Kansas Field Conference
June 7–9, 2023

Southwest Kansas

History, Industries, and Adaptation

Field Guide

Coordinated by Blair Schneider

Kansas Geological Survey Open-File Report 2023-56

This project is operated by the Kansas Geological Survey and funded, in part,
by the Kansas Department of Health and Environment, Kansas Department of Transportation,
Kansas Department of Wildlife and Parks, Kansas Department of Agriculture,
Kansas Water Office, and The Nature Conservancy.

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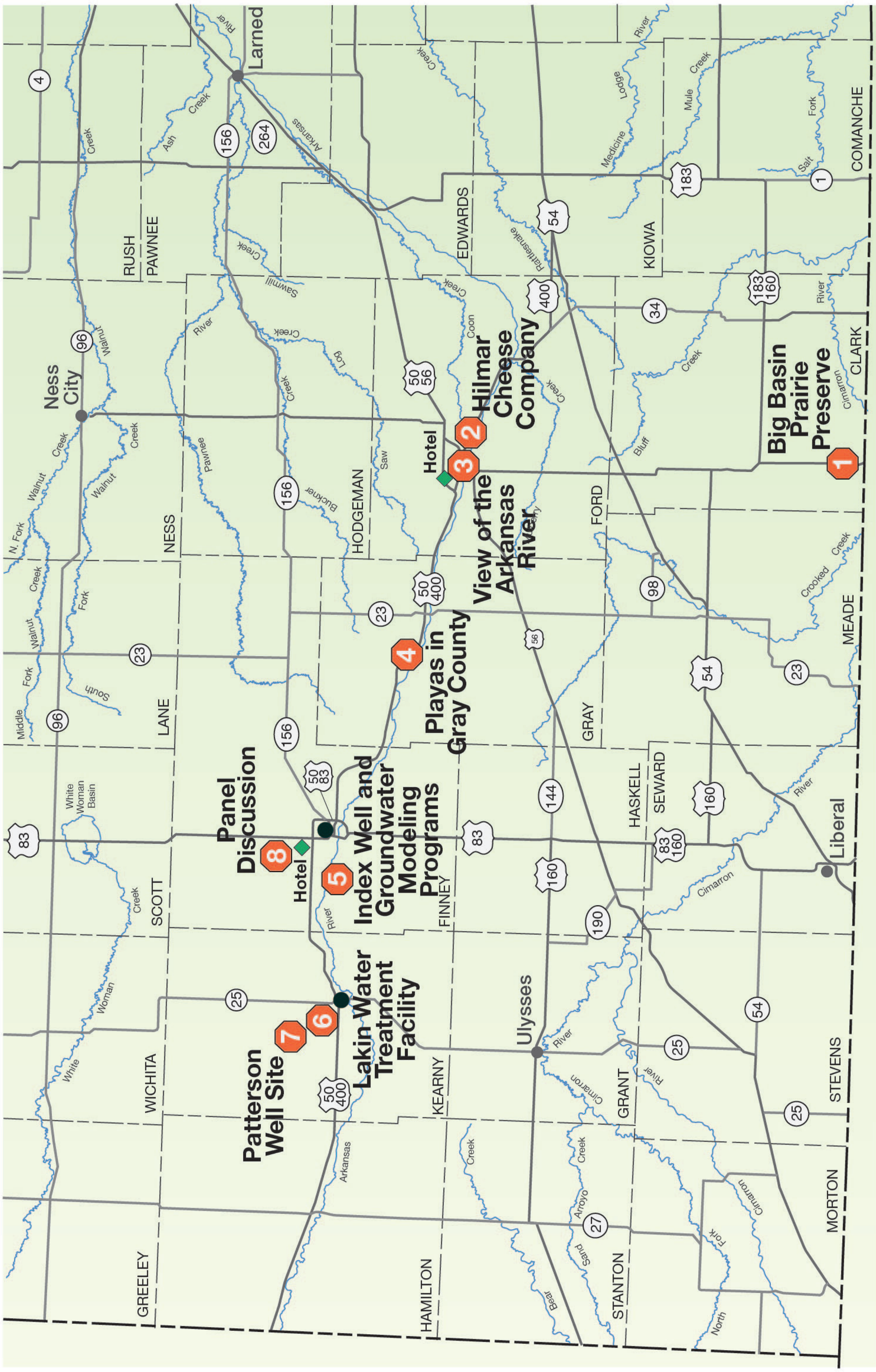

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NOTES

Southwest Kansas

History, Industries, and Adaptation

June 7–9, 2023

Welcome to the 28th Kansas Field Conference. This year will focus on how natural resources significantly influence the industries of southwest Kansas. Three broad categories characterize the sites on our 2023 tour: water, industries, and adaptation. Historically, the industries of southwest Kansas have made great contributions to the state's economy, primarily through agriculture and oil and gas resources. A consequence of these booming industries, however, is the significant stress they place on the availability of water resources. In some parts of southwest Kansas, fewer than 25 years' worth of usable water remains in the aquifer that serves as the main source for irrigation, industry, and human consumption. Adaptation, the overarching theme that connects our stops, is key to the future in this region. Although exploitation of water resources has resulted in significant issues related to water quality and quantity, local communities are working with state agencies and non-profit organizations to adapt and change the way they use and reuse water resources to work toward a more sustainable future for southwest Kansas.

