
Table 2. 2012 precipitation totals compared to normal precipitation by county.

County	2012 Precipitation (in.)	Normal Precipitation (in.)
Hamilton	9.50	17.50
Kearny	10.80	18.90
Finney	13.80	19.90
Stanton	11.70	17.50
Grant	12.50	18.20
Haskell	14.30	19.70
Gray	15.50	21.00
Ford	18.00	22.90
Morton	13.10	17.60
Stevens	13.30	18.50
Seward	13.90	19.80
Meade	14.70	21.30

In GMD3, low annual precipitation falls on an area where 1,383,587 acres, 26% of all land area, are irrigated farm ground. This irrigated ground requires on average about 1.8 million acre-feet of irrigation to supplement low rainfall. Irrigation water use totaled 2.1 million acre-feet in 2012. Many producers exhausted their water right in full and still failed to have a harvestable crop. Many others pumped more than their authorized quantity to salvage a harvestable crop. The Kansas Legislature revised the MYFA program during this drought to allow for overpumping on the condition that irrigators be held to a lower authorized water use over the next 4 years to offset the drought use. Water levels decline every year due to demand exceeding aquifer recharge. As aquifer storage declines, well pumping flow rates diminish. Reduced pumping capacity prevents for some water users from accessing enough water to overcome the effects of drought. This problem will only become worse over time, as water becomes less available. It is important that producers have the information they need to take steps to conserve water and preserve the ability to mitigate drought.

Several communities along the Arkansas River Valley have risk in obtaining quality drinking water. Water quality in the Arkansas River is generally poor due to high mineralization levels, including sulfate and uranium. The Arkansas River in western Kansas is among the most saline rivers in the United States. Uranium levels in the Arkansas River generally exceed the Environmental Protection Agency (EPA) drinking water standards. Tests from water samples have measured uranium levels as high as 90.9 µg/L, more than three times the EPA's 30 µg/L maximum contaminant level. Quality is worse during low flows associated with drought than during high flows. This poor-quality water degrades drinking water sources for the cities of Lakin, Deerfield, Holcomb, and Garden City, KS, and for domestic wells within the valley. Degradation of water quality is exacerbated by excessive pumping of fresher groundwater supplies. During drought conditions, more water is pumped from the aquifer, and river flows are typically poorer quality and less usable for irrigation. The City of Lakin has violated drinking water standards for Uranium in the past and built a nanofiltration facility to remove enough uranium from their drinking water supply to be EPA compliant. The cities of Deerfield and Holcomb currently have no treatment facility capable of removing uranium and are at risk of becoming noncompliant soon. The Kansas Legislature passed House Resolution no. 6018 and Senate Resolution no. 1729 in 2019, requesting among other things that state and local partners in Kansas and Colorado work with Reclamation to address the concerns regarding the contamination of the Arkansas River basin. Figure 3 shows the level of contamination of the local alluvial aquifer and the High Plains Aquifer due to recharge from the river system, by tracking sulfate concentration.

In Kansas, temperatures over the last decade have been among the warmest on record, with the only exception being the 1930s "Dust Bowl" era. Maximum temperatures do not show statistically significant trends, but minimum temperatures show a significant warming rate. Winter temperatures show the greatest warming effect, indicating that impacts on winter wheat are likely to be more important than those on other major crops (Lin, Harrington, Ciampitti, Gowda, Brown, Kisekka 2017). Warmer temperatures increase evapotranspiration, which also increases plant demand for water. This potentially makes the effects of future droughts more severe than past droughts, which will increase the rate of aquifer decline, reduce the quality of groundwater reserves, and reduce the ability of producers to respond to drought with readily available water resources.



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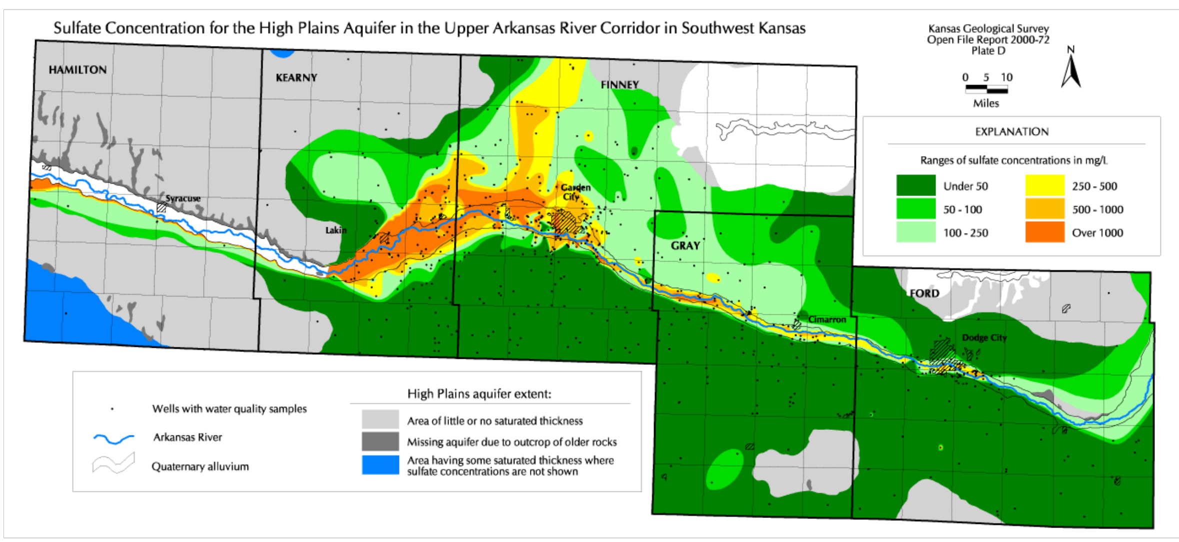

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Figure 3. Sulfate concentration for (a) the quaternary alluvial aquifer and (b) the High Plains Aquifer in the upper Arkansas River corridor in southwest Kansas.

Evaluation Criterion D – Project Implementation

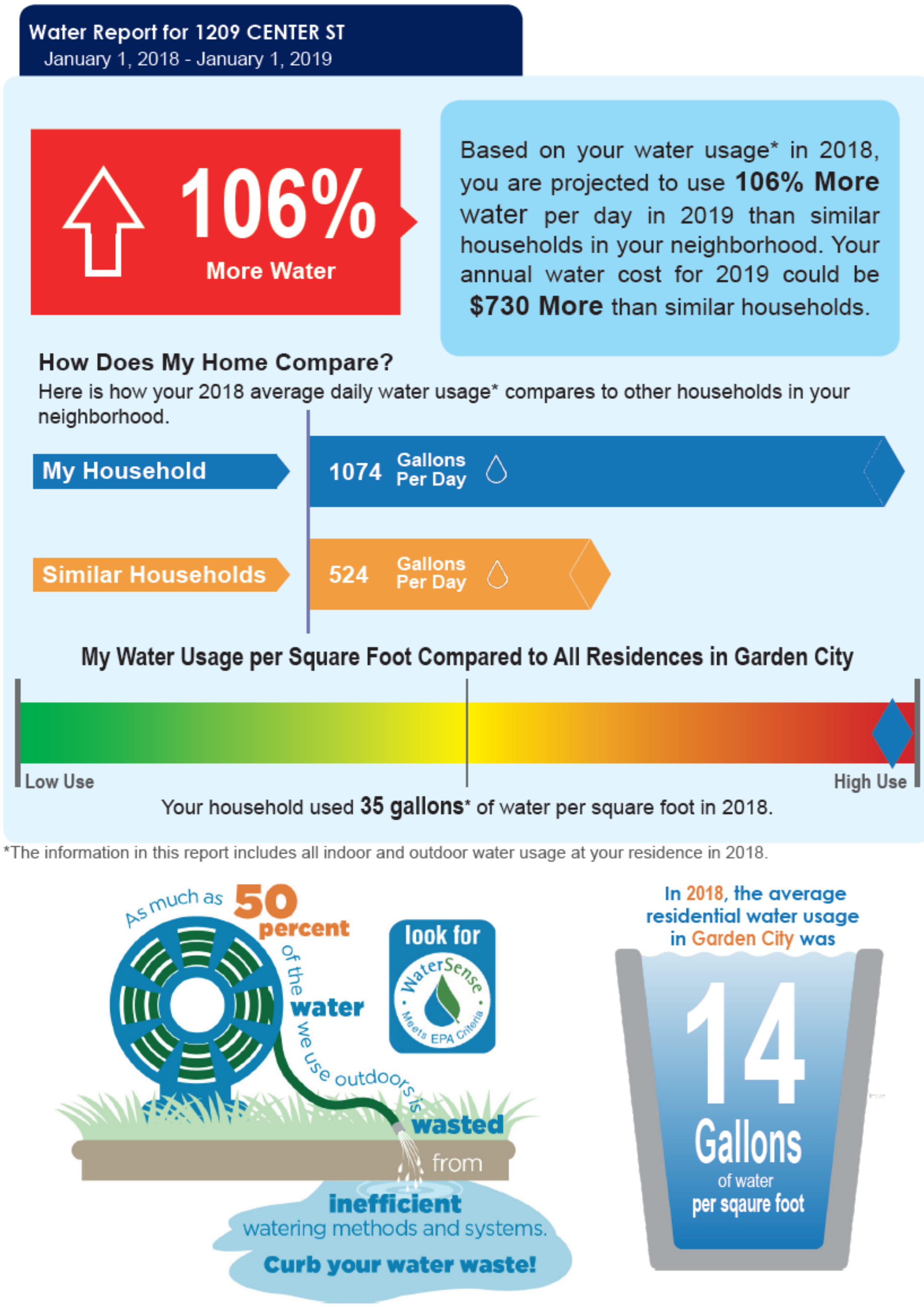
Upon receipt of the grant reward, GMD3 staff will work with the KGS to develop a tool to identify similar wells for comparison within a five-mile radius for every irrigation well in Finney County, KS. This tool will be an application run within ArcGIS Pro. Aquifer parameters, crop type, soil type, and land valuation will be used to determine wells that are suitable for comparison. The tool will generate reports in batch to be sent to all irrigators detailing how they used their water in the previous year compared to water use peers with similar production circumstances in their area. The identity of water use peers will remain confidential. The report will include an economic analysis detailing any energy cost based upon water use compared to the average costs among peers. Drought monitor information from the previous year of the growing season months for their reported crop type(s) will be included in the report. The report will also provide producers current aquifer saturated thickness, rate of aquifer decline, and a breakdown of how reductions in use by various amounts can extend the life of their irrigation project. Reports for 2019 water use will be mailed to every irrigator in Finney County in 2020. The system will be evaluated and updated as needed based upon feedback. Reports for 2020 water use will be mailed to every irrigator in GMD3 in 2021.

GMD3 will work with the City of Garden City to design the reports in a way that is concise, informative, and easily understood. The City of Garden City has worked on a similar project comparing water use between similar households. This experience makes them a valuable partner for this project. See Figure 4 on the next page for an example of the reports the City of Garden City generates. These reports were generated using Adobe InDesign. The information and format of the reports generated by this project will be different, but they will be modeled after the Garden City program.

GMD3 will work with FCEDC to statistically analyze data provided by the comparison tool and ensure that wells are properly grouped so that useful comparisons can be provided in the reports to irrigators. FCEDC provided similar services to the city of Garden City for their use comparison projects.

Local power companies will be contacted to determine service areas and general energy costs. An ArcGIS shapefile will be created to delineate boundaries where costs change. Local aquifer conditions will be used to estimate dynamic head and days pumped, then estimated energy use will be calculated. This shapefile will be incorporated into the tool to provide the economic analysis provided in the annual report. The shapefile will be updated regularly to account for any changes in cost and aquifer conditions.

Kansas is a leader nationally in available hydrologic and water use data. Water use, crop type, and energy source data will be sourced from DWR. All water users must submit a report to DWR detailing their water use annually, subject to a fine. This information is available via Freedom of Information Act open records request. All aquifer data will be sourced from the KGS. The KGS maintains extensive databases containing aquifer characteristics based upon drillers' logs, water levels from observation wells measured annually, and aquifer thickness. Existing and future groundwater model data may also be incorporated to the extent practicable. All this data is available spatially and can easily be built into the tool run on ArcGIS Pro.


