Project title: Creating fresh approaches to water use efficiency for communities and wildlife in a water-stressed area of Central Kansas.

Grantee Name: The Nature Conservancy

Key team members:

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Project dates: 08/14/2020 - 3/27/2024

Award Number (FAIN): NR203A750013G025

Project Summary:

In the Rattlesnake Creek basin in central Kansas, crop production is supplemented with groundwater pumped from the Great Bend Prairie Sand Aquifer (a formation of the High Plains aquifer). This same groundwater supports critical habitat at Quivira National Wildlife Refuge, a wetland of international importance. This provided an opportunity to develop irrigation strategies in this region that could be exported to other areas of the High Plains (Ogallala) aquifer experiencing water shortages. This project increased adoption of monitoring technologies and improved application packages; provided technical assistance for maintenance and improvements of irrigation systems; investigated attitudes around practice adoption and irrigation efficiency; created peer networks for producers to share experiences and ask questions; and created a 7-step toolbox for irrigation efficiency that is being adopted in other groundwater dependent regions.

Project Goal and Objectives:

The overarching purpose of the partnership between The Nature Conservancy (TNC), K-State, and local communities was to use a systems approach to achieve reduced water usage in crop production while maintaining crop yields and profitability, minimizing economic harm to local agricultural communities while fulfilling the senior water right of Quivira National Wildlife Refuge (NWR).

This project proposed a technology transfer and training related to improved Irrigation Management Technology and practices on croplands. The technical approach was supported by the generation and strengthening of social networks. Specific objectives for this project included **1)** Increase adoption of improved water application packages (mobile drip irrigation or other alternatives), soil moisture sensors, and the KanSched irrigation scheduling mobile app, to test improvements in irrigation efficiency and irrigation water management, maintaining crop water productivity while minimizing groundwater withdrawals; **2)** Develop water budgets and irrigation scheduling tools; **3)** Facilitate a peer-to-peer mentoring network for enhanced communication; **4)** Identify successful techniques and strategies that could be adapted to other communities trying to minimize groundwater withdrawals and sustain local aquifers.

On-Farm Trials allowed broader adoption of technology and water-saving practices through 1) financial assistance with the upfront costs of installation, expanding application of these technologies and allowing evaluation on a broader scale than a single research farm; 2) Facilitation of direct technical assistance (TA) for adoption of technologies and irrigation scheduling; 3) Demonstration of the utility of these practices to agricultural production and water use reductions; and 4) Facilitation of a peer-to-peer mentoring network, where producers discussed their experience and outcomes with the technology.

Project Background:

This On-Farm Trial project focused on the Rattlesnake Creek basin in south-central Kansas. Due to low annual rainfall (average 23-26 in/yr), crop production risk is reduced with supplemental water drawn from the Great Bend Prairie Aquifer, a High Plains Aquifer subsidiary. Over 98 percent of the water use in the basin is from groundwater (Barfield, 2015). In addition to supporting agricultural production in the region, the Great Bend Prairie Aquifer and its associated streams are crucial to the health of Quivira National Wildlife Refuge (NWR). Established in 1955, Quivira NWR is administered by the U.S. Fish and Wildlife Service (USFWS) and provides vital resting and feeding ground for migratory shorebirds and other waterfowl in the Central Flyway, as well as winter nesting for Bald eagles. It is critical habitat for the federally listed whooping crane (*Grus americana*), and the state-listed western snowy plover *(Charadrius nivosus).*

The timing of irrigation withdrawals from the aquifer coincides with Quivira NWR's time of greatest need for water to flood the marshes and provide habitat for migrating shorebirds. The hydrology of the area is such that seasonal water table depletions cause Rattlesnake Creek to become a losing stream during the growing season. Quivira NWR holds a right to surface water from Rattlesnake Creek, and this right is senior to approximately 95 percent of the other water rights in the basin. Thus, seasonal depletion of the aquifer has become a point of contention in the region. The project team saw an opportunity to develop irrigation strategies in this region that could be exported to other areas of the High Plains (Ogallala) aquifer experiencing water shortages. We also saw an opportunity to benefit a wetland wildlife refuge of international importance while also working with and supporting the agricultural community.

Project Methods:

Objective 1: Our original goal under this objective was to enroll 25 center-pivot irrigated fields to be equipped with irrigation and soil moisture monitoring systems and improved application packages. We received enormous interest and exceeded our goal, enrolling 38 fields. The original proposal focused on mobile-drip irrigation as the improved application package, but working with NRCS, we were able to offer a broader range of options to improve irrigation efficiency (see Appendix 1). Participating landowners received an incentive payment of 50 percent of the upfront costs of installing these components. They also received maintenance and technical assistance with their system, an annual subscription to aerial imagery services, and access to Extension resources and the peer network. Participants were required to share certain operation data during the project period (see Appendix 2).

Objective 2: Water budgets (estimating the amount of water the field requires at a given time) using ET-based irrigation scheduling and complemented by soil water sensors can help document the irrigation needs for the site and allow evaluation of several sensor technologies. Working with GMD5, we purchased and installed two new weather stations in the project area to improve precision and accuracy of the KanSched model in estimating evapotranspiration. We also evaluated the overall performance of KanSched in providing irrigation scheduling information at the producer field scale.

Objective 3: To understand general perceptions of water management issues, practice adoption, and information needs, we developed and distributed a survey via mail and online. Detailed methods and results are available in the resulting publication: Sampson, G. S., Aguilar, J., Baldwin, C., Davidson, J., & Mehl, H. (2024). Water Management and Information Gaps in the High Plains Aquifer. *Journal of the ASFMRA,* 2024, 116-129.

We hosted 6 events and field days during the grant period, during which we highlighted participating producers and provided space for them to share their experiences with their peers. We also presented project progress annually at the WaterPACK annual meeting (local producer group), and at the Governor's Water Conference. In the final year of the project, the project team hosted booths at the Kiowa and Stafford County fairs to reach a broader audience.

Although we originally intended to hold KanSched workshops, these efforts were hindered by the COVID pandemic and later, issues with the KanSched application (discussed below). These workshops were replaced with other outreach activities, such as booths at county fairs, preparation of outreach materials, and peer networking events, field days, and the WaterPACK annual meeting.

Objective 4: Based on our experiences and data collected through this project, we developed a Toolbox for irrigation efficiency (Appendix 6). We have presented these recommendations in public meetings and meetings with Kansas state agencies and the Governor's office.

Project Results:

Objective 1: Our project team enrolled a total of 38 fields, representing 21 participating entities (figure 1). Participants chose the technology based on their comfort level towards the given technology, the compatibility of the technologies with their current farming operation, and the financial feasibility to pay for technology costs not covered by cost-share. Mobile-drip irrigation (MDI) is the most expensive single-item technology amongst the choices. KanSched would have been the least expensive (or free) tool for producers, however, compounded by software issues, it was not a viable option during most of the project period. Soil moisture sensors were the most popular tool that was used in this project in conjunction with rain gauges, autonomous pivot, and control panel telemetry.