Water and adaptation

Southwest Kansas lies within the High Plains region, which covers the western third of the state. The High Plains are built from materials worn from the Rocky Mountains, which were formed during the late Cretaceous Period, about 66 million years ago, into the Neogene Period, between 23 million and 2.6 million years ago. During the Neogene Period, vast amounts of sediment eroded off the mountains and flowed eastward in meandering streams. Over millions of years, masses of material filled in stream valleys and covered hills to create a huge, gently sloping floodplain, the remnants of which are the High Plains. The Ogallala Formation was created during this deposition of sediments from the Rocky Mountains and is composed of sand, gravel, and other debris.

The most important natural resource of this region is the High Plains aquifer, which includes the Ogallala aquifer. The High Plains aquifer extends across eight states and covers more than 30,000 square miles in western and central Kansas, supplying 70–80% of water used by Kansans.[1] Because the High Plains aquifer will be a key focus of this year's field conference, a copy of "The High Plains Aquifer," a KGS public information circular, has been included in your guidebook.

Water and adaptation will be a focal point of our stops across all three days of the conference. Day one begins with a keynote presentation by The Nature Conservancy to discuss collaborative efforts between multiple stakeholder groups in the Kansans for Conservation Coalition. Kansans for Conservation Coalition is a coalition of diverse organizations working collaboratively to ensure a healthy and sustainable future for Kansas, focused on water, land, outdoor recreation, and environmental education resources for Kansans (see flyer in folder pocket). Day two features lunch by the Arkansas River in Dodge City to talk about the history of the Ark River in southwest Kansas and the role that surface water resources play in available water use for the region. Day two also includes stops at a playa in Gray County, where we will discuss the role that playas play in recharging the High Plains aquifer, and at the Kearny-Finney Index Well near Garden City, one of 32 wells monitored by the KGS as part of our Index Well Program to track aquifer water levels in central and western Kansas. Day three will provide a deeper dive into groundwater quality issues and how southwest Kansans are adapting to diminishing groundwater quality with a visit to the Lakin water treatment plant. Day three will end with a panel discussion on the "Future of Water in Southwest Kansas," featuring representatives from the area's groundwater management districts and southwest Kansas residents.

Industries and adaptation

The first stop on day two, Big Basin Prairie Preserve, will provide an opportunity to see a variety of geological formations that are representative of the region as well as to discuss the importance of tourism to the economy of western Kansas (table 1). The total economic impact of tourism for Kansas in 2021 was $11.2 billion dollars.[2] The southwest region of the state, which includes 25 counties, saw a 25.8% increase in visitor spending in 2021 and provided more than 4,800 jobs in the region.[3] The primary objective in managing the Big Basin preserve is to maintain the site in its natural state and thus preserve a unique ecological and geological area of the southwest region.

After leaving Big Basin, we will head back north to take a drive around the construction of

Table 1. Summary of the economic impact of tourism in southwestern Kansas in 2021.[4] Amounts in millions of current dollars.

County	Lodging	Food & beverage	Retail	Recreation	Transport	Total	Growth rate
Clark	$0.2	$0.2	$0.1	$0.1	$0.3	$0.8	21.0%
Comanche	$0.4	$0.5	$0.3	$0.2	$0.4	$1.8	23.4%
Edwards	$0.2	$0.4	$0.2	$0.2	$0.8	$1.7	14.4%
Finney	$22.5	$35.8	$27.8	$14.1	$29.1	$129.2	24.4%
Ford	$22.7	$34.1	$20.4	$41.1	$28.1	$146.3	29.4%
Grant	$1.4	$3.1	$1.3	$0.9	$1.8	$8.5	1.8%
Gray	$0.4	$0.8	$0.5	$0.2	$1.2	$3.2	23.9%
Greeley	$0.0	$0.0	$0.1	$0.1	$0.1	$0.4	2.3%
Hamilton	$0.2	$0.5	$0.2	$0.2	$1.1	$2.2	10.7%
Haskell	$0.3	$0.6	$0.3	$0.3	$1.0	$2.5	13.9%
Hodgeman	$0.1	$0.1	$0.1	$0.0	$1.0	$1.4	7.2%
Kearny	$0.3	$0.6	$0.4	$0.2	$1.4	$2.9	18.1%
Kiowa	$0.4	$0.5	$0.3	$0.3	$2.1	$3.5	11.3%
Lane	$0.1	$0.1	$0.1	$0.1	$1.0	$1.5	24.9%
Meade	$0.4	$0.7	$0.4	$0.3	$2.0	$3.7	30.7%
Morton	$0.3	$0.6	$0.3	$0.2	$1.2	$2.5	9.1%
Ness	$0.3	$0.4	$0.2	$0.1	$0.8	$1.9	15.0%
Pawnee	$1.3	$2.3	$1.3	$0.8	$1.9	$7.7	1.8%
Rush	$0.3	$0.3	$0.2	$0.1	$2.0	$3.0	16.4%
Scott	$1.8	$3.2	$1.7	$1.3	$2.7	$10.7	10.0%
Seward	$14.3	$22.6	$13.6	$8.9	$19.5	$78.8	33.3%
Stanton	$0.2	$0.3	$0.2	$0.1	$0.1	$1.0	20.4%
Stevens	$2.5	$3.7	$1.6	$1.0	$2.7	$11.6	40.5%
Wichita	$0.0	$0.2	$0.1	$0.2	$0.3	$0.9	-2.8%
Region Total	$70.5	$111.8	$71.8	$71.1	$102.7	$427.8	25.8%
State Total	**$937.2**	**$1,809.2**	**$1,114.1**	**$1,113.9**	**$1,986.3**	**$6,960.8**	**25.6%**