Water Report for 1209 CENTER ST
January 1, 2018 - January 1, 2019
106%
More Water
Based on your water usage* in 2018, you are projected to use 106% More water per day in 2019 than similar households in your neighborhood. Your annual water cost for 2019 could be $730 More than similar households.
How Does My Home Compare?
Here is how your 2018 average daily water usage* compares to other households in your neighborhood.
My Household
1074 Gallons Per Day
Similar Households
524 Gallons Per Day
My Water Usage per Square Foot Compared to All Residences in Garden City
Low Use
High Use
Your household used 35 gallons* of water per square foot in 2018.
*The information in this report includes all indoor and outdoor water usage at your residence in 2018.
As much as 50 percent of the water we use outdoors is wasted from inefficient watering methods and systems.
Curb your water waste!
look for
WaterSense
Meets EPA Criteria
In 2018, the average residential water usage in Garden City was
14
Gallons
of water
per sqaure foot

a

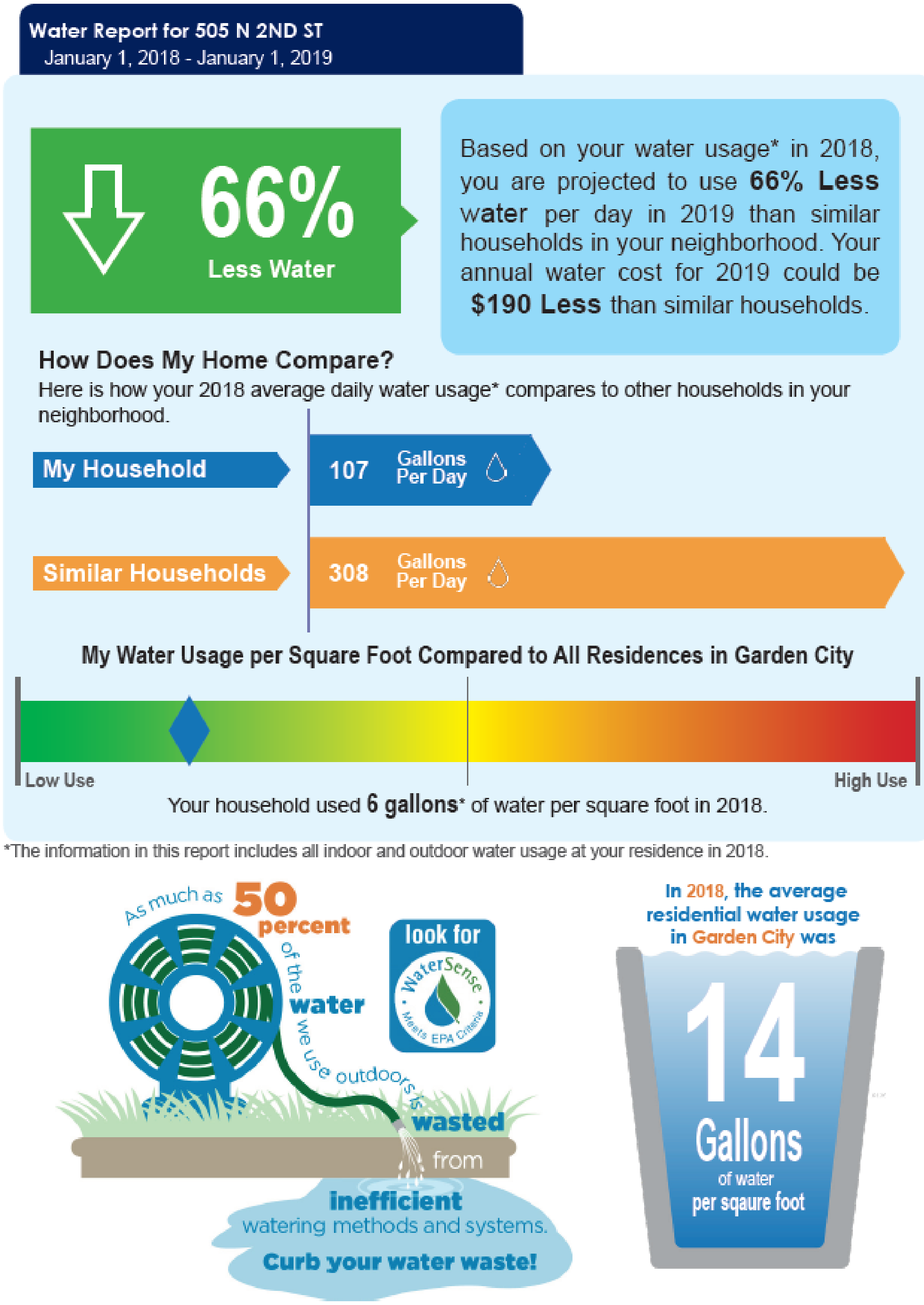


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Figure 4. Examples of comparison reports generated by the City of Garden City, where (a) water use is greater than water use peers and (b) water use is less than water use peers.

GMD3 will inspect at least 1,852 well sites each year. Inspections will include ensuring that flowmeters are properly installed and operating, verifying that the flowmeter is sealed with no signs of tampering, timing the flowmeter to calculate pumping rate, and notifying the landowner of any action that may need to be taken. GMD3 has implemented similar programs in the past using contractors at a payment rate of $27 per site visit. The inspection program is already budgeted for by GMD3. In addition to the flowmeter inspection service, GMD3 staff will also provide flow verification tests when requested to ensure that the metered flow rate is accurate, provide services to measure the water level in the well, and will measure pH, conductivity, and total dissolved solids where water quality is questionable.

GMD3 will develop a database to track changes in water use relative to neighboring similar wells. This database will be used to track and evaluate the overall performance of this project. The project will be deemed a success if disparities in water use between producers improve by a statistically significant margin while overall water use also declines over a ten-year period. Reduction in use improves drought resiliency by ensuring that more water is available from storage in the future.

The project will operate under the following schedule of tasks and milestones:

Table 1. Schedule of tasks and milestones.

Task/Milestone	Date to be completed by
Create shapefile delineating energy cost boundaries.	May 1, 2021
Develop working tool to identify similar wells for comparison.	August 1, 2021
Develop report format and information to be sent to irrigators.	August 1, 2021
Mail reports for 2019 water use to all irrigators in Finney County.	September 1, 2021
Update tool and reports based upon irrigator feedback.	May 1, 2022
Mail reports for 2020 water use to all irrigators in GMD3.	September 1, 2022
Develop database to track changes in water use at well level.	December 1, 2022

Evaluation Criterion E – Nexus to Reclamation

The project area is in the Arkansas River basin, which is home to the Trinidad Reservoir and the Fryingpan Arkansas Project, including Pueblo Reservoir and the Arkansas Valley Conduit, all of which are Reclamation projects. The proposed work will conserve, and therefore contribute, usable water to the Kansas portion of the basin by increasing the management efficiencies and usability of Stateline flows to Kansas.

GMD3 has worked with Reclamation on other projects within the project area, including a System Optimization Review to determine priority projects for the ditch companies along the Arkansas River within GMD3, a Plan of Study under the Basin Study program to identify a path forward for local stakeholders in Kansas and Colorado to work together to address water quality concerns within the Arkansas River basin, a Viability Analysis for Water Supply Alternatives for Hamilton, Kearny, and Finney Counties, Kansas to determine best strategy for Kansas communities affected by poor water quality in the Arkansas River to continue to meet EPA drinking water standards as water quality continues to degrade, and Water and Energy Efficiency grant to upgrade the headgate infrastructure and line a portion of the Farmers Ditch system, located near the city of Deerfield, KS within the project area.

This project has the potential to reduce demand from the Ogallala Aquifer. Any reduction in demand will improve the usable life of clean water within the system for cities and industry to utilize and reduce the rate of quality degradation from seepage along the Arkansas River corridor.

Evaluation Criterion F – Department of the Interior Priorities

This project addresses Department of the Interior priority 1: Creating a conservation stewardship legacy second only to Teddy Roosevelt. The project will utilize science to identify best practices to manage land and water resources and adapt to changes in the environment. Irrigators will be given more information than they have ever had access to before regarding their water supply, its use, and economics. This project will also provide GMD3 with a database of water use information that will allow them to identify water users who most efficiently manage their resources. This will allow GMD3 to promote best management practices more effectively under the GMD3 management program for different regions and different levels of drought. The information generated by this project will be invaluable to water users and officials to raise the level of management capacity in dealing with climate change and any associated increase in drought frequency and longevity.

Project Budget

Funding Plan and Letters of Commitment

The non-Federal share of project costs will be funded as in-kind contribution from GMD3. GMD3 will budget $100,008 to be contributed over the two project years for flowmeter inspections. This funding will allow GMD3 staff to visit 3,704 well sites during irrigation seasons by paying contractors $27 per site visit. GMD3 has implemented similar programs in the past and has arrived at that cost through experience. GMD3 will ensure that wells are properly installed and functioning and will record the flow rate for wells that are operating during the site visit. This will ensure accuracy of the reported data that will be used for the comparison reports. It is an essential service that has already been budgeted for.

Budget Proposal

Table 3. Total project cost table.

SOURCE	AMOUNT
Costs to be reimbursed with the requested Federal funding	$92,026
Costs to be paid by the applicant	$100,008
Value of third-party contributions	$0
TOTAL PROJECT COST	$192,034

Table 4. Summary of non-Federal and Federal funding sources.

FUNDING SOURCES	AMOUNT
Non-Federal Entities	
1. Southwest Kansas Groundwater Management District 3	$100,008
Non-Federal Subtotal	**$100,008**
REQUESTED RECLAMATION FUNDING	**$92,026**

Table 5. Budget Proposal

BUDGET ITEM DESCRIPTION	**COMPUTATION**		**Quantity Type**	**TOTAL COST**
	$/Unit	**Quantity**		
Contractual/Construction				
Kansas Geological Survey	45,450.00	1	Hydrologic Tool	$45,450
Finney County Economic Development	150.00	80	Hours	$12,000
City of Garden City	150.00	40	Hours	$6,000
GMD3 Flowmeter Inspection Program	27.00	3,704	Site Visits	$100,008
Supplies and Materials				
Printing Costs	0.50	11,400	Reports	$5,700
Mailing Costs	0.60	11,400	Reports	$6,840
Radio Advertisement	40.00	50	Advertisements	$2,000
Promotional Video	5,000.00	1	Lump Sum	$5,000
Ultrasonic Flow Test Meter Kit	6,149.00	1	Lump Sum	$6,149
Sonic Water Level Measurement Kit	1,145.00	1	Lump Sum	$1,145
Electric Water Level Meter w/ Drawdown Function – 500 ft	1,248.00	1	Lump Sum	$1,248
Water Pump Tachometer	294.00	1	Lump Sum	$294
Portable pH/EC/TDS/Temperature Meter	200.00	1	Lump Sum	$200
Salaries and Wages				
TOTAL ESTIMATED PROJECT COSTS				**$192,034**

Budget Narrative

Contractual/Construction

The KGS will develop a tool to identify similar wells and generate most of the information for the reports. For each well location, the tool will identify all other irrigation wells within 5 miles and compare soil type, aquifer conditions, land valuation, and crops grown. The tool will select the wells most like the well for which the report is being generated. The KGS will also provide township-level data for each well site showing the remaining aquifer saturated thickness, providing an estimate for the remaining usable life, and providing an estimate on the increased lifespan of the local aquifer if the water use neighborhood were to reduce consumption by 10%. $45,450 has been budgeted to the KGS for this project.

The Finney County Economic Development Corporation will work with the data generated and provide statistical support to help with development of the tool. They will also work to help provide quality control from the large dataset and reports that get generated. Finney County Economic Development provided a similar service to the City of Garden City for their water use reporting program and came highly recommended for this task. Finney County Economic Development charges $150 per hour for their consulting services, and 80 hours have been budgeted for this project, totaling $12,000.

The City of Garden City will provide support in formatting and generating the reports. The project budget allows for 40 hours of support service from the city at $150 per hour, totaling $6,000.