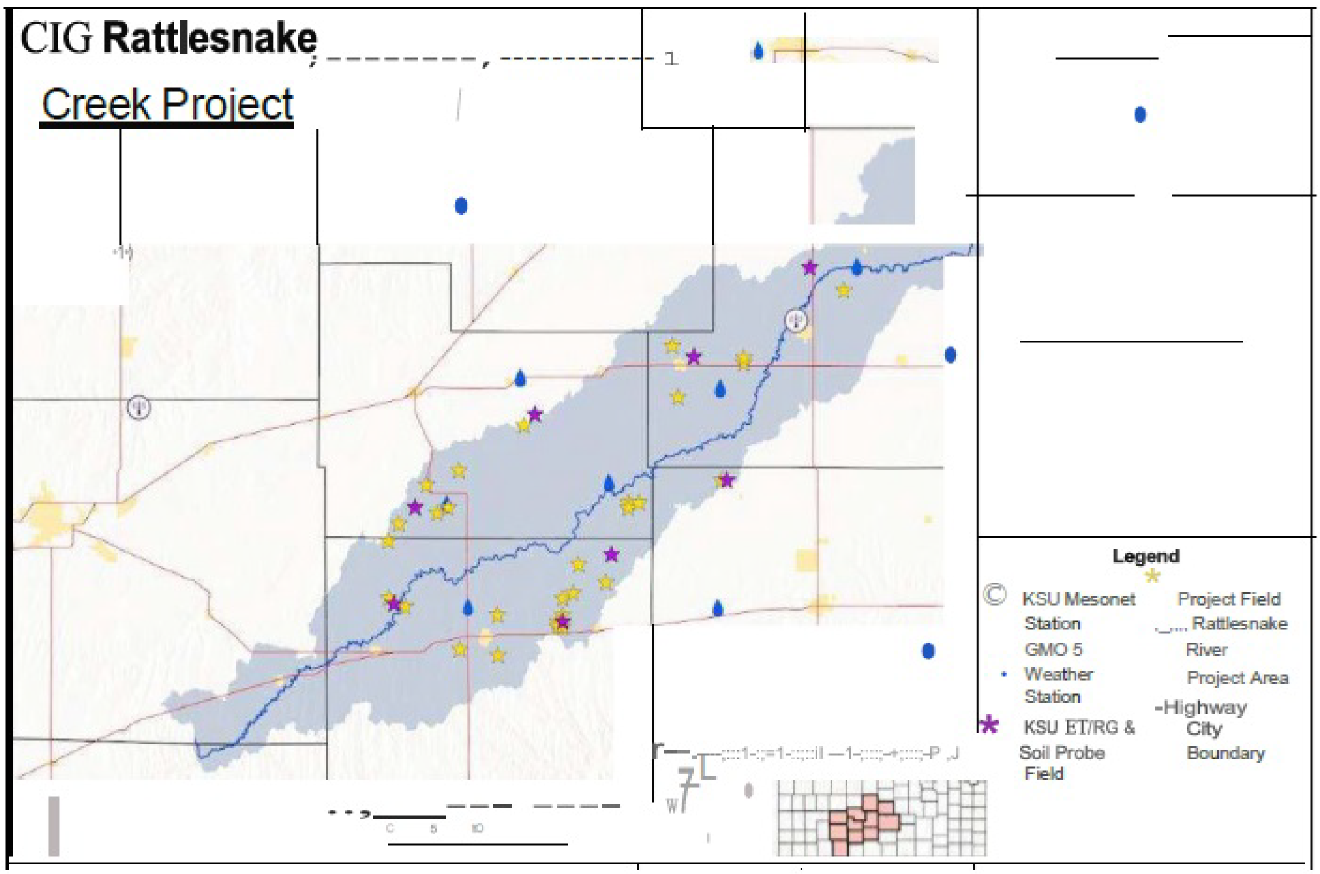


Figure I Participating fields and weather station locations in the study area.

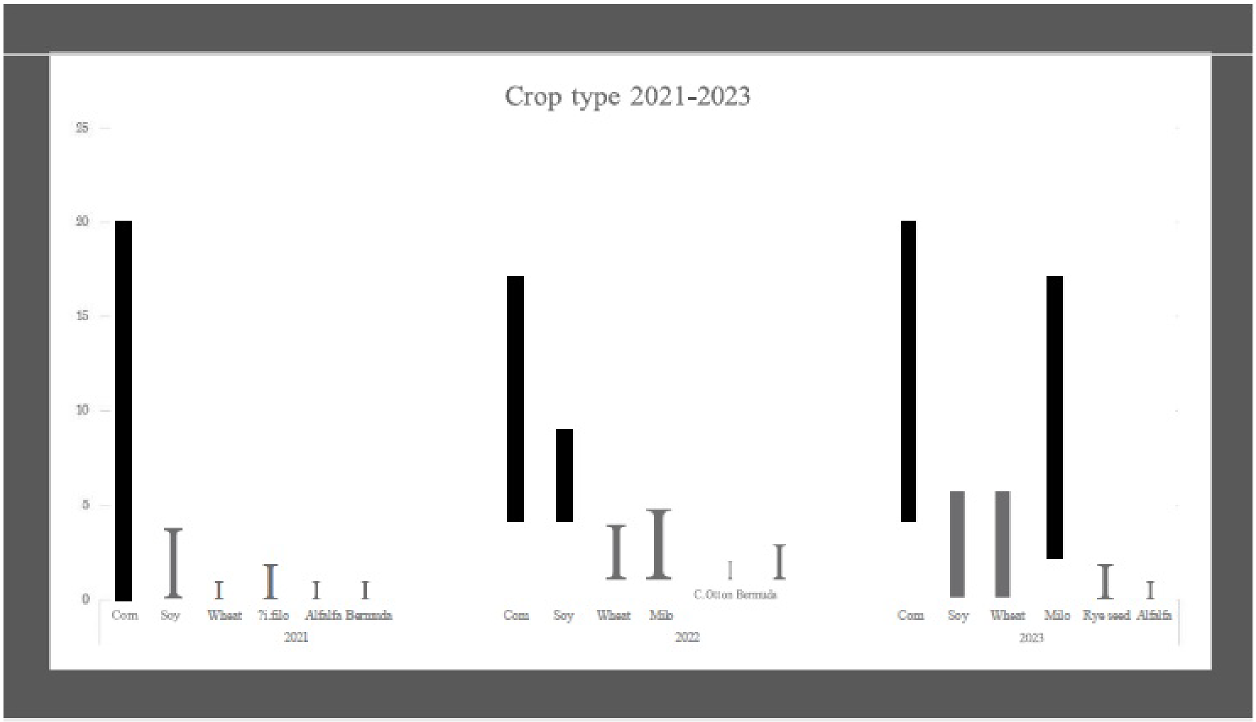


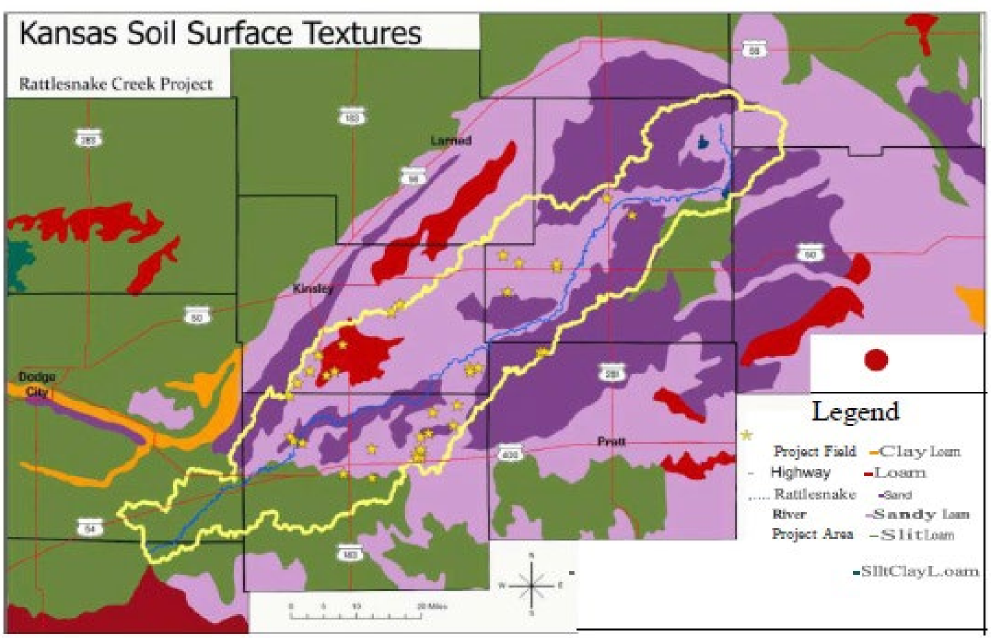
Figure 2 Crop type selection in participating fields during the project period.

Year and Crop	Average of WaterUse (AF)	Average of WaterUse (in/ac)	Average of Yield (bu/a)	Average of WUE (bu/ac-in)	Average of Effective Rainfall	Average of Potential ET	Average of Actual ET
2021	**167**	**15.4**	**206**	**13.6**	**10.24**	**26.5**	**22.2**
Corn	162	15.5	224	14.8	10.52	26.3	22.3
Soybean	193	14.9	121	7.7	8.93	27.2	21.7
2022	**190**	**17.7**	**139**	**7.3**	**3.82**	**28.7**	**22.1**
Corn	193	20.3	199	9.7	3.55	29.7	23.1
Cotton	126	12.4	nd	nd	1.24	26.6	21.8
Sorghum	92	7.5	4	0.5	2.47	16.3	11.8
Soybean	195	17.9	64	3.6	5.11	29.6	22.6
Wheat	250	10.3	70	10.0	nd	nd	nd
2023	**154**	**15.2**	**172**	**10.9**	**7.44**	**26.3**	**21.0**
Corn	161	15.9	223	14.1	7.40	26.4	21.0
Soybean	157	15.5	69	4.5	7.58	26.0	21.0
Wheat	100	9.9	nd	nd	nd	nd	nd
Averages	**174**	**16.3**		**10.2**	**6.83**	**27.4**	**21.9**

Table 1. Summary of Water Use for All Producers (excluding hailed fields)

During the project period, a few confounding factors changed how some of the participants farmed. Severe drought conditions in the basin in 2021 and 2022 caused increased water usage, as well as increased feed prices, influencing changes in crop type selection in the 2023 growing season (figure 2). Precipitation conditions over the project period are shown in Appendix 3. The Multi-year Flex Account (MYFA) program by the Division of Water Resources (DWR) was utilized by some participants. This allowed them to manage their annual water allocation across several years (typically three years). Despite the flexibility provided by MYFA, wells that have low capacity may still struggle to produce adequate irrigation water to realize normal crop production during a drought year. In addition to drought conditions, a notice from the state went out in early 2023 that outlined possible onerous federal water rights administration within the watershed related to non-attainment of necessary water levels in Quivira NWR. These factors created uncertainty and some inconsistency in practice adoption and crop type selection.