the new Hilmar Cheese factory in Dodge City, which is set to open later this year. The new facility is expected to create 247 new jobs and represents $460 million in capital investment. The project is estimated to bring an additional $550 million in capital investment and 750 new jobs within a 50-mile radius of Dodge City by late 2023. We will explore how this industry is adapting to water resource challenges with innovative conservation efforts built directly into its workflow.

On the last day of the conference, participants will visit the Patterson field site north of Lakin, which is operated by Berexco. The Patterson field is an oil and gas production field that was discovered in 1941 in Kearny County and is being tested as a carbon capture, utilization, and storage (CCUS) site. The Patterson field site is another example of diverse stakeholders collaborating and adapting to ensure that future generations can continue to thrive. The KGS's Energy Research Program has led or played a key role in five large-scale CCUS projects funded by the U.S. Department of Energy. Economic interest in capturing and storing carbon emissions increased in 2018 when the Internal Revenue Service updated a tax incentive, known as 45Q, for companies willing to capture and store CO_2. Oil and gas production, ethanol, electrical-power generation, pipeline, agriculture, and other industries are eligible for this incentive.

Resources

[1] R. C. Buchanan, B. B. Wilson, J. J. Butler, Jr., *The High Plains Aquifer* (Kansas Geological Survey Public Information Circular 18, 2023), 6 p.

[2] Tourism Economics, *The Kansas Visitor Industry* (Prepared for Kansas Tourism, 2022), 18 p. https://bit.ly/3N4iKgF

[3] Kansas Tourism, *Regional and County Economic Impact: 2021* (Kansas Tourism — Economic Impact, 2023). travelks.com

[4] Kansas Tourism, *Regional and County Economic Impact: 2021.*

About the Kansas Field Conference

The Kansas Field Conference is designed to give policymakers the opportunity to explore and discuss natural resource issues. Participants have a chance to see what effects government and business decisions can have on natural resources and communities and to talk with government officials, business owners, researchers, and others who are directly involved with the various sites. We aim to provide a broad, informed perspective that will be useful in formulating policies and programs.

The annual field guide furnishes background about each site and can serve as a useful reference long after the conference is over. Field guides also are posted on the KGS website (www.kgs.ku.edu). You are encouraged to ask questions and contribute to the discussions. The bus microphone is open to everyone. Please remember that the intent of this conference is not to resolve policy or regulatory conflicts. By bringing together experts, we hope to go beyond merely identifying issues; we want the combination of first-hand experience and interaction among participants to result in a new level of understanding about the state's natural resources and concerns.

When possible, we attempt to provide a forum for all sides of a contentious issue. The opinions presented during the conference are not necessarily those of the Kansas Geological Survey or the field conference co-sponsors. Nonetheless, we believe it is important for participants to hear various viewpoints on complex issues. The Kansas Geological Survey and co-sponsors appreciate your attendance at this year's conference.

Sponsors

The Kansas Field Conference is made possible and kept affordable through the generous support of many groups. In addition to the co-sponsors listed below, the 2023 field conference received support for socials and meals from Hy-Plains Feedyard. We thank them for their support.

Kansas Geological Survey

The KGS is a research and service division of the University of Kansas. Its mission is to study and report on the state's geologic resources and hazards. Much of the KGS focus is on energy, water, and a better understanding of the state's surface and subsurface geology. By statutory charge, the KGS role is strictly one of research and reporting. The KGS has no regulatory functions. The main headquarters of the KGS is in the West District of the University of Kansas in Lawrence, and the Kansas Geologic Sample Repository of the KGS is in Wichita.

The following KGS staff are participating in the 2023 field conference:

- Blair Schneider, Geologist/Outreach Manager
- Jay Kalbas, Director
- Scott Ishman, Associate Director for Research
- Brownie Wilson, Manager