The GMD3 meter inspection program will help to ensure that reported data is accurate. Each summer, GMD3 will hire seasonal labor to physically visit roughly ¼ of all irrigation wells within the district. Site visits are unscheduled but authorized under K.S.A. 82a-28(l). During each visit, wells will be checked for proper flowmeter installation. The inspector will ensure that the meter is sealed with no signs of tampering. If the well is running during the time of the site visit, the register on the meter will be timed to obtain pumping rate. A tag will be left on the meter to let the landowner know that the well was inspected and if any action needs to be taken on their part to repair or reinstall the meter. GMD3 will pay $27 per site visit, and plan on visiting 3,704 well sites during the 2 years of the project period. The total amount budgeted is $100,008.

Supplies and Materials

This project will require reports to be generated for each of the 1,789 irrigation wells in Finney County during the first year and for each of the 9,573 irrigation wells in GMD3 during the second year. The budget allows $0.50 per report for printing costs and $0.60 per report for mailing costs. Total amounts budgeted are $5,700 for printing and $6,840 for mailing.

GMD3 will run radio advertisements to notify members of the new reports and help to educate them on what to expect and how to respond. The budget allows for 50 advertisements, costing $40 per advertisement. The total amount budgeted is $2,000.

GMD3 will create a promotional video to help explain the program and promote conservation. This video will be posted on the GMD3 website and explain what data is used to identify wells for use comparison, where the aquifer data comes from, and how all of that data can benefit each producer. The budget allows $5,000 for creation of the video.

An ultrasonic flow test meter kit and a tachometer will be purchased to be used by GMD3 staff to verify flow rate and proper well operation. This is a service to be provided to members as requested and will ensure that reported data is accurate.

A sonic water level measurement kit and a 500 ft electric water level meter with drawdown function will be purchased to be used by GMD3 staff to measure depth to water in wells. This is a service that will be provided to ensure that regional water level data is accurate.

A portable pH/EC/TDS/temperature meter will be used by GMD3 staff to collect water quality data and verify regional data. Many water contaminants can be tracked with conductivity because the source of contamination will have a different conductivity than the fresher underlying Ogallala/High Plains Aquifer. This field equipment will provide an inexpensive way to help GMD3 locate areas with water quality issues and inform irrigators. Irrigators with poor water quality often have different water demands than irrigators with fresher water, so this will help identify comparable fields for the reports generated by this project.

Environmental and Cultural Resources Compliance

Will the proposed project impact the surrounding environment? Please briefly describe all earth-disturbing work and any work that will affect the air, water, or animal habitat in the project area. Please also explain the impacts of such work on the surrounding environment and any steps that could be taken to minimize the impacts.

This project will not impact the surrounding environment. This is a non-construction project with no earth-disturbing activities.

Are you aware of any species listed or proposed to be listed as a Federal threatened or endangered species, or designated critical habitat in the project area? If so, would they be affected by any activities associated with the proposed project?

Threatened or endangered species within GMD3 include the Arkansas River shiner, the whooping crane, and the least tern. None of these species will be affected by the activities of the proposed project.

Are there wetlands or other surface waters inside the project boundaries that potentially fall under CWA jurisdiction as "Waters of the United States?" If so, please describe and estimate any impacts the proposed project may have.

The Arkansas River flows through a portion of the project area and potentially falls under CWA jurisdiction as a "Waters of the United States." This project will have no impacts on the Arkansas River or any other surface water bodies.

When was the water delivery system constructed?

Nearly all the water used in this project area is sourced from the Ogallala/High Plains Aquifer. There is no single delivery system that this project addresses, but rather thousands of individual wells. Major irrigation well development within the project area surged in the 1950s and continued until the 1980s, when GMD3 requested the state adopt rules that effectively closed most of the district to new appropriations.

Will the proposed project result in any modification of or effects to, individual features of an irrigation system? If so, state when those features were constructed and describe the nature and timing of any extensive alterations or modifications to those features completed previously.

This project will not result in any modification or effects to individual features of an irrigation system.

Are any buildings, structures, or features in the irrigation district listed or eligible for listing on the National Register of Historic Places? A cultural resources specialist at your local Reclamation office or the State Historic Preservation Office can assist in answering this question.

There are no buildings, structures, or features that are listed or eligible for listing on the National Register of Historic Places.

Are there any known archeological sites in the proposed project area?

There are no known archeological sites in the proposed project area.

Will the proposed project have a disproportionately high and adverse effect on low income or minority populations?

The proposed project will not have a disproportionately high and adverse effect on low income or minority populations.

Will the proposed project limit access to any ceremonial use of Indian sacred sites or result in other impacts on tribal lands?

The proposed project will not limit access to any ceremonial use of Indian sacred sites or result in other impacts to tribal lands.

Will the proposed project contribute to the introduction, continued existence, or spread of noxious weeds or non-native invasive species known to occur in the area?

The proposed project will not contribute to the introduction, continued existence, or spread of noxious weeds or non-native invasive species known to occur in the area.

Required Permits or Approvals

No permits or approvals are required for this project.

Existing Drought Contingency Plan

See the Kansas Water Plan Volume III – Guiding Principles: Reducing our Vulnerability to Extreme Events, and the relevant portion of the State Water Resources Planning Act, K.S.A.

82a-927 and K.S.A. 82a-928, attached to this document. Also see the GMD3 Drought Resiliency Program section of the GMD3 Draft Management Program, also attached to this document.

Letters of Project Support

Letters from the Finney County Economic Development Corporation and the City of Garden City, KS Public Utilities Department are attached to this submittal.

Official Resolution

An official resolution from the GMD3 Board of Directors will be submitted within 30 days of this submittal.

Works Cited

Lin, X., Harrington, Jr., J., Ciampitti, I., Gowda, P., Brown, D., & Kisekka, I. (2017). Kansas Trends and Changes in Temperature, Precipitation, Drought, and Frost-Free Days from the 1890s to 2015. *Journal of Contemporary Water Research & Education, 162*, 18-30.

Finney County Economic Development Corporation

Mr. Mark Rude
Southwest Kansas Groundwater Management District No. 3
2009 E. Spruce St.
Garden City, KS 67846

July 23, 2020

Re: Water Use and Climate Evaluation Service to Irrigators for Drought Resiliency in Southwest Kansas

Mr. Rude,

Please pass along this letter of support of the District's application for the **Water Use and Climate Evaluation Service to Irrigators for Drought Resiliency in Southwest Kansas** grant. Finney County Economic Development Corporation is eager to work with our District to help preserve the most important resource we have as a community, our water.

We believe that customer outreach and education is paramount to the overall effort to conserve and better use our water. We also feel that sharing data as well as being forward thinking is an ideal way for our community to address the issues that we face as a region.

I fully support the efforts in our region to further the understanding of our water use while giving our community members the tools to be able to make the best choices, both to accomplish short term goals as well as ensure long term viability of our water.

Sincerely,

Shannon Dick
Strategic Analyst

GARDEN CITY
— KANSAS —

PUBLIC UTILITIES DEPARTMENT

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Mr. Mark Rude
Southwest Kansas Groundwater Management District No. 3
2009 E. Spruce St.
Garden City, KS 67846

July 22, 2020

Re: WaterSmart – Drought Response Program: Drought Resiliency Projects for Fiscal Year 2021

Mr. Rude,

Please convey this letter of support for the Districts application for the WaterSmart – Drought Response Program: Drought Resiliency Projects for Fiscal Year 2021. The City of Garden City has been working with customers for the past several years to help them better understand their water use footprint in the community. We have received positive support from our customers and had many meaningful conversations with water users. The report is part of a discussion within our community regarding water conservation that has had a positive impact on our water consumption over the past few years.

While the efforts of Garden City to reduce consumption has value to water savings in the aquifer, the community represents less than 3% of the overall water consumption in Finney County. A significant outreach effort, such as the effort you propose to the Bureau of Reclamation, will provide hard data to water users that must utilize to find water savings at the producer level. Additionally, the work product resulting from this proposal will benefit water resource policymakers in their efforts to shape water policy for the region in the future.

I wholeheartedly endorse efforts in our region to promote an increased understanding of water consumption issues by water consumers.

Sincerely,

Fred Jones
Water Resource Manager

2018 Kansas Statutes

82a-927. State water plan; long-range goals. The long-range oals nd objectives of the tate of K nsas for management, conservation and development of the waters of the state, are hereby declared to be:

(a) The development, to meet the anticipated future needs of the people of the state, of ufficient upplies of water for beneficial purposes

(b) the reduction of damaging floods and of losses resulting from floods

(c) the protection and the improvement of the quality of the water supplies of the state;

(d) the sound management, both public nd private, of the tmos pheric, urface, nd oundwater upplies of the state;

(e) the prevention of the waste of the water supplies of the st te;

(f) the prevention of the pollution of the water supplies of the state;

(g) the efficient, economic distribution of the water supplies of the state;

(h) the sound coordination of the development of the water esources of the tate with the development of the other resources of the state; and

(i) the protection of the public interest through the conservation of the w te re ou ce of the t te in a technologically and economically feasible manner.

History: L. 1965, ch. 558, § 1; L. 1981, ch. 398, § 9; L. 1986, ch. 392, § 4; July 1.

2018 Kansas Statutes

82a-928. State water plan; policies to achieve long-range goals listed. The policies of he tate o Kansas that are deemed desirable for the achievement of the long-range goals and objectives as set forth in K.S.A. 82a-927, and amendments hereto, and hat hall erve as guidel nes or public orporations and all agencies o he state, relative o their responsibilities with respect o he water resources of he tate whenever physical and economic conditions permit, are hereby declared to be:

(a) The utilization of nonstructural methods, ncluding loodplain regulation, and tructural measures or he reduction of flood damage;

(b) the design of proposed levees and dikes so a to reduce flood r ks n agricultural areas to a hance of occurrence in any one year of 10% or less;

(c) the design of proposed levees and d kes o as o reduce lood r ks n urban areas to a hance of occurrence in any one year of 1% or less;

(d) the design of proposed orage ructures or he protection of agricultural areas so a to provide ufficient capacity to control the volume of a flood having a c hance of occurrence in any one year of 4% or less;

(e) the design of proposed orage ructures or he protection of urban areas o provide ufficient apacity o control the volume of a flood having a chance of occurrence n any one year of 2% or less;

(f) the development of adequate water orage to meet, as nearly as practicable, present and anticipated water uses hrough planning and onstruction of multipurpose reservoirs and hrough he a quisition rom he federal government o orage n federal reservoirs and by agreements w h he federal government regarding he use of storage;

(g) the nclusion in publicly nanced ructures or he conservation, management and development of he water resources of he tate of reasonable amounts of orage apacity or he regulation of he low lows o he watercourses of the state;

(h) the achievement of he primary drinking water standards promulgated by he ecretary of health and environment pursuant to K.S.A. 65-171m, and amendments thereto;

(i) the identification of minimum desirable reamflows o preserve, maintain or enhance baseflows or n-stream water uses relative o water quality, fish, wildlife, aquatic life, recreation, general aesthetics and domestic uses and for the protection of existing water rights;

(j) the maintenance o he surface waters o he state within he water quality standards adopted by he secretary of health and environment as provided by K.S.A. 65-164 to 65-171t, inclusive, and amendments thereto;

(k) the protection o the quality of he groundwaters of he ate as provided by he Kansas groundwater exploration and protection act and other acts relating thereto;

(l) the management o the groundwaters of he tate as provided by the Kansas water appropriation act and the provisions of K.S.A. 82a-1020 to 82a-1040, inclusive, and amendments thereto;

(m) the provision of inancial and technical assistance o publ orporations oncerned with management, onservation and development of water resources;

(n) the review and coordination o financial assistance or research that may be provided by federal or ate agencies o public orporations concerned with management, ons ervation and development of water resources o prevent duplication of effort;

(o) the development of groundwater recharge projects;

(p) the encouragement of local nitiative n the planning, implementation, funding and operation of local water programs to the extent that the same are supportive of state water programs;

(q) the design of municipal water ystems to provide an adequate water upply to meet the needs during a drought having a 2% chance of occurrence; and

(r) the encouragement of he use of agricultural oil and water onservation practices and ructures o control erosion and to effectively utilize precipitation and runoff.

History: L. 1965, ch. 558, § 2; L. 1981, ch. 398, § 10; L. 1986, ch. 394, § 3; L. 1987, ch. 402, § 3; July 1.