During the project period, we worked on 38 fields with varying cropping rotations. The major commodity crops were corn, soybean, cotton, sorghum, and wheat (Table **1).** Of these crops, corn and soybeans were the only crops that were present in all three project years. The years 2021 and 2022 were relatively dry years compared to 2023; however, the effective rainfall for 2023 was lower than expected due to the nature of the storms - high intensity rainfall that tended to run off the field. The average water use was during the much drier 2022 season where water use was recorded by the use of an increase of 2-in/ac compared to the other two years of the study. The total potential evapotranspiration for 2022 was 2-inches higher than the other years. Corn yield was relatively lower in 2022 (199 bu/ac) due to the drought, and actual ET values were about an inch different (21.0-22.2 inches).



Soil moisture: Both sandy and tighter clay soils are found in the Rattlesnake Creek Watershed, and soil type impacts irrigation needs. For example, sandy soils need irrigation to go 0.6 - 0.7 inches every 2 days, whereas clay loam soils can store more water in the profile (~I-inch every 4 days).

Figure 3 Soil surface texture and location of participating fields in the project area.

Soil moisture sensors also perform differently on different soils. Since most of the soil sensors in the market are capacity- type sensors, they are typically more robust in sandy soils devoid of the clay particles that affect the capacitance signal. Although soil moisture sensors were aggressively promoted to the farmers, the majority were not really using soil moisture sensors effectively. Part of the reason is the learning curve associated with this technology, plus a lack of trust in the soil moisture readings. It was only during the second to third years of the project that we saw farmers starting to use the sensors more.

Technology Users								Non-tech users						
Year and Crop	Avg. of Water Use (AF)	Avg. of Water Use (in/ac)	Avg. of Yield (bu/a)	Avg. of WUE (bu/ac -in)	Avg. of Effect ive Rainf all	Avg. of Total ET	Avg. of Actua l ET	Avg. of Water Use (AF)	Avg. of Water Use (in/ac)	Avg. of Yield (bu/a)	Avg. of WUE (bu/ac -in)	Avg. of Effect ive Rainf all	Avg. of Total ET	Avg. of Actua l ET
2021	**138**	**12.4**	**187**	**15.3**	**10.11**	**26.4**	**22.4**	**175**	**16.2**	**211**	**13.1**	**10.28**	**26.5**	**22.2**
Corn	146	12.9	212	17.0	10.17	26.3	22.4	166	16.2	227	14.2	10.61	26.3	22.3
Soybean	105	10.4	87	8.4	9.84	26.8	22.4	223	16.3	132	7.4	8.63	27.3	21.5
2022	**173**	**16.6**	**98**	**5.8**	**4.02**	**29.6**	**22.7**	**202**	**20.7**	**177**	**8.5**	**4.03**	**29.7**	**23.0**
Corn	165	18.2	137	7.7	3.25	29.9	23.4	201	20.9	216	10.3	3.63	29.7	23.0
Soybean	180	15.1	60	3.9	4.80	29.4	22.0	206	20.3	68	3.4	5.41	29.8	23.2
2023	**172**	**16.7**	**178**	**10.9**	**7.37**	**26.6**	**21.3**	**158**	**15.5**	**170**	**10.9**	**7.44**	**26.3**	**21.0**
Corn	162	16.0	231	14.5	7.37	26.6	21.3	161	15.8	221	14.1	7.40	26.3	21.0
Soybean	192	18.3	72	3.9				150	14.9	69	4.7	7.58	26.0	21.0
Averages	**162**	**15.3**	**141**	**9.7**	**6.44**	**28.3**	**22.5**	**180**	**17.7**	**187**	**10.8**	**7.23**	**27.6**	**22.2**

Table 2. Summary statistics on corn and soybean fields during the project period.

We designed our project to capture sufficient data to detennine whether soil moisture sensor use can help improve irrigation water use efficiency. However, due to soil type differences, well capacity, weather events, farmer's action and other factors, data sets had too many variables to make consistent comparisons. Another factor, as pointed earlier, is the different adoption stages of the cooperators. We need a longer time frame to see the effect of the management decisions made by farmers during the project. However, stories from a few cooperators do show its usefulness particularly when there are rainfall events. Soil moisture sensors tend to be useful when rainfall events are either in the forecast or have just occurred. Knowing when to stop or start irrigation is key to improving irrigation efficiency.

Data collected was inconclusive on the impact of technology to either water use or yield. In our discussion with team members and farmers, it was noted that this was likely related to differences in comfort level and the skill of farmers using the new technology. Farmers varied in their eagerness to use and incorporate the technology in their management decisions. We need more years of data to show an impact in their water use and efficiency attributable to their use of the technology. Another reason was that when a farmer controlled multiple fields, if one had a sensor and raingauge, irrigation decisions based on that instrumentation were often applied to additional fields lacking those technologies.

Importance of Technical Assistance: One of the assumptions coming into the project was that the majority of the irrigation systems we would encounter would be in good working condition. We were wrong in this assumption. More than 53% of the system evaluations showed one or two parameters had minor to major adjustment problems resulting in either non-uniform application of water or the system is not efficient enough that the farmers are paying more for their irrigation system. Some of the issues needed follow-up adjustment or continued reassessment. One of the outcomes from this project is the demonstrated need for continued technical assistance or education to assist producers with keeping their irrigation systems efficient and effective.

Irrigation technologies are continuously evolving and improving. However, some of these changes are not always perfect, seamless and effective. In this project we helped identify improvements, bridging the gap between technology/data providers and producers, and through repeated contact and assistance, our team members became the trusted advisors of the users/producers. Good examples of conveying information from the field to the technology providers were the adjustments that were made to Autonomous Pivot, KanSched, Netafim PMDI, and K-State Mesonet based on producer feedback. Adoption level and learning process, both for young and old producers, new and existing users, are expected to improve due to the technical assistance provided during this project.

Although our data sets were too short and variable to draw general conclusions about the performance of irrigation system technology, this project did produce invaluable information on what worked and what didn't work on individual operations. Producer experience informed their future technology adoption decisions, including increased use of technology, selecting different technology better suited to their operation, or rejection of new or additional technologies. Crucial to adoption is the support provided at the individual level and for an extended period of time. During the four years this project was operational, with bi-weekly visits to the farm, frequent interaction between team members and producers, reviewing end-of-year crop and water management results annually, facilitating communication between team members, producers, and vendors, and showing a dedicated interest in assisting producers with their irrigation system improvements resulted in a successful project. While assistance during the first year is critical, continued assistance in various forms spanning years are needed to transform thinking and technology familiarity and lead to true and enduring improvements in irrigation management. Short term projects will likely be ineffective and frustrating for all involved. Building trust takes time and consistent effort but is the most effective way of supporting technology adoption.by producers. By the end of the project, the most rapid changes were occurring, the most interest was being expressed, and the most skill in supporting the producers was being offered. Without funding for additional years, this favorable forward momentum will be lost. Early adopters were carefully, if informally, observed and their success evaluated by other producers who then made the decision to adopt new technologies. We found that younger producers were most likely to suffer through learning pains and other obstacles to become more proficient irrigators.

Using rainfall beneficially: Rainfall received by each participating field during the growing season tends to be highly variable. This is typical in the region. We used KanSched graphs post-growing season to demonstrate the difference between rainfall received and effective rainfall (the amount of rainfall available to crops). By leaving room in the soil moisture profile (ie. keeping a field below pore-space saturation but above maximum allowable depletion), effective capture and use of that rainfall increased and surface runoff decreased. Our outreach promoted that irrigation scheduling is not just the process of when and how much water to apply, but rather the process of delaying any unnecessary irrigation with the hope of increasing effective rainfall. We saw this play a major role in the cropping practice of some participants, but across the fields, it did not show significant numerical differences on users and non-users of technology. For example, field D1 decreased irrigation by about 4.8 inches during the growing season, and by doing so increased the effective rainfall from 7.63 to 10.0 inches. It's a win-win scenario both on the pumping cost and groundwater withdrawal, but also on capitalizing the rainfall when it falls. Example KanSched graphs (developed post-season) are shown in Appendix 7.

Economic evaluation: One of the parameters that this project would like to promote going forward is the change in the focus from yield per unit area, to yield per unit water used (e.g. bu/ac-in) also known as water use efficiency (WUE). This parameter is central to the economic evaluation since the goal is geared towards more efficient and effective use of irrigation water in relation to the yield. Though the WUE difference was non-evident between the technology user and non-users over the years, based on our conversations during one-on-one meetings, individual farmers were able to gauge their conservation performance across all their fields using this parameter. This encouraged them to improve their operation, maintenance and agronomic management.

Interestingly, when comparing the energy use of tech users and non-tech users, it showed a numerical difference (Table 3). Across all years in com and soybean fields, tech users have lower cost of energy use of $1,600 or about $3.60/AF. This one parameter can justify the cost of using irrigation technology in the field.

Table 3. Cost of Energy between technology users and non-technology users.

	Avg of Water Use (AF)	Avg of Water Use (in/ac)	Avg of WUE (bu/ac-in)	Avg of Effective Rainfall	Avg of Actual ET	Avg of Energy Use Cost	Participants
Tech Users							
2021	137.98	12.43	15.26	10.11	22.42	$4,745	5
Corn	146.15	12.94	16.98	10.17	22.43	$4,938	4
Soybean	105.3	10.41	8.4	9.84	22.4	$3,974	1
2022	172.76	16.65	5.79	4.02	22.73	$5,553	8
Corn	165.48	18.24	7.68	3.25	23.44		4
Soybean	180.05	15.05	3.9	4.8	22.02	$5,553	4
2023	171.93	16.73	10.94	7.37	21.3	$5,739	3
Corn	161.85	15.95	14.45	7.37	21.3	$3,588	2
Soybean	192.1	18.3	3.93			$10,040	1
Subtotal	**161.74**	**15.35**	**9.71**	**6.44**	**22.52**	**$5,346**	**16**
Non Tech Users							
2021	175.43	16.21	13.08	10.28	22.18	$6,071	18
Corn	165.97	16.19	14.22	10.61	22.32	$5,505	15
Soybean	222.73	16.34	7.4	8.63	21.47	$8,900	3
2022	202.24	20.72	8.48	4.03	23.03	$7,141	19
Corn	200.77	20.89	10.3	3.63	22.98	$7,349	14
Soybean	206.34	20.26	3.4	5.41	23.21	$6,558	5
2023	157.55	15.54	10.95	7.44	20.99		15
Corn	161.08	15.84	14.09	7.4	21		10
Soybean	150.48	14.94	4.67	7.58	20.98		5
Subtotal	**180.07**	**17.67**	**10.79**	**7.23**	**22.18**	**$6,606**	**52**

Objective 2: In the proposal, we indicated that we were going to work on an ET-based irrigation scheduling tool like KanSched. Unfortunately, when we were using the KanSched web version, we noticed several issues on the program affecting both the performance and accuracy of the tool. As we were troubleshooting, it became apparent that some of the issues were related to the server (electric surge damaged portions servers and upgrade compatibilities), some are from coding glitches, and a few are related to the updates of the coding language and compatibility of a couple of modules (graph and summary). The combination of these issues created a major setback in utilizing KanSched during this project. By the time we were able to fix the bugs, farmers are ready to move on to the next level of scheduling tools (true mobile app experience, automatic input of ET and rainfall values, and automatic notifications), which are beyond the scope and capability of our current resources. Although KanSched was not adopted by any of our producers during this project, we still used the KanSched platform to summarize the results on water use. We utilized multiple versions of KanSched to run the seasonal water use for each field (Appendix 7).

This issue has opened up conversations across multiple states (WERA1022), since many universities are also having difficulty maintaining irrigation scheduling tools for producers to use. In most cases, due to a project, a tool is developed but after the project expires, updates on the tools are rarely implemented until software/technology upgrades outpace the useability of the tools. Under that scenario, KanSched is the only tool, to our knowledge, that has outlived most of the other university-maintained irrigation scheduling tools.

KanSched or similar irrigation scheduling tools need to be updated to catch up with the standards and expectations of the users, the irrigators. Its current version works well for applied research but is not appealing to farmers who demand for more advanced technology.

3-year findings

- 2-3" (20-30 AF) reduction in application (average per field) is possible and significant for this region if more fields adopt our approach.
- Higher flow rate= higher tendency to over-irrigate
- MDI is recommended for lower capacity wells, and can get water 1-2" deeper into the root zone than conventional nozzles. MDI has the greatest water-savings potential in early crop growth stages.
- Pressure regulators wear out over time and can increase flow rate up to 25%, unevenly.
- Irrigation scheduling can produce significant water savings if producers are willing to keep their soil water below field capacity (but above maximum allowable depletion). However, this requires trust in the monitoring technology and ET calculations, and often goes against the advice of crop consultants.
- Technology can help save water, but it is ultimately dependent on how producers use the technology and manage their water.
- Field-specific precipitation data is important.

Objective 3: *Irrigation attitudes surveys* - Detailed results and discussions of our surveys are available in the publication referenced in the Methods (Sampson et al., 2024).[1] There were 140 surveys returned either fully or partially filled out by irrigators in our study region, out of 1,148 documented water-rights holders who received mailings. When asked about technology utilization, nearly 90% of respondents reported using crop consultants and nearly two-thirds use remote pivot monitoring. Approximately one-third of respondents use soil moisture probes, and less than one-third use aerial imagery or other forms ofremote sensing technology, variable frequency drives, variable rate irrigation speed control, or rain sensors. We asked irrigators to identify the three most important considerations when choosing to make changes to their irrigation or cropping system (Panel A, Table 2 in the publication). The three most frequently chosen considerations were the potential for increased income generation (78%), need for greater irrigation efficiency (69%), and availability of farm labor (34%). Positive or negative experiences of peers was chosen by 29% of respondents. Other questions address implementation of conservation practices, and barriers and challenges facing producers. Survey respondents near unanimously viewed regulatory uncertainty, including the risk ofreduced allocations, as a top concern confronting the future of irrigation in the region. Drought, energy costs associated with operating pumping plants, and reduced pumping capacities were also highly cited as irrigation challenges and concerns. Crop consultants, the producer's own past experiences, and peer producers ranked the highest in terms of reliable provision of information. Equipment dealers, trade groups, and state agencies ranked the lowest in terms of reliability.

Workshops and field days - Field days and outreach events were delayed in 2020 and 2021, due to the COVID pandemic. We held 3 field day events, hosted peer networking sessions at WaterPACK annual meetings, and presented our progress annually at the Governor's Conference on Water and the Future of Kansas.

The field day on August 20, 2021 featured mobile drip irrigation. A breakfast meeting in the farm shop featured an hour of short presentations followed by a short walk to a nearby corn field where a project participant displayed his pivot modifications and talked about the success and challenges he encountered with the new technology. Field day participants observed first-hand how the mobile-drip system pulled through the crop.

The July 22, 2022 field day featured short talks on water conservation and producer experiences, followed by a demonstration of irrigation technology on project participant's adjacent field. K-State presented a booth demonstrating various nozzle configurations in operation to display water droplet patterns.

[1] Sampson, G. S., Aguilar, J., Baldwin, C., Davidson, J., & Mehl, H. (2024). Water Management and Information Gaps in the High Plains Aquifer. Journal of the ASFMRA, 2024, 116-129. The publication is available for free from AgEcon Search (http://ageconsearch.umn.edu).

Figure 4 Field day in July 2022

In order to reach a broader audience, project team members set up booths at the Kiowa and Stafford county fairs in July 2023. The booths featured irrigation technology publications, a photo slideshow, and displayed a pivot model,an evapotranspiration gauge and rain gauge. They talked to the producers and general public about the irrigation innovation project, then in its final year, and answered and responded to water or technology questions and comments.

On December 6, 2023, after the end of the last field season, the project team hosted a peer-networking dinner. Two project participants shared an honest, straightforward account of their innovative irrigation technology adoption experience. The described unexpected challenges, the need for workarounds as they implemented the technology, how it related to the rest of their operation, impact on crop yields, and other management considerations. Both participants reported feeling positive about their experiences, and also reported an intense learning curve facilitated by the TA provided on the project.

It is worth noting that many participating producers communicated a belief that the peer network might be the most important part of the project. They enjoyed sharing their experiences, and saw an opportunity to avoid wasting time and money repeating others' mistakes. They also saw an opportunity to change the community culture to one in which they lean on each other instead of competing for the best yield. Younger farmers are learning and trying new things, and the peer networks gave them a space to ask neighbors for advice.

After the end of the last growing season, we asked each of our participating producers two questions:

1. Will you continue using the technology you acquired through this grant- and/or which part of the tech will you continue?
2. Would you recommend the tech you have to others?