Reducing our vulnerability to extreme events

Issue Statement

Floods, droughts, winter storms and other extreme weather events affect Kansas on a regular basis. Severe flooding occurred in Kansas in 1935, 1951, 1965, 1973, 1976, 1981, 1983, 2007, and again in 2011, when the Missouri River flooded in northeastern Kansas, while drought gripped the remainder of the state. Droughts have repeatedly occurred in Kansas, with most aware of the "dirty thirties" and the 1950s drought. Proxy evidence indicates droughts in Kansas of even greater severity and duration over the past thousand years. Climatologists have warned that Kansas is facing a warming trend in our future, with more frequent droughts and floods likely.

The goal is to reduce our vulnerability to extreme events. This requires plans and actions to create resiliency that will assure clean water delivery to citizens and industry, and reduce economic and environmental impacts of extreme events to communities, farming, ranching, the energy sector, transportation, and recreation.

Importance of the Issue

While weather extremes are not new to Kansas, planning is needed to incorporate resiliency to potential climate extremes. Intense precipitation events pose a risk of flooding and increase the risk of soil erosion, leading to higher sediment, nutrient and other pollution loads in streams. Water related infrastructure can also be at risk, threatening the delivery of safe water for drinking and other uses. On the other end of water availability, drought, delivery of water is also the key need. Water can be in short supply requiring careful management, conservation and possibly additional supplies.

Flooding usually occurs relatively quickly when precipitation falls faster than it can be absorbed or above the ability of a channel to contain it. Preparation in the form of plans to warn of flooding, protect infrastructure and keeping sediment and nutrients entering water bodies at a minimum can decrease adverse effects and duration of any impacts.

Drought on the other hand often comes on slowly, building to an inability to supply sufficient water as storage, above or below ground is not replenished. Again planning to identify key needs and indicators can reduce extreme impacts of a drought.

Extreme events impact agricultural production associated industries as well as property. For example, the USGS estimates the United States averages $8-9 billion every year in losses due to drought. The Kansas Department of Agriculture estimates the cost of the 2012 drought at more than $3 billion in crop losses - the loss of production and the price farmers would have received. The 2011 drought cost Kansas production agriculture roughly $1.8 billion, the department estimated last year, along with about $366 million in herd liquidation that year as cattle flooded livestock auction houses by midsummer. More than $1.3 billion in crop insurance indemnity payments for failed commodities were paid in 2012, according to the U.S. Department of Agriculture's Risk Management Agency. Flood damages in 2011 along the Missouri River over $1 billion in Nebraska, Iowa, Missouri and Kansas. This included repairs to levees, roads, other infrastructure, and cropland. This does not include damages to homes and personal property, while major reservoirs are credited with preventing billions of dollars of flood damage upstream.

Three planning considerations are risk reduction, risk management and recovery and involve clearly defined options to manage, prepare for, respond to and recover from extreme events. Water-management involves three major areas: (1) floodplain management to decrease loss during floods, (2) flood-forecast and warning systems, and (3) planning adequate availability and efficient use of water resources during droughts.

Needs (gaps) to reach goal

Review current infrastructure adequacy for flood protection from even larger rainfall events, and evaluate reservoir storage space to provide sufficient water yield during longer, more intense droughts. In order to prepare for such events is it important to identify and characterize potential impacts of extreme weather-related events on source water quality, treatment and distribution processes, and finished water quality.

The National Climatic Assessment Report, 2013, projects that current temperatures will increase by two to four degrees Fahrenheit by 2100. Even small increases in average temperatures raise the risk of heat waves, wildfires, and droughts, as well as higher surface water evaporation and more turbulent atmospheric conditions leading to severe weather. According to projections, the total amount of precipitation may stay about the same, but occur in less frequent, more intense storms.

Flood Management

Floodplain maps provide guidance for local land use planning however, other considerations often take precedence when development occurs in floodplains. Flood management involves both structural and non-structural measures to utilize floodplains and wetlands to minimize loss of life and damage to property from flooding and benefit the ecosystems from periodic flooding. Flood resiliency requires well-developed procedures for communication between forecasting agencies and emergency services, downstream communities and transportation users with real-time information on developing flood events. Outreach to Public Water Suppliers to provide tools to evaluate how they would address flooding of any portion of their water supply infrastructure is an important element of risk reduction.

Drought Management

Drought management is needed by all sectors that use water. Additional storage of water in reservoirs or in aquifers gives Kansans greater ability to manage changes in the precipitation timing, duration and frequency, with longer dry spells in-between. This can be accomplished by the building or purchase of additional storage or the recovery of existing storage already lost to sedimentation.

To mitigate drought, public water suppliers need to continue to reduce water loss in their systems, and have an updated, approved drought plan. Currently emergency plans are required but drought plans are not. For communities using a common source of supply, drought plans should be consistent in use restrictions to minimize political issues of fairness and equitability. Alternate supplies need to be developed for Public Water Supply (PWS) systems vulnerable to drought.

Adaptation to changing conditions and minimizing harm during severe droughts are also necessary in agriculture. No or strip till, drought tolerant crops, and decision support tools such as irrigation scheduling and crop water allocator can help manage risk. Many federal and state lakes provide an alternate water supply for livestock during droughts.

Approach to address needs (gaps)

The resiliency of infrastructure to floods and droughts needs to be evaluated, and a long range plan developed to restore or build additional storage. The structural integrity of dams to manage increased flood flows needs evaluated, along with development of new inundation maps. New dams/reservoirs and other infrastructure should be designed to be robust with ability to manage changing climatic conditions. A robust reservoir is one in which the amount of water that it can reliably supply will not significantly change even when extreme events are at their worst.

State, federal and local government can develop plans for resiliency under extreme events: improve coordination; enhance monitoring and early warning capabilities; develop water shortage impact assessments; and have preparedness, response, and recovery programs. Other efforts include municipalities and industry maintaining emergency and drought plans, active education opportunities for water system operators and decision makers, and building awareness of other tools for emergencies.

Support planning and warning tool development for flood and drought (National Integrated Drought Information System (NIDIS)).

References

https://www.ipcc.ch/pdf/special-reports/srex/SREX_Full_Report.pdf

http://greatplainsclimate.org/p.aspx?tabid=17

http://www.planning.org/policy/guides/pdf/climatechange.pdf

http://ks.water.usgs.gov/pubs/reports/wsp.2375.ks.html

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log of the well, pump test data if available, and water quality samples, and maintains within the Kansas Geological Survey (KGS) a record system of well logs and water quality data available to the public. GMD3 will utilize the information made available under the GE&P Act and work with KDHE staff and other partners in its implementation in harmony with the management program.

GMD3 Drought Resiliency Program

Drought. Drought affects southwest Kansas frequently with a subtle onset that develops significant impacts over time. Long-term historical climate variability estimates over the last 1000 years produced by Layzell and others at the KGS indicate significant historical climate variability beyond modern experience and data. Vast development of local groundwater reservoir storage pumped to replace rain deficiencies has provided great drought resiliency and agribusiness advantage for the region. Significant value has been realized by decoupling economy from local rainfall and climate variability through the development and use of stored groundwater for irrigation. This has led to aquifer depletion, causing a re-aridification of irrigated farms consistent with the subtle onset of drought as reserves are diminished. The response to severity of drought relates both directly to the three drought stages of Watch, Warning and Emergency described in Tables 2 and 3 of the Kansas Drought Operations Plan, and also to the extent local aquifer inventory and infrastructure has preserved the capacity to mitigate local water shortage conditions. The Kansas Drought Operations Plan can be accessed at: https://kwo.ks.gov/reports2/climate-and-drought-monitoring-response. The Kansas 2007 Municipal Water Conservation Plan Guidelines reflect the drought response stages in the Kansas Drought Operation Plan. Programs will be implemented to inform members in their use and available supply conditions with interactive water management and technology tools. GMD3 will encourage and support regular review and updating of water conservation plans.

U.S. Drought Monitor – The U.S. Drought Monitor is produced weekly through a joint effort of the U.S. Department of Agriculture, The U.S. Department of Commerce – National Oceanic and Atmospheric Administration and the National Drought Mitigation Center. Advice from local experts throughout the nation, including the Kansas State Climatologist, is used in producing the Monitor. This composite drought map incorporates information and products from hundreds of experts representing many entities and levels of government in an effort to represent the extent, magnitude, impacts, and probability of drought occurrence. Short term management program drought response tools like Multi-Year Flex Accounts and long-term strategies for type 2 groundwater reservoir maintenance will be employed to help determine the destiny of water use in the district. GMD3 will develop water use, climate, and conservation feedback to members utilizing annual water use report, site visits and other data to inform and assist members in their decisions affecting their drought resiliency.

State mandated water conservation plans approved by GMD3. Water conservation plans mandated by the Chief Engineer as a condition of water use have been tied to many water rights in the district. They are intended to provide information and encourage Type (1) water conservation originating from a joint state and district initiative, with legislation passed the 1991 legislative session. Under that law (K.S.A. 82a-733), the Chief Engineer may require applicants for permits to appropriate water, water users with relatively high use, and water users applying for any state administered grant, loan or cost-share moneys for water-related projects to develop water conservation plans. GMD3 has historically advised and assisted the state and members with plan approval and completion of conservation plan requirements aided by State Water Plan

funding from the Kansas Water Office. The KWO develops and maintains guidelines for water conservation plans (K.S.A.74-2608). Current state guidelines for irrigation conservation plans are available at: https://kwo.ks.gov/docs/default-source/reports-page/water-conservation-reports/2006-kansas-irrigation-wcp-guidelines-jan2006.pdf?sfvrsn=6
Municipal (public water supply) guidelines are available at:https://kwo.ks.gov/docs/default-source/reports-page/water-conservation-reports/2007-municipal-wcp-guidelines-aug2007.pdf?sfvrsn=4

Water conservation under state guidelines. Under statewide Kansas Water Office guidelines, water conservation is defined as:

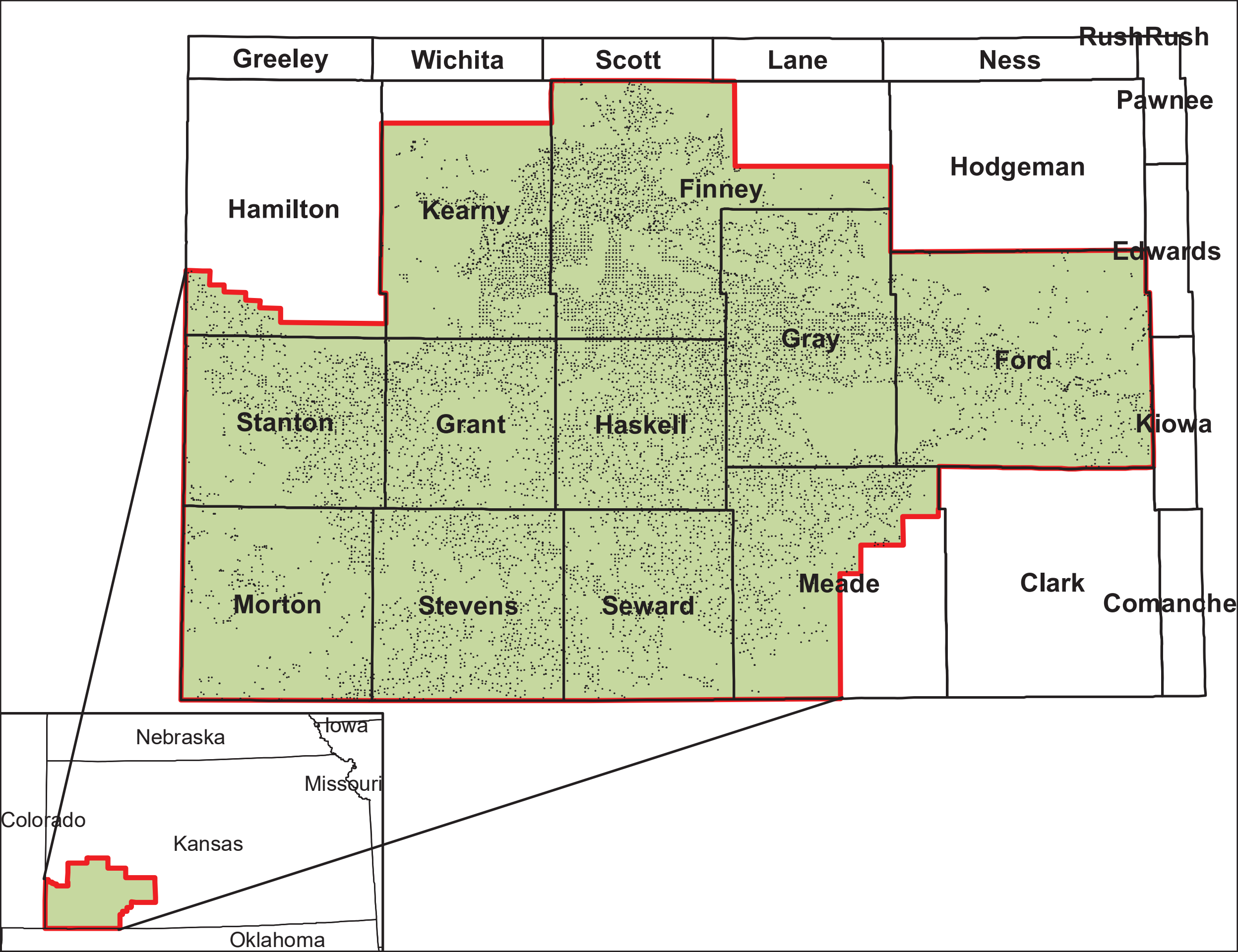
> "*The utilization of cost-effective water use efficiency practices to curtail the waste of water and to ensure that water use does not exceed reasonable needs.*"