Every participant except one answered yes to both questions. Some provided the caveat that it will depend on future water administration and potential cuts. Two participants mentioned that the new technology is not feasible without cost-share. Some notable quotes:

"I will be using the sprinkler package tech and knowledge in the future and it is helping me improve my future projects even at full price. The Autonomous pivot is still too pricey and I'm not sold on it enough to pay full price yet. I think emerging technology is still cost prohibitive to adopt without cost share so this type of project is very vital to trying out new tech and getting useful ones discovered. "

"Yes, I will keep using the probes, pressure transducers, and watch flow rates to try and catch problems before they become problems. Yes. I've already had the opportunity to show one of my neighbors the

value of the transducers. He is renozzling a pivot right now because of pressure issues I was able to show him. Thanks for all your work making this a success."

"We will definitely keep using the mobile drip lines and keep adding pressure transducers to the other systems. I didn't really find the moisture probes that helpful. We are relying on crop scouts for that piece. I would definitely recommend the tech to others. The networking with you guys was also super informative."

"I do feel like mobile drip has a place to fill when growing row crops. The water savings are real. Especially for deeper rooted ones like corn or cotton. On soybeans 15" or 20" spacing of drip lines would be preferable due to the shallower rooting tendencies of them."

Objective 4: We synthesized all of our data, experiences, and observations into a 7- step toolbox. Our intention is for this toolbox to be adopted by other communities trying to minimize groundwater withdrawals and sustain local aquifers. The full toolbox is available in Appendix 6.

Project Outputs :

- Publications: A full list of publications produced for this project is provided in Appendix 5.
- Media: Groundwater Management District #5 is hosting a webpage dedicated to this project, including links to publications and other resources. https://gmd5.org/rsc-irrigation-innovation
- Kansas State University developed outreach and training materials for KanSched that will remain available online. https://www.youtube.com/channel/UCtgMYlNkJ_ri6tsvWD148OO
- Conference attendance and presentations:
    - November 18th, 2021. "Rattlesnake Creek Irrigation Innovation Project: Creating fresh approaches to water use efficiency for communities and wildlife." Governor's Conference on Water and the Future of Kansas. Virtual.
    - March 15, 2022. Project update and peer networking, WaterPACK annual meeting. Greensburg, KS.
    - February 20, 2023. Project update and peer networking, WaterPACK annual meeting. St. John, KS.
    - March 7, 2023. "The Rattlesnake Creek partnership." Invited Testimony, Kansas Legislature, House Committee on Water. Topeka, KS.
    - November 16th, 2023. "Creating Fresh Approaches to Water Use Efficiency for Communities and Wildlife in the Rattlesnake Creek Basin." Manhattan, KS.
    - February 28, 2024. Project update and peer networking, WaterPACK annual meeting. St. John, KS.
- Outreach events:
    - August 20, 2021. "Mobile-drip irrigation field day." 23 attendees.
    - July 22, 2022. "Irrigation Innovation field day." 17 attendees.
    - July 18-22, 2023. Stafford County fair booth.
    - July 26-August 5th, 2023. Edwards County fair booth.
    - December 6th, 2023. End-of-project producer appreciation dinner and peer network. 20 attendees.

Project Impacts:

This CIG project exceeded expectations by enrolling 21 producers on 38 total fields for participation. Each field benefitted from technical assistance with system maintenance and upgrades, and new monitoring and application technology. Each field represents approximately 130 irrigated acres, for a total of 4940 total impacted acres.

Our outreach and peer networking has also created new connections between producers in the community. As we continue to work in this area, we will continue to monitor these connections and provide opportunities to expand the network.

Because of the success of this project, the personnel involved have become trusted advisors for the agricultural community and for state agencies. We have been approached for program guidance by the Kansas Water Office, and the Division of Conservation. Both of these agencies have incorporated our approach and our toolbox into their own programs working in other areas of the High Plains aquifer. We have also been consulted by the Governor's office as they build out a long-term plan for water in the state of Kansas.

The project team is committed to continuing our work in the project area and beyond. We will continue to work with our participants, supporting their practice adoption and monitoring their outcomes. Potential next steps include expanding this work to include cover crops and other soil health practices. We also see an opportunity to work with crop consultants to incorporate our approach into their recommendations. Finally, we are planning a videography project to capture knowledge from the older generations to provide advice and insight for younger generation farmers.

Appendix 1 - Program Technical Assistance Flyer

Requirements: Must be located in the Rattlesnake Creek watershed and producer must be EQIP-eligible.

Program Options

	Level 1				Level 2					
	Base Technology				Base Technology (Level 1) + Irrigation System Improvement (select 1 below)					
Description	-Center pivot with real-time monitoring -Continuous rainfall monitoring -Aerial imagery -KanSched -Sensor Sensor Options				Mobile drip irrigation-full conversion		Mobile drip irrigation- hybrid	System package improvement		
		Soil moisture sensor	Plant based sensors	Autonomous pivot system	Circular planting	Straight row planting	MDI on first 2 spans only	Bubble with shroud	Moving pad	Fixed pad
Estimated Cost	$5,000-$12,000				$25,000-$30,000		$13,000	$17,400	$8,600	$7,400
50% cost share available for all levels and options subject to availability*										
Brand/ Model/ Type Examples**	Agsense FieldNet Watchdog Ceres	AquaSpy Trellis	Phytech	APS	Dragon-Line Precision Mobile Drip Irrigation			Senniger Nelson Komet		
# Available	10	35			3	3	5	2	10	2

*A maximum of 3 technology systems (Levels 1 & 2) per entity or agricultural producer will be funded through this project.

**Suggested suppliers sell equipment useful for irrigation. Brand names are for product identification purposes only. No endorsement is intended, nor is criticism implied of similar products not mentioned.

ANALOGY

Sandwich		Hamburger			Topping Available for Additional Cost					
Cheese					Cheddar	Monterey Jack	Provolone	Pepper Jack	Brie	American
Bun		White	Wheat	Pretzel						

Reduce irrigation costs • Save money • Increase water use efficiency

Appendix 2 - Data collection table

RATTLESNAKE CREEK

Irrigation Innovation Project

Data Collection

To evaluate the effectiveness of your installed irrigation technology package, the following data will need to be collected for the 3 years both pre- and post-installation (total 6 years).

Reporting Period	Data Type	Description
Initial	System Design	Pivot/sprinkler design specifications
	Power type*	
	Soil type	
Annual	Cropping History	Type of crop/cover crop planted
		Acres Planted
		Emergence date
		Days to maturity
		Crop yield
		Tillage practices
	Applied Water	Initial soil moisture
		Water quantity applied to cover crop, if any
		Annual water use report
	Power	Annual pumping cost
	Precipitation	Measured rainfall at field (if available)
		Annual precipitation
		Growing season rainfall
Weekly	Applied Water	Amount of water applied
		Measured rainfall at the field
Other	Survey	Survey 1
		Followup Survey 1
		Followup Survey 2
		Survey 2 (final)

Appendix 3 - Drought observations

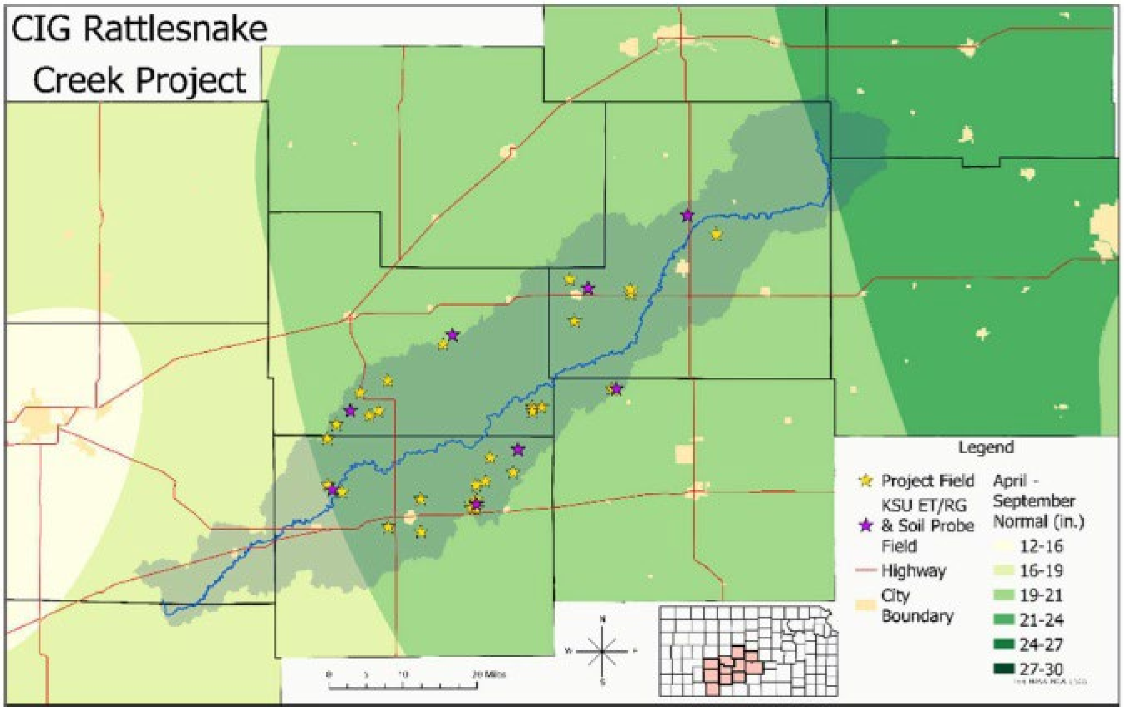


Figure 5: Normal precipitation across study area

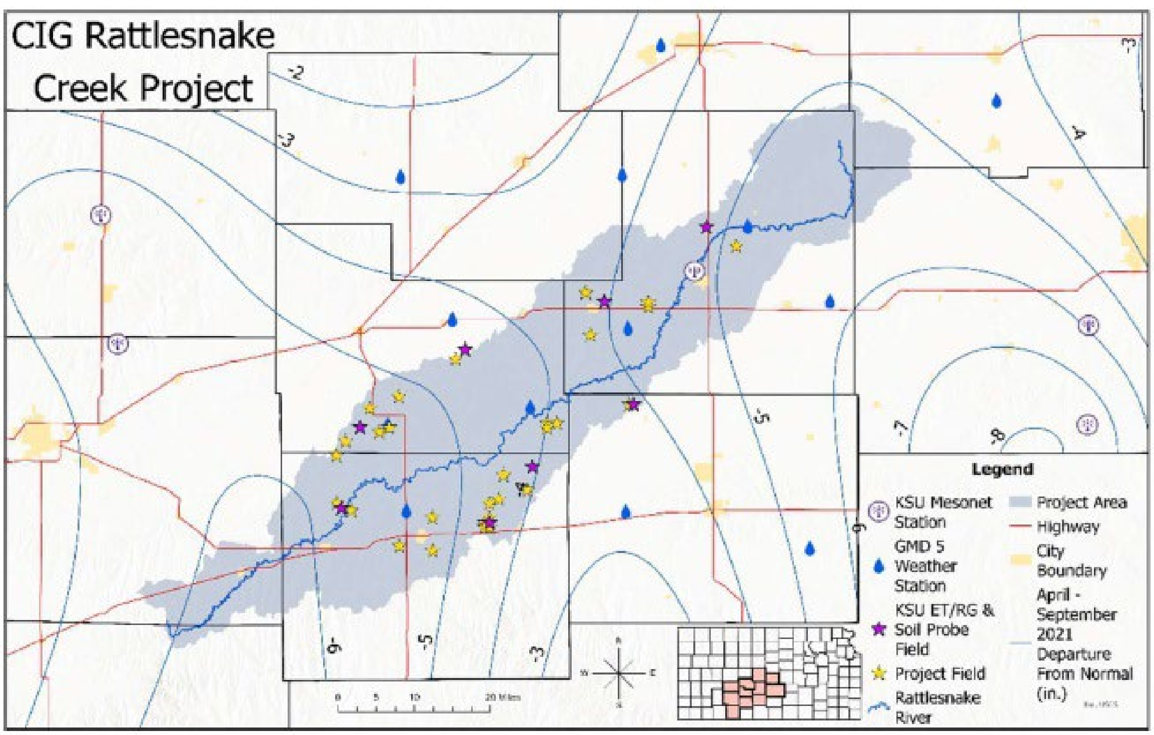


Figure 6: 2021 Departure from normal precipitation

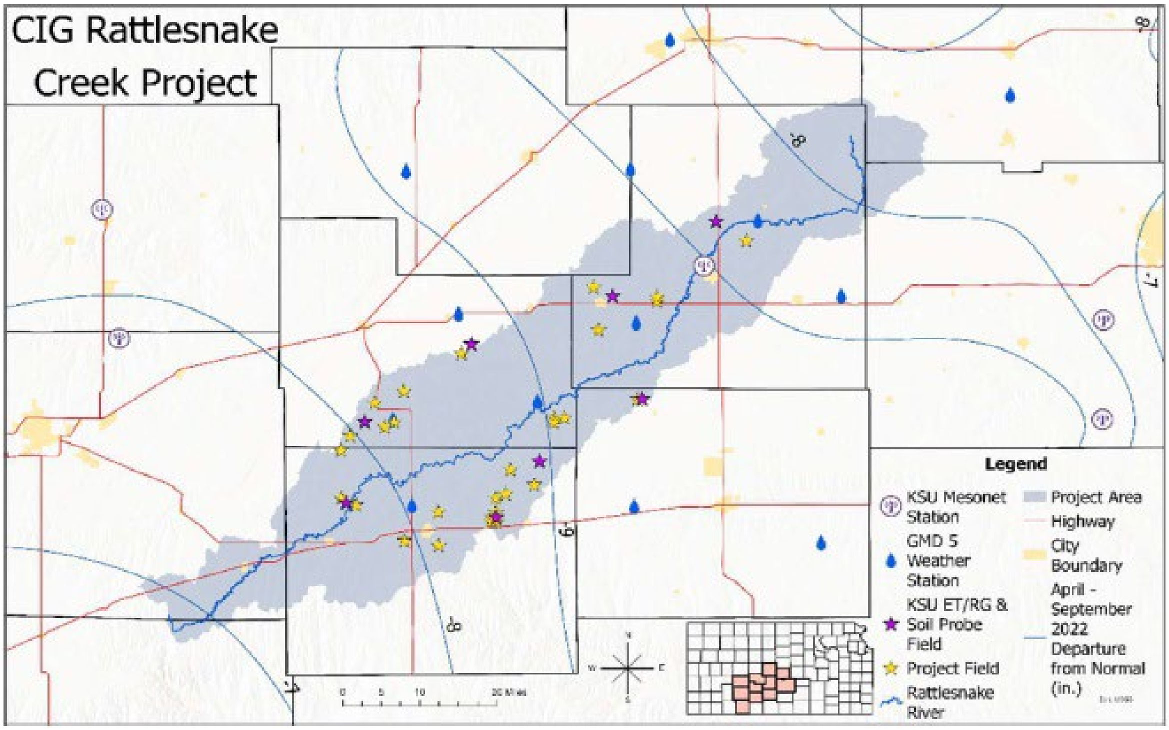


Figure 7: 2022 Departure from normal precipitation

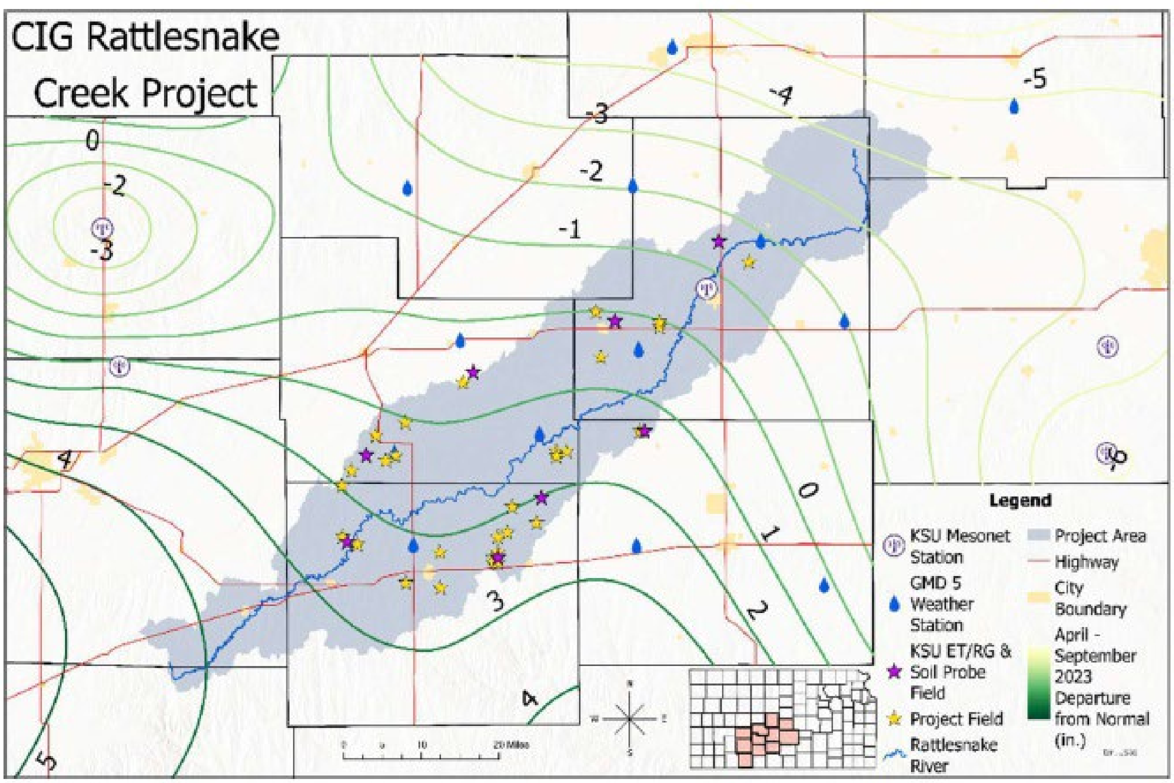


Figure 8: 2023 Departure from normal precipitation

Appendix 4 - Data summary tables (DataSummaryMay2024.xlsx)

Separate file

Appendix 5 - Publications review

During the nearly 4 years of the CIG project, two publications were written specifically for the project, and several other related publications were co-written by member of the project team.