This general definition implementing K.S.A. 82a-733 of the KWAA and other water use considerations focuses on use efficiency, which is Type (1) water conservation activity under the GMD3 management program. Type (2) water conservation that is emphasized in our management program needs other guidelines. GMD3 will seek to develop district guidance to assist members and others in developing an understanding of the terms and conditions of their water rights, water use agreements, and conservation activities consistent with the management program. Per Subsection (g) and (h) of K.S.A 82a-733, GMD3 will review and consider approval of conservation plans and practices and retain this authority for any proposal to set plans aside or to provide due consideration thereof in the conservation activities of IGUCAs, LEMAs, and WCAs.

GMD3 water conservation plan guidelines. GMD3 will investigate, develop and update water conservation plan guidelines for Type (2) conservation under separate guidance documentation to achieve the following:

1. Provide a plan template that can be used to develop water conservation plans to meet the requirements of the GMD3 management program, the state, federal interests, and other partners.
2. Provide considerable flexibility to develop and monitor water conservation plans consistent with the management program.
3. Provide an online source for Guidelines and Plan templates, so that members, consultants, and other management partners can easily download a template or develop a Plan.
4. Include a subsection on source conditions and management goals.
5. Make plans useful to member water managers, so that the majority of GMD3 water users can be directly involved in the management of their local water sources and use destiny.
6. Curtail waste of water using readily available best practices that ensure water use does not exceed reasonable needs.

Benefit-to-cost ratio effect of conservation plans. K.S.A 82a-733 requires the Kansas Water Office to conduct benefit-to-costs review for conservation plan guidelines. Benefits and costs should be estimated over the projected life of the water conservation plan and discounted to present day value equivalents for determination of whether benefits exceed costs under classic economic theory. A common way to compare the benefits and costs of a conservation plan is to divide total benefits by total costs. The result is called the benefit-to-cost ratio, or B/C ratio. A B/C ratio greater than one indicates that benefits are greater than costs while a B/C ratio less than one indicates that costs are greater than benefits. A B/C ratio exactly equal to one indicates that costs are expected to exactly balance benefits of the water conservation plan. Alternative



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Kansas Trends and Changes in Temperature, Precipitation, Drought, and Frost-Free Days from the 1890s to 2015

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Abstract: Kansas extends 660 km from the moderate elevations and semi-humid conditions of the Lower Missouri Basin to the High Plains lying above the Ogallala Aquifer and along the Rockies' eastern slope. Such characteristics result in significant climate variability across the state, making timely and accurate climate trend and change information valuable for water resources management and crop production. Here we used high-quality daily and monthly climate observations spanning a long-term period of 121 years 1895-2015) to assess trends and changes in air temperature, precipitation, drought, and frost-free days across Kansas. We show that a statewide average warming rate of 0.06°C 0.11°F) per decade was mainly driven by trends in daily minimum temperatures. However, there were no statistically significant trends in precipitation in either western, central, or eastern Kansas. Western Kansas tended toward increasing dryness, but central and eastern Kansas trended wetter as indicated by changes in the Palmer Drought Severity Index PDSI), a trend that was consistent with a weak wetting signal in eastern Kansas. The length of frost-free season increased by 5.2 days in western, 7.2 days in central, and 12.6 days in eastern Kansas, which reflected more warming in the east and less in the west, especially for changing magnitudes of nighttime temperatures. Such increases of frost-free days, especially in moisture-limited areas e.g., western Kansas), might increase seasonal evapotranspiration loss, thus exacerbating soil moisture stress and associated management challenges.

Keywords: *climate, water resources, drought, climate change, trends*

Nearly seventy years ago, Snowden Flora, a meteorologist of the U.S. Weather Bureau located in Kansas, published the 'Climate of Kansas' (Flora 1948). This book did an excellent job of documenting the weather and climate conditions for Kansas, based on instrumental observations from the late nineteenth century to the 1940s, and putting them into an accurate historical perspective. Following up this work, a few scientists have published research and educational bulletins and/or books detailing aspects of the climate of Kansas. For example, Bark, in 1963, published a Kansas Agricultural Experiment Station Bulletin on precipitation change in Kansas. Later, Feyerherm and Bark (1964) calculated wet and dry days in Kansas, and in the mid-1990s, Goodin et al. (1995) published the Kansas Climate and Weather Atlas. These publications have not only advanced climate science in Kansas, but more importantly, they successfully helped to assist Kansas stakeholders in climate-informed decision-making. However, these publications are constrained by the use of a limited set of climate stations and/or relatively short periods used for data analysis.

The ability to organize a more comprehensive documentation of Kansas climate now exists. One of the reasons is that climate scientists working on long-term climate data quality and data homogeneity have been making significant progress addressing climate data quality starting from the 1980s (Karl et al. 1986; Karl and Williams 1987; Menne and Williams 2009; Menne et al. 2012). Another reason to provide updated information on Kansas climate trends and changes is that climate change, including detection and attribution, has been vigorously and extensively studied since 1990, the year of the first Intergovernmental Panel on Climate Change (IPCC) Assessment Report in which the challenge of climate change was addressed (IPCC 1990).

This study is designed to foster the growth of climate science information in the areas of long-term climate changes and extreme weather records for Kansas. As the IPCC authors Field et al. 2012; IPCC 2013) concluded that "it is likely that anthropogenic influences have led to warming of extreme daily minimum and maximum air temperatures at the global scale" and that "there is medium confidence that anthropogenic influences have contributed to intensification of extreme precipitation at the global scale".

While these global scale changes have an influence on the climate of Kansas, other factors help explain the specific conditions across the state. At the local scale, climates are affected by various factors that include topography, elevation, proximity to oceans, water in lakes and rivers, irrigation practices and other land cover changes, and latitude. The borders of Kansas extend 660 km to include the moderate elevations and abundant precipitation conditions (more than 1,000 mm [~40 inches] of annual precipitation) of the Lower Missouri Basin to the drier High Plains lying along the eastern slope of the Rockies with less than 500 mm [~20 inches] of annual precipitation). The Gulf of Mexico, which extends westward to the 98th meridian, is the source of the vast majority of moisture for precipitation in Kansas. Northward flow of water vapor associated with low-level jets is frequently pushed eastward and this atmospheric moisture flow pattern contributes to three quite distinct precipitation climate zones of Kansas: a semiarid western third, an intermediate central third, and a semi-humid eastern third (Flora 1948).

Given the mid-latitude and mid-continental location of Kansas, pronounced thermal and hydrologic seasonality characterizes the climate of Kansas. The primary objective of this study is to document and analyze trends and changes in air temperature, precipitation, drought, and frost-free days that have occurred from 1895 to 2015, as well as the related extreme climate records for the 1891-2015 period across Kansas.

Data and Methods

Daily climate data were obtained from the Global Historical Climatology Network (GHCNd). The U.S. component of GHCNd is an integrated version of NCEI's National Centers for Environmental Information) daily surface observations, including the U.S. Cooperative Observer Network, the Automated Surface Observing System (ASOS), and other observing systems, and represents the most complete historical record of daily data for the United States. Thirty long-term climate stations (Fig. 1) were selected across Kansas for January 1, 1891 to December 31, 2015 based on data availability and station continuity. This daily dataset is part of the U.S. Historical Climatology Network (USHCN) program (Menne et al. 2012). This dataset was subjected to high-quality control (Alexander et al. 2006), but there were still erroneous observations for some Kansas stations. We first identified erroneous temperatures by using the fourth standard deviation as a threshold and then visually assessed suspected records by a spatial correlation method (Alexander et al. 2006). For daily precipitation observations, we only used them to assess the climate extreme records (when analyzing monthly and annual precipitation, we used the monthly dataset) for Kansas.

The U.S. Historical Climatology Network (USHCN, version 2.5) consists of 31 high-quality stations in Kansas and the data quality of monthly average temperatures has been rigorously examined (Menne and Williams 2009; Lawrimore et al. 2011; Menne et al. 2012) (Fig. 1). These 31 USHCN stations have long been commonly selected for use in evaluating climate changes on the global, regional, and state scales and these temperatures are considered a high-quality reference base when evaluating climate change from 1895 to 2015.

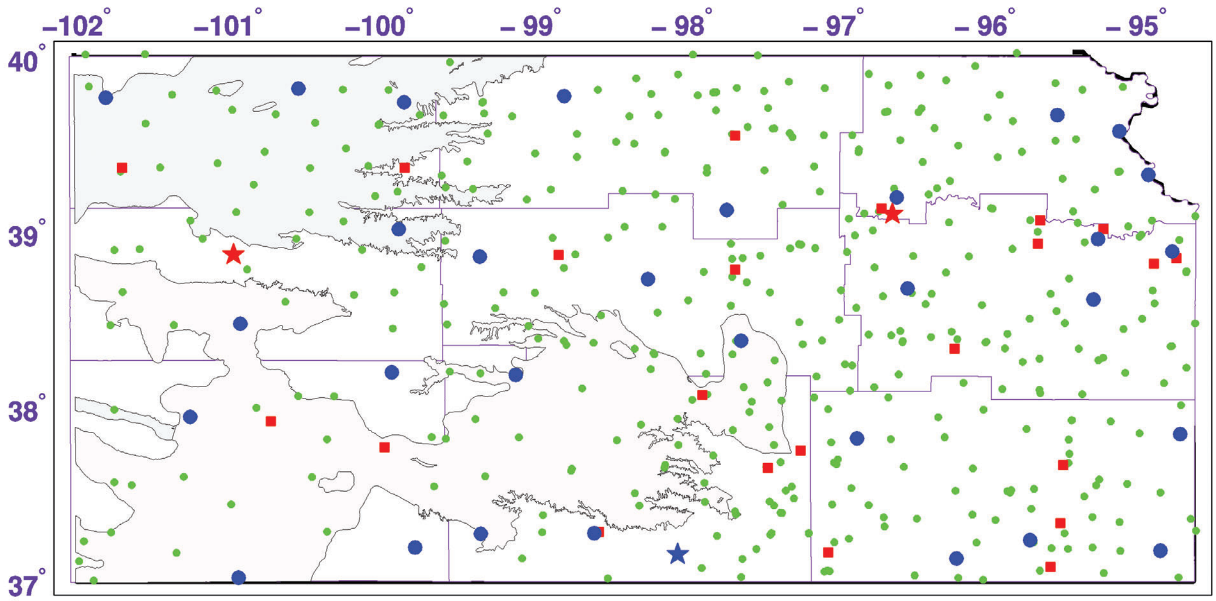

Figure 1. 433 total active daily climate observing stations (green dots) which include 30 long-term (over 1860s to current) high quality daily stations (blue dots) and 31 long-term monthly stations (blue dots plus one blue star) in Kansas selected by the Global Historical Climatology Network (GHCN). Kansas also has 22 federal ASOS stations (red squares) with data from the 1970s to current, and two U.S. Climate Reference Network (USCRN) stations red stars), from 2002 to current. Aquifers in western Kansas and the nine crop reporting districts are shown. Each third of Kansas contains at least nine high-quality stations analyzed in this report. (View color figure online at http://onlinelibrary.wiley.com/journal/10.1111/(ISSN)1936-704X.)

In both daily and monthly datasets that we used in this study, all missing data were retained without any filling or replacement by estimation. Monthly anomalies for maximum, minimum, and average temperatures were departures from a base period of 1981 to 2010 (WMO 1989; WMO 2009). The time series for the state of Kansas was aggregated using an equally weighted station average from each station when the observation was available. It should be noted that the monthly climate data were different from the daily climate data in that there were extensive and high-quality data homogeneity techniques employed in generating the monthly datasets but these procedures were not used for the daily dataset (Menne et al. 2012).

For derived climate variables in this study, the PDSI was selected, an index originally developed and calibrated using western Kansas climate in 1965 (Palmer 1965). The PDSI was calculated from the monthly temperature, monthly precipitation, and Kansas' available water capacity (Guttman 1991). The second climate variable we selected is the frost date, which is defined in this paper as a day with the daily minimum temperature below freezing (0°C). The length of the frost-free season (frost-free days) is defined as the difference between the last-spring freeze and the first-fall freeze dates (Easterling 2002).

To robustly examine the trends, the adjusted standard error and adjusted degree of freedom methods were selected for assessing the statistical significance of temperature trends at 95% confidence levels (von Storch and Zwiers 1999; Santer et al. 2000; Karl et al. 2006; Lin et al. 2016). This approach is a modification of ordinary least squares linear regression, substituting the effective sample size in a regression time series to account for the effect of temporal autocorrelation in the time series or its residual series. The extent of sample number reduction implemented in our linear trend analysis depends upon the strength of the autocorrelation. A strong autocorrelation means that individual values in the sampling series are far from being independent so that the effective number of independent values must be much smaller than the sample size. A trend in a time series significantly different from zero is tested by computing the ratio of the estimated trend and its adjusted standard error, a stricter test than using standard *p*-values. Note that the 95% confidence intervals used in this paper are adjusted by inverting the Student's *t*-distribution to obtain effective sample size and using the critical value $1-\alpha/2 = 0.975$ (two-tailed) (Lin et al. 2016).

Results

Temperatures

Over the last decade, temperatures have been among the warmest on record for Kansas, with the only exception being the extreme heat of 1930s "Dust Bowl" era (Figs. 2a and 2b). Statewide annual average temperature varied from a low of 11.3°C (52°F) in 1912 to a high of 14.9°C (59°F) in 2012. Such a swing, 3.6°C (6.5°F), documents an aspect of temperature variability that is one of the reasons that Kansas' agricultural economy is vulnerable to climate change and climate variability. One pronounced result from observations over the last 121 years was the warming of the minimum temperature (nighttime temperatures) much greater than that of maximum temperatures (Figs. 2a and 2b). Maximum temperatures do not have statistically significant trends over the last 121 years but minimum temperatures show a significant warming rate of 0.078 ± 0.03°C per decade (0.14°F per decade). Kansas' average temperature increase, 0.059 ± 0.03°C per decade (0.11°F per decade), was mainly driven by the rise in minimum temperatures (Fig. 2).

When examining seasonal temperature trends, the results indicate that none of four seasons have any statistically significant trend (Fig. 3) except for the winter season, showing significant warming using a 90% confident level Fig. 3d). In addition, it is clear that this warming trend of winter temperatures was accompanied with larger inter-season variations compared to spring, summer, and fall seasons (Fig. 3d). These results suggest that temperature change impacts on winter wheat are expected to be more

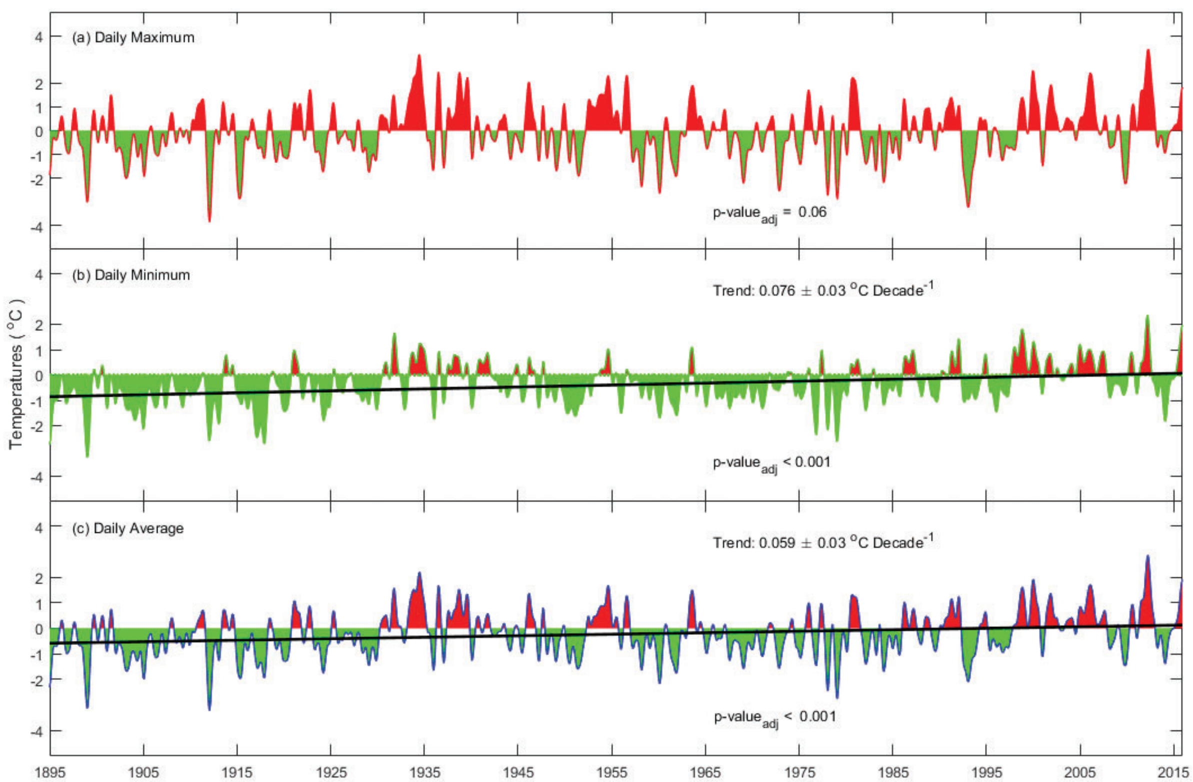

Figure 2. Kansas monthly temperature anomaly time series over 1895 to 2015: (a) daily maximum temperature; (b) daily minimum temperature; and (c) daily average temperature. The base period used is 1981 to 2010 and a 13-point Gaussian filter was used to smooth the data (red line for daily maximum, green line for daily minimum, and blue line for daily average temperatures). When trends (black lines) are statistically significant the trend rates are displayed. All adjusted p values are shown. (View color figure online at http://onlinelibrary.wiley.com/journal/10.1111/(ISSN)1936-704X.)

important than that on other major crops in Kansas (Zhang et al. 2015; Zhang and Lin 2016). It should be noted that this century-scale increase in temperature documented with the analysis of data from stations in Kansas is comparable with the 0.6 to 1.0°C (1.1 to 1.8°F) increases observed across the United States (Karl et al. 2006). Notice that when minimum temperature data are analyzed on a seasonal basis, the data indicate an increase in all four seasons, with the steepest slope in spring (not shown).

Precipitation

Precipitation in Kansas is highly variable from year to year and across the state, with the statewide annual average exhibiting a low of 439 mm (17 inches) in 1956 to a high of 1,110 mm (44 inches) in 1951 (Fig. 4 and Table 1). For the western third, central third, and the eastern third of Kansas, long-term (1895-2015) mean annual precipitation totals were 531 mm (21 inches), 660 mm (26 inches), and 945 mm (37 inches), respectively (Fig. 4). These long-term statistics are slightly larger than those presented by Flora (1948): 474 mm (19 inches) for western, 658 mm (26 inches) for central, and 878 mm (35 inches) for eastern Kansas. Over the last two decades, annual precipitation amounts have increased, but due to large inter-annual (year-to-year) variability the long-term annual precipitation does not show any statistically significant increase or decrease (Fig. 4) at the 95% confidence level for 1895 to 2015. It was clear that if one considers the 90% confidence level, both central and eastern Kansas did present a weak increasing trend (7.08 ± 7.0 mm per decade (0.3 inches per decade) for central and 8.80 ± 9.1 mm per decade (0.4 inches per decade) for eastern, at 95% confidence level) (Fig. 4).

For the state as a whole, the precipitation is 218 mm (9 inches) during spring (March-April-May), 279 mm (11 inches) in summer (June-July-August), 169 mm (7 inches) in fall (September-October-November), and 70 mm (3

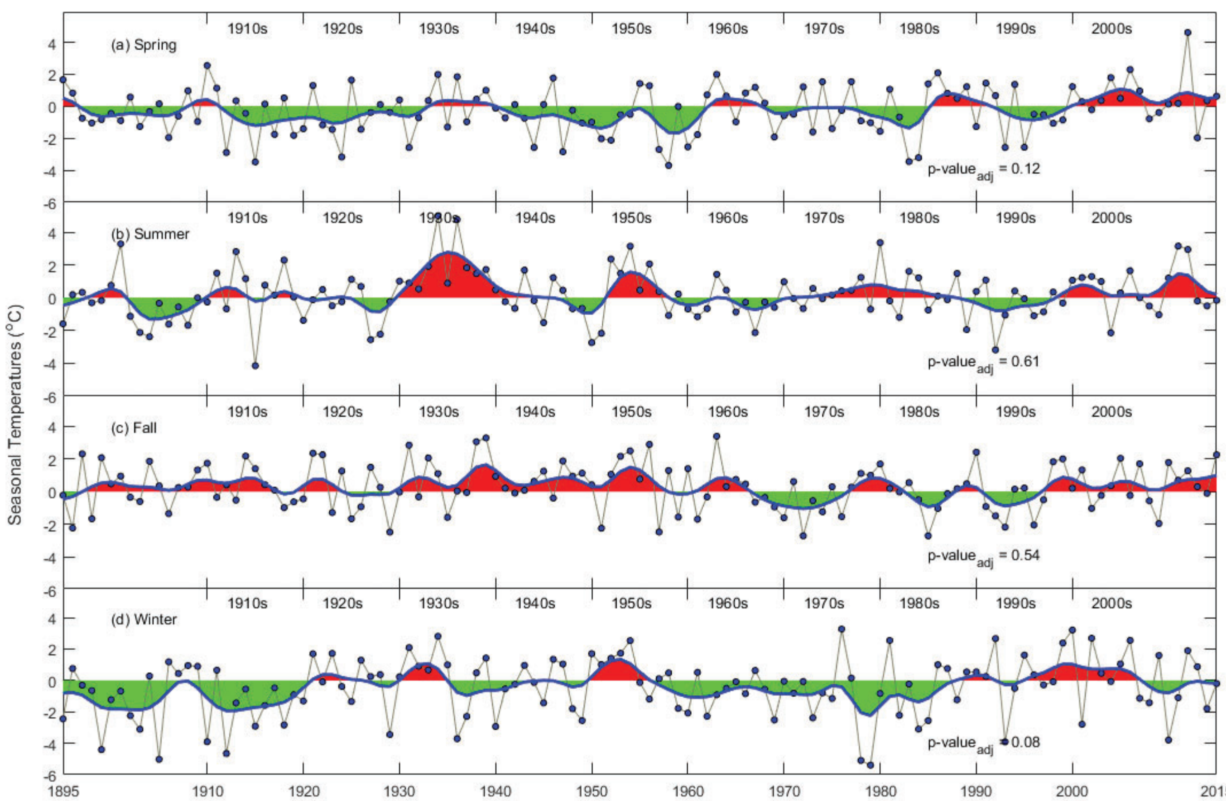

Figure 3. Kansas seasonal temperature anomaly time series over 1895 to 2015: (a) Spring; (b) Summer; (c) Fall; and (d) Winter. The base period used is 1981 to 2010 and a 13-point Gaussian filter was used to smooth the data blue lines). When trends are statistically significant the trend rates are displayed. All adjusted p values are shown. (View color figure online at http://onlinelibrary.wiley.com/journal/10.1111/(ISSN)1936-704X.)