1. Water Management and Information Gaps in the High Plains Aquifer.
   https://search.ebscohost.com/login.aspx?direct=true&profile=ehost&scope=site&authtype=crawler&jrnl=0003116X&AN=177889120&h=Tx5m8wXyLqsPlempU%2FQYfmSwcfjWWdFz03VFxzYiQfKBnoElaqjKSuDlvHWnGJRmnpx60X8UKby4RHvz10f4sg%3D%3D&crl=c

   What motivates irrigators to become more efficient? What information would be useful in helping them move towards a more efficient operation? Are there circumstances or challenges that are difficult to surmount? With the help of a focus panel comprised of irrigators and project staff, an eighteen question survey was developed and mailed to all water rights holders in Ground Water Management District 5 (GMD5), where project activities were focused. Key insights included the widespread use of remote pivot monitoring and crop consultant. Other remote technologies were much less common. Income generation, irrigation efficiency, and less reliance on farm labor were most frequently listed as motivators. Barriers to new technology adoption included cost of new or refitted equipment, the need to maintain historical water use to protect against future water allocation reductions, and a lack of information on return-on-investment for new practices. Conservation practices were most often use to reduce soil erosion and improve water utilization. Key concerns were regulatory uncertainty, lack of water in the aquifer, and impaired water quality. Personal challenges were most often connected with drought, future water allocations, fuel costs, and aging equipment. Information needs included interpretation of agency programs, selection of remote sensing equipment, evaluating the need for pumping plant upgrades, and expected benefits of implementing conservation practices. Crop consultants were most often cited as the main source of information.

2. Interpreting and Using Center Pivot Sprinkler Designs
   https://archive.gmd5.org/Misc/CIG/CP_Sprinkler_Designs.pdf

   Center pivots come with a full set of design specifications that cover not only original setup, but provide operational information too that can be useful during the life of the pivot. Over time, modifications, repairs, and adjustments are likely to be made that negatively affect pivot performance, especially as deviation from the original specifications increases. These will affect how and how much water is applied, affecting irrigation efficiency and crop performance. This four-page Extension document assists irrigators with understanding how their pivot should perform, and where to find key information in the specifications to adjust their pivot back to its designed performance level.

3. Soil Moisture-Sensing Systems for Improving Irrigation Scheduling
https://archive.gmd5.org/Misc/CIG/BAE-1543.pdf
Tips on Selecting a Soil Water Sensor
https://archive.gmd5.org/Misc/CIG/Soil_Water_Sensor_Tips.pd[

   Applying irrigation water only when needed is key to irrigation efficiency. Soil moisture sensors can improve irrigation scheduling decisions and the efficacy of water applications. Selecting a soil moisture sensor involves considerations of soil type, number of sensors to install, installation location and method, how often data will be collected, formatted, and accessed. This four-page Extension publication describes the options available and deployment of soil moisture sensors. A related one-page fact sheet lists additional selection considerations.

4. Accessing ET for Kansas Irrigation Scheduling
https://archive.gmd5.org/Misc/CIG/Accessin g_ET_Irrigation_Scheduling.pd[

   Irrigation application timing is closely tied to weather conditions that affect plant growth and development. Evapotranspiration is used in weather-based irrigation scheduling systems to identify when plant and soil conditions are likely to benefit from irrigation. This brief Extension publication walks through the steps to find web-based ET information for use in irrigation scheduling.

5. Costs, Benefits, and Limitations oflrrigation Management Technologies
https://archive.gmd5.org/Misc/CIG/Irrigation_Management_Techniques.pdf

   Irrigators can often improve their water efficiency through use of new technologies, but want to know that the benefits outweigh the costs incurred. Four irrigation tools are evaluated in this 6-page publication adapted from the Ogallala Water project, gives an overview of four commonly used tools: weather stations, irrigation scheduling, soil moisture sensors, and remote irrigation system management. Trade names are provided along with a chart comparing the advantages and benefits of each tool with its costs and limitations. A list of publications providing additional information on each topic is also provided.

6. Sampson, G. S., Aguilar, J., Baldwin, C., Davidson, J., & Mehl, H. (2024). Water Management and Information Gaps in the High Plains Aquifer. Journal of the ASFMRA, 2024, 116-129. The publication is available for free from AgEcon Search (http://ageconsearch.umn.edu).

Water is a critical input to agricultural production in arid regions. Understanding irrigator perspectives and determining their information and technical needs are critical to increasing water conservation while maintaining profitable yields. This paper summarizes survey data for 140 irrigators operating in the High Plains Aquifer portion of south-central Kansas.

We document adoption of different farm management practices, key challenges facing irrigators, information gaps, and qualitative information obtained from open- ended questions. Survey response patterns are discussed in the context of local water use conflicts and water governance.

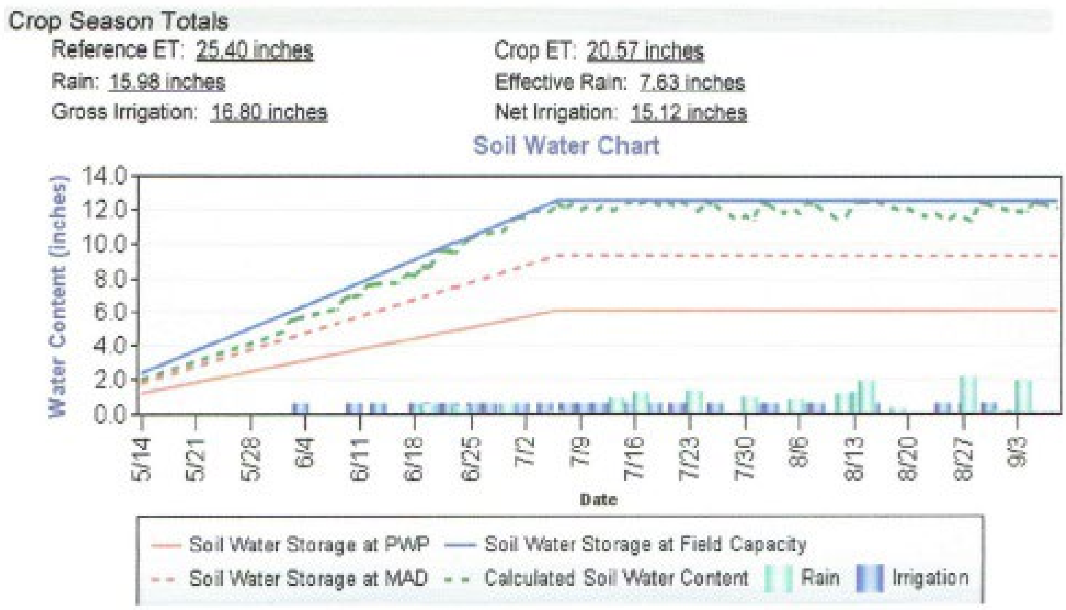
Appendix 6 - Toolbox for achieving efficient irrigation

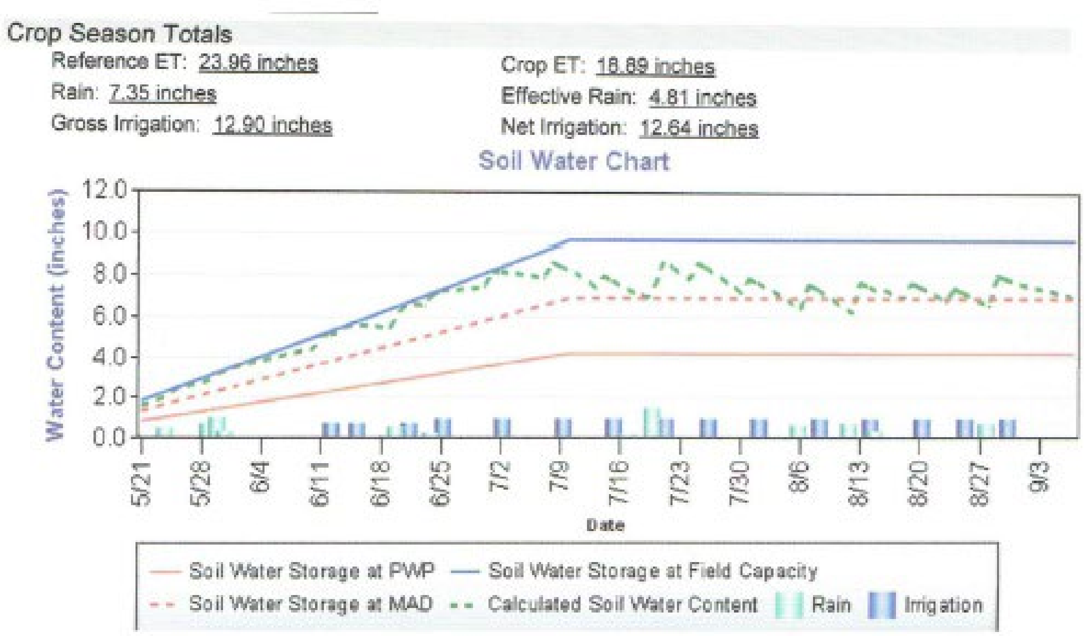
1. Make sure that your **irrigation system** is running at its **optimum condition**
   a. Do a baseline testing of well, pump and irrigation system
   b. Compare flow rate and pressure (psi) with Sprinkler Package Design
   c. Don't assume regulators perform as new
   d. Re-orifice package, adjust impellers, speed up pump engine, modify generator pulley as needed to get 480 Volts
   e. If the well can sustain the yield, reduce pivot flow rate to 5.4-6.7 gpm/acre (~0.27-0.33 in/day) for most row crop application
2. **Evaluate opportunities** for better water use
   a. Create All-Farm Water Use spreadsheet
   b. Group water use by crop
   c. Focus on yield per unit water used(bu/ac-in) or crop water use efficiency (WUE)
3. **Apply water evenly** in the field
   a. Maintain End Tower pressure 5 psi more than regulator setting
   b. Monitor center pivot end tower pressure (e.g. Ag Sense, FieldNet, Field Wise, etc.)
   c. Evaluate the seasonal graph of pressure and position (psi vs. angle 0-360)
   d. Use Aerial Imagery to monitor for crop development and sprinkler patterns, soil challenges, fertility issues, runoff, excess rain, etc.
   e. Increase last 3 sprinkler flow rates on overhang to apply water more evenly after removing end-gun
   f. Close the drain hoses at the end of the tower when running, and add purge valve if needed
   g. Avoid using butterfly valve at pump discharge
4. **Soak it in** where it is placed
   a. Improve infiltration at soil surface
   b. Increase wetted footprint where you see runoff (e.g., overhead sprinklers = 80 ft. vs. bubblers = 3 ft. wetted diameter); Use moving plates and space drops closer together whenever possible
   c. Use other practices such as cover crops, green manure crops, and dammer-diking to reduce runoff
   d. Minimize big droplets-impact erosion at soil surface
   e. Use outrigger booms at towers and overhang to increase wetted footprint
   f. In many cases do not go below 10 psi regulators to maintain moderate droplet size
   g. Use truss rod hose clips to widen wetted footprint
5. **Slow pivot down** to apply 0.8-1.2-in. depth irrigations if possible unless significant runoff occurs or in very sandy soils
   a. Improve portion of irrigation water entering root zone (application efficiency) by reducing "Service Factor" (i.e. loss ofE on ET; can be ~0.17 in.) per irrigation event
   b. Consider 3-4 days irrigation frequency, unless sandy soils, then 2-2.5 days
6. **Make better use of rainfall**
   a. Measure rain at field. Use tipping rain gauge with telemetry if possible
   b. After a rain event, re-establish moisture lag of 2-4 day irrigation cycle through progressive watering (i.e., move fast when starting then gradually slow down [in incremental pies] to finish the cycle)

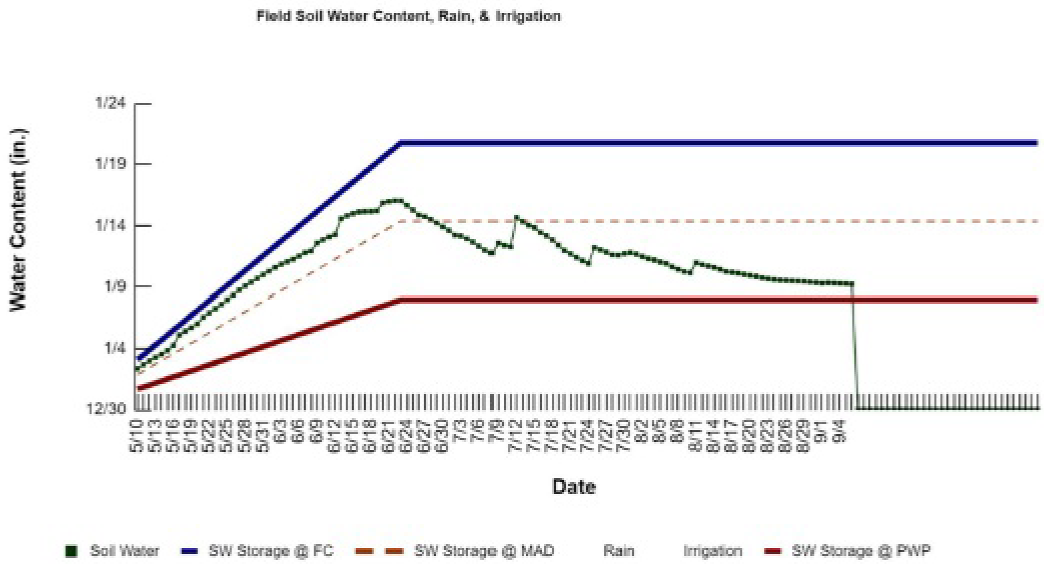
    c. If conditions allow, hold off irrigation if high probability of rainfall is in the forecast

7. **Properly schedule your irrigation**
    a. Use the same **start/stop** position near pivot road
    b. Use a checkbook budget like KanSched and Autonomous Pivot, to determine when to irrigate and how much
    c. Use Soil Moisture or Plant Based sensors with Telemetry to "close the loop"
        1. Install on "start" side of pivot start/stop position
        2. Install on soil type with lower water holding capacity, if prevalent

Appendix 7 - KanSched graph examples






Field Soil Water Content, Rain, & Irrigation
Water Content (in.)
1/24
1/19
1/14
1/9
1/4
12/30
Date
Soil Water
SW Storage @ FC
SW Storage @ MAD
Rain
Irrigation
SW Storage @ PWP

RATTLESNAKE PROJECT DATASET SUMMARY

NRCS Conservation Innovation Grants

Project Fact Sheet

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Grantee Name: The Nature Conservancy

Contact Name and Email: Heidi Mehl, Heidi.mehl@tnc.org

Website Address: www.nature.org

Duration of Project: 8/14/2021 to 3/27/2024

Project Title:

Creating fresh approaches to water use efficiency for communities and wildlife in a water-stressed area of Central Kansas.

Project in a Sentence:

This project improved water use efficiency through monitoring and application technology, technical assistance and system maintenance, and peer networks.

Project Elevator Pitch:

In the Rattlesnake Creek Basin in Central Kansas, crop production is supplemented with groundwater is supplemented with groundwater pumped from the Great Bend Prairie Sand Aquifer (a formation of the High Plains Aquifer). This same groundwater supports critical habitat at Quivira National Wildlife Refuge, a wetland of international importance. This provided an opportunity to develop irrigation strategies in this region that could be exported to other areas of the High Plains (Ogallala) aquifer experiencing water shortages. This project increased adoption of monitoring technologies and improved application packages; provided technical assistance for maintenance and improvements of irrigation systems; investigated attitudes around practice adoption and irrigation efficiency; created peer networks for producers to share experiences and ask questions; and created a 7-step toolbox for irrigation efficiency that is being adopted in other groundwater dependent regions.

Deliverables:

- 4,940 total impacted acres
- Community peer networks
- Publications
  - Water Management and Information Gaps in the High Plains Aquifer
  - Interpreting and Using Center Pivot Sprinkler Designs
  - Soil Moisture-Sensing Systems for Improving Irrigation Scheduling
  - Accessing ET for Kansas Irrigation Scheduling
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How We Are Innovation in Natural Resources Conservation:

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