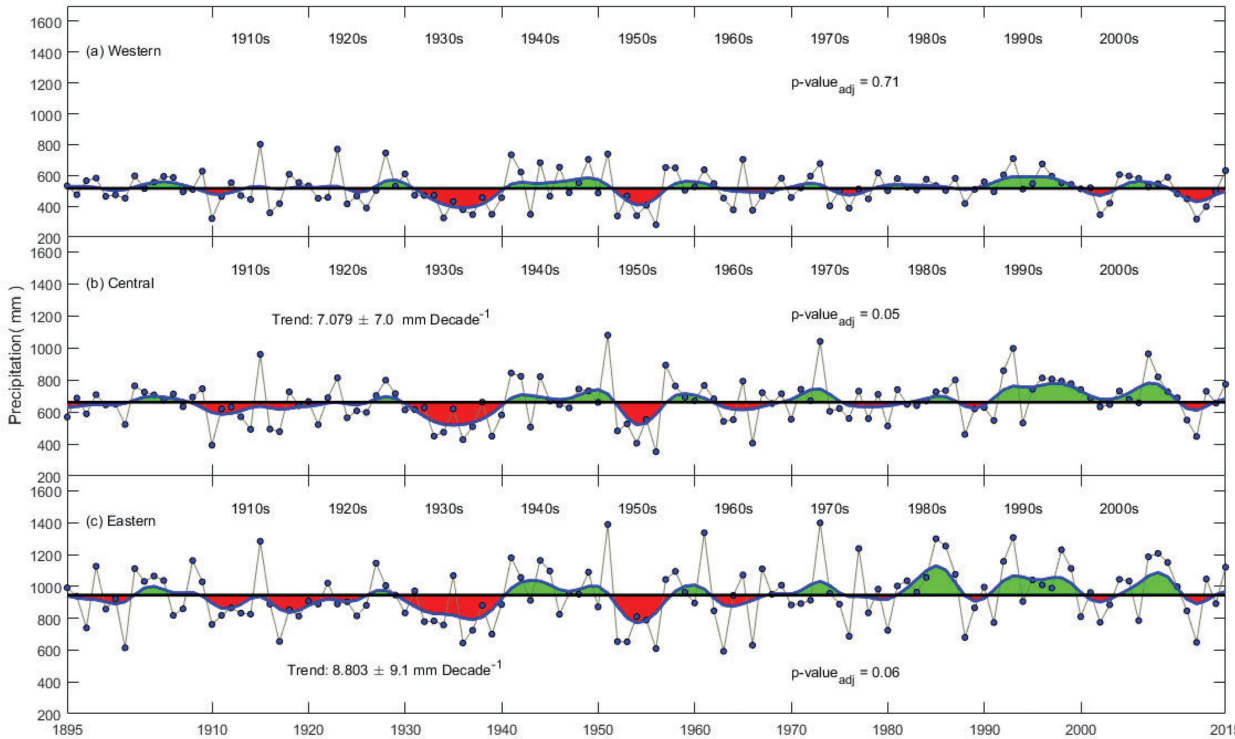

Figure 4. Kansas annual precipitation time series over 1895 to 2015: a) Western; (b) Central; and (c) Eastern Kansas precipitation variations. The black lines are period-of-observation mean over 1895 to 2015 (inclusive). A 9-point moving average was used as a smoother (blue lines). When trends are statistically significant the trend rates are displayed. All adjusted p values are shown. (View color figure online at http://onlinelibrary.wiley.com/journal/10.1111/(ISSN)1936-704X.)

inches) in winter (December-January-February) seasons (Fig. 5). Winter season precipitation has a comparatively small inter-annual variation. There were no statistically significant trends in seasonal precipitation amount at the 95% confidence level. For the whole U.S., extreme precipitation events are increasing (Karl et al. 2006) and data for Kansas documents a statewide increase in the magnitude of extreme rainfall events, with greater increases in the east (Rahmani et al. 2016). At the 90% confidence level of statistical significance, seasonally, only spring precipitation showed an upward trend.

Drought

Droughts are one of the most devastating natural disasters. Over the course of the time period studied here, the water resources and agricultural economy of Kansas have been considerably effected by drought events. The 1930s drought is often considered the worst drought on record in Kansas (Fig. 6a). This was the driest series of years since instrumental observations began starting in the late 1800s. Sporadic weather observations in the mid-1800s have helped document droughts during that settlement period.

By going over more than 1,000 years of tree-ring data (Cook et al. 2004), it becomes noticeable that the droughts in 1930s were not the worst in history in terms of either drought duration (consecutive years of drought) or drought intensity (the magnitude of drought index) in Kansas. Multiple-year droughts have often occurred in Kansas. The state as a whole has not experienced more frequent or more extreme droughts in recent years compared to either the last 1,000 years (Cook et al. 2004) or the most recent 121-year period (Fig. 6). When the data were subdivided by dividing the most recent 121-year period into two periods (1895 to 1955 and 1956 to 2015) for each of the three regions of Kansas, only western Kansas was dryer on average during the most recent 60-year period when compared to data from 1895 to 1955 (Fig. 7). Both central and eastern Kansas showed

Table 1. Kansas top ten hottest and coldest years (top panel), and driest and wettest years (bottom panel) from 1895 to 2015.

Rank	Hottest Year	°C (°F)	Rank	Coldest Year	°C (°F)
1	2012	14.9 (58.9)	1	1912	11.3 (52.3)
2	1934	14.5 (58.1)	2	1951	11.4 (52.5)
3	1954	14.3 (57.7)	3	1993	11.4 (52.6)
4	2006	14.2 (57.6)	4	1924	11.4 (52.6)
5	1938	14.2 (57.5)	5	1917	11.5 (52.7)
6	1939	14.1 (57.4)	6	1979	11.6 (52.8)
7	1946	14.1 (57.4)	7	1903	11.6 (52.9)
8	1933	14.1 (57.3)	8	1895	11.6 (52.9)
9	1931	13.9 (57.1)	9	1929	11.6 (52.9)
10	1921	13.9 (57.1)	10	1985	11.7 (53.0)

Rank	Driest Year	mm (inches)	Rank	Wettest Year	mm (inches)
1	1956	439 (17.3)	1	1951	1110 (43.7)
2	1966	490 (19.3)	2	1973	1085 (42.7)
3	2012	493 (19.4)	3	1915	1049 (41.3)
4	1936	503 (19.8)	4	1993	1044 (41.1)
5	1952	511 (20.1)	5	1961	968 (38.1)
6	1939	526 (20.7)	6	1941	953 (37.5)
7	1910	526 (20.7)	7	2007	930 (36.6)
8	1917	533 (21.0)	8	1944	925 (36.4)
9	1963	536 (21.1)	9	1985	912 (35.9)
10	1988	541 (21.3)	10	1992	909 (35.8)

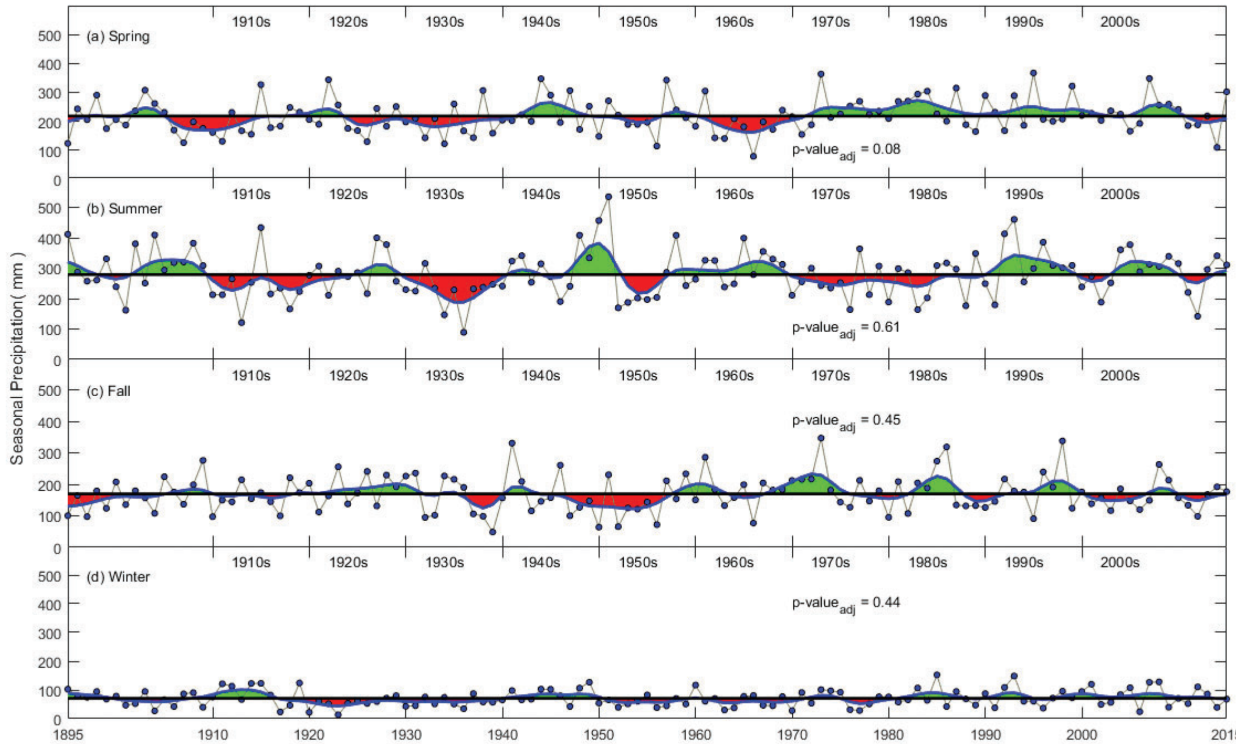

Figure 5. Kansas seasonal precipitation time series over 1895 to 2015: (a) Spring; (b) Summer; (c) Fall; and (d) Winter seasons. The black lines are period-of-observation mean over 1895 to 2015 (inclusive). A 9-point moving average was used as a smoother (blue lines). When trends are statistically significant the trend rates are displayed. All adjusted p values are shown. (View color figure online at http://onlinelibrary.wiley.com/journal/10.1111/(ISSN)1936-704X.)

wetter tendencies in the most recent 60-year period. Recent wetter conditions are challenging summer row crop establishment and final harvest. The drought change information observable in Figure 7 is consistent with precipitation trends for Kansas (Fig. 4).

Frost-free Days

The number of days that the minimum daily temperature falls below freezing is an important indicator for crop production, water management, and ecosystems in Kansas (Lin et al. 2014). Length of the frost-free season and changes in the length of that season have a direct implication for crop production in Kansas. The distinct patterns of first and last frost dates across Kansas result in the shortest growing season occurring in western Kansas (170 days) and longer average growing seasons occurring in central Kansas (182 days) and eastern Kansas (189 days) (Fig. 8). These long-term averages for Kansas are changing (Lin et al. 2014). The frost-free season length in all regions of Kansas exhibits a statistically significant increase from 1901 to 2014 at a rate of 0.99 ± 0.79 days per decade in western Kansas, 0.94 ± 0.90 days per decade in central Kansas, and 1.47 ± 0.74 days per decade in eastern Kansas (Fig. 8). A longer frost-free growing season could give Kansas producers an opportunity to explore cropping alternatives. This longer season could increase yields if other biotic (insects, diseases) and abiotic (heat, drought) stresses do not limit crop growth and development.

Top Ten Hottest, Coldest, Driest, and Wettest Years

Table 1 provides the top ten hottest, coldest, driest, and wettest years, respectively, based on the daily climate data. The hottest year was 2012 and coldest year was 1912. Five of the ten hottest years occurred during the 1930s. Both the driest and wettest years occurred in the 1950s. Perhaps surprisingly, only two of the driest years were during the Dust Bowl decades of the 1930s (Table 1). The temperature

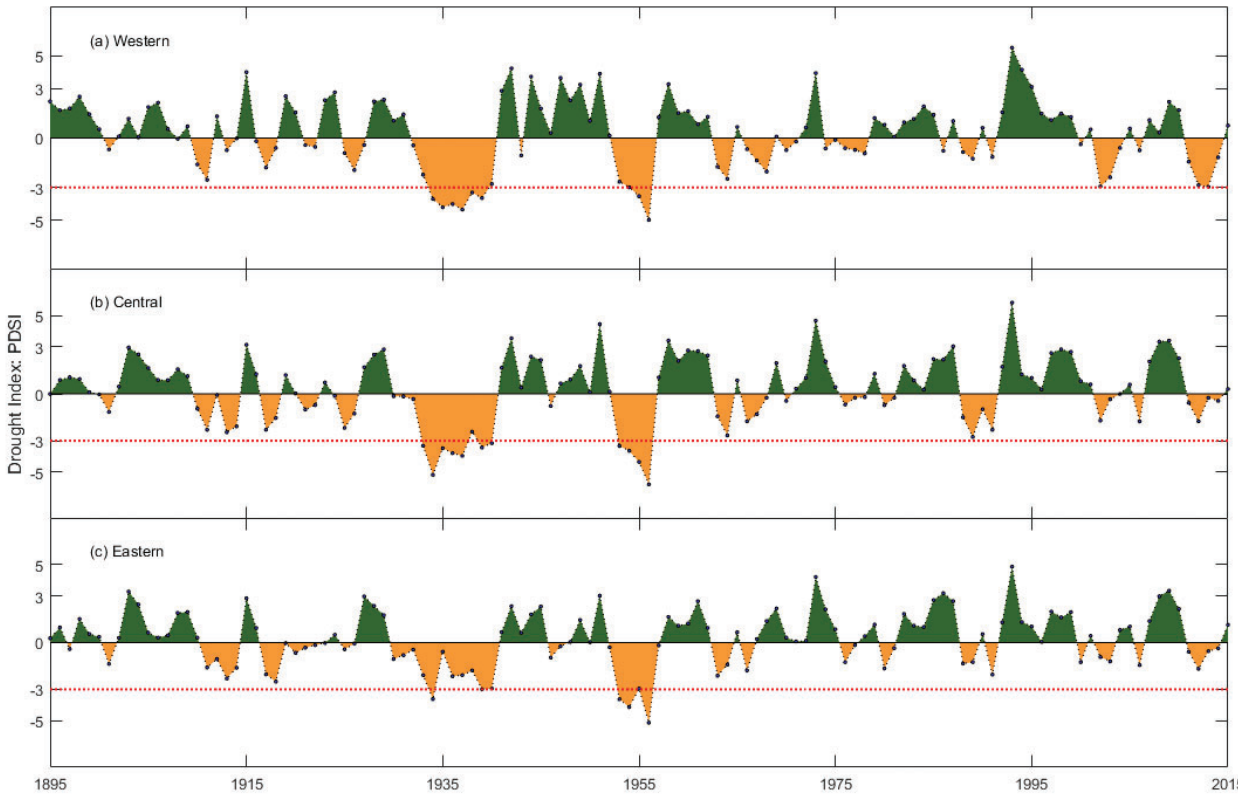

Figure 6. Average annual Palmer Drought Severity Index (PDSI) from 1895 through 2015: a) Western; (b) Central; and (c) Eastern thirds of Kansas. The more negative the PDSI, the drier (orange). On the opposite side, the more positive the PDSI, the wetter (dark green). The dotted red lines PDSI -3) are indicators of severe drought occurrence. (View color figure online at http://onlinelibrary.wiley.com/journal/10.1111/(ISSN)1936-704X.)

difference between the hottest year and coldest year is about 2.7°C (5°F) in Kansas. Perhaps more significantly, the precipitation difference is 671 mm (26 inches) between the wettest and driest years, which is more than annual expected precipitation in central Kansas Fig. 4b). These significant swings of temperature and precipitation make Kansas crop and livestock productions relatively vulnerable to changes of increasing climate extreme events in the short-term and/or longer-term perspectives, which will require that adaptive measures be taken for sustaining Kansas agricultural production.

Summary and Conclusions

Accurate, historical climate information is a key resource for managing Kansas water resources and improving agricultural production. As the climate of Kansas continues to vary over time, information on past conditions and ongoing trends will help those managing other climate-sensitive resources across the state. Average temperatures in Kansas have significantly trended up during the last 121 years, a period in which the daily minimum temperature increased faster than the daily maximum temperature. The warming rate in Kansas, 0.06°C per decade (0.11°F per decade), is comparable with the U.S. as well as global warming rates (approximately 0.07°C per decade, IPCC 2013). This nighttime warming might not directly drive evapotranspiration loss as a whole, but it could have significant impacts on crop production, especially for winter wheat (Lobell and Oritz-Monasterio 2007; Melillo et al. 2014; Zhang et al. 2015).

Both drought and frost-free-days metrics were derived from available temperature and precipitation data. The drought events in 2011, 2012, and 2013 in Kansas were significant but not unprecedented climate phenomena, as they fell within historical variability ranges. Long-term observed precipitation in the state did not exhibit

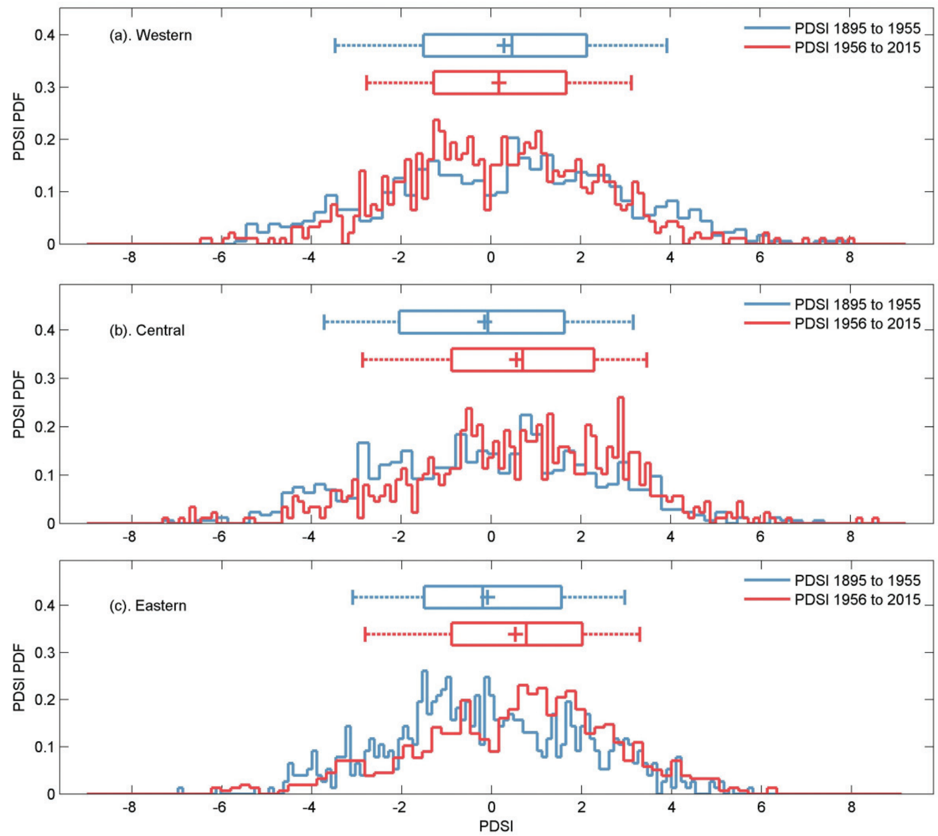

Figure 7. Probability density function (PDF) of Palmer Drought Severity Index (PDSI) during 1895 through 1955 and 1956 through 2015 in a) Western; (b) Central; and (c) Eastern Kansas, respectively. The negative numbers to the left of "0" on the x axis represent drier-than-average conditions; the positive numbers to the right of "0" represent wetter-than-average conditions. Only in western Kansas is there a slightly drier-than-average pattern in the 1956 to 2015 period (red lines) compared to the 1895 to 1955 period (blue lines). In central and eastern Kansas, the most recent time period has been slightly wetter. (View color figure online at http://onlinelibrary.wiley.com/journal/10.1111/(ISSN)1936-704X.)

any significant trends. Only western Kansas tended to be drier in more recent years, while central and eastern Kansas tended to be wetter. The temperature trends across Kansas have no obvious difference although climatology is distinctly different. Additional detail regarding these weak trends towards drier or wetter conditions could be valuable for Kansas water resource management interests. The frost-free season length, in contrast, demonstrated a clear and statistically significant increase across all of Kansas, with increases of 5.2 days in the west and 12.6 days in the east. These differences mirror the overall spatial trends of more warming in eastern Kansas, driven primarily by nighttime temperatures.

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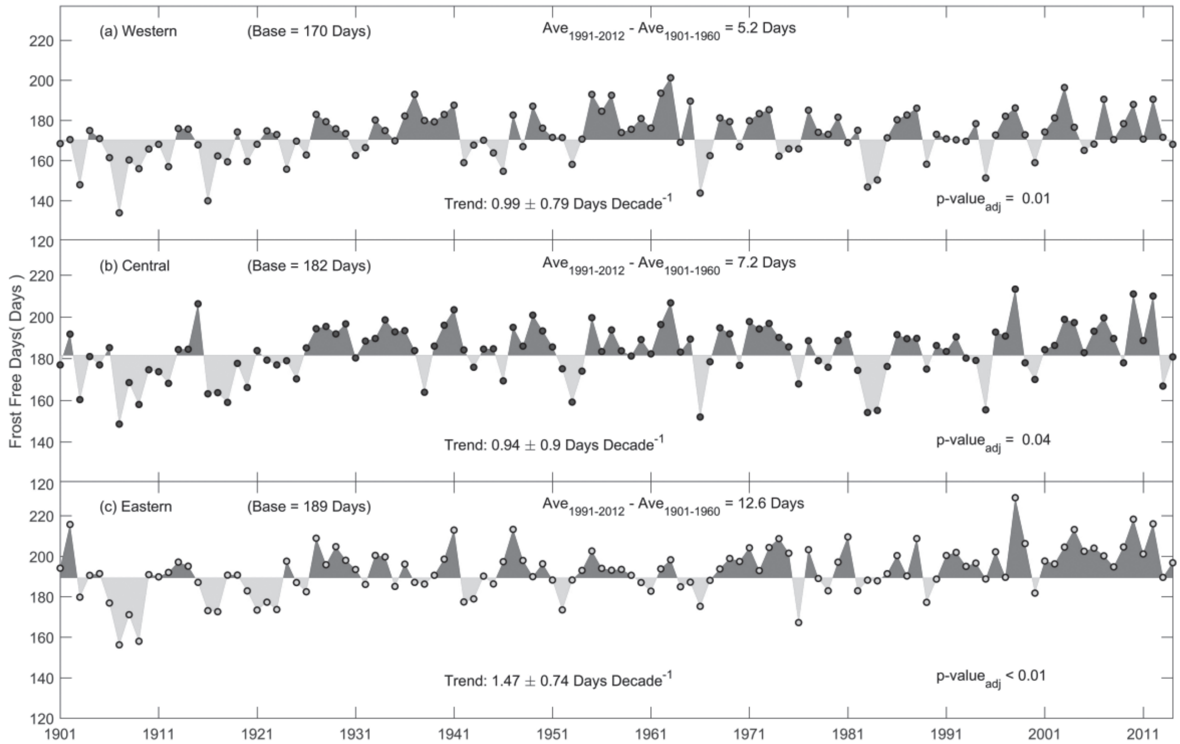

Figure 8. Time series of the frost-free season length in Kansas from 1901 to 2014: (a) Western; (b) Central; and (c) Eastern Kansas. The base indicates average number of frost-free days calculated from 1901 to 1960 (60-year period as a base period). The Ave 1991-2012 – Ave 1901-1960 is the difference of frost-free season length between 1991-2012 and 1901-1960. When trends are statistically significant the trend rates are displayed. All adjusted p values are shown. (View color figure online at http://onlinelibrary.wiley.com/journal/10.1111/(ISSN)1936-704X.)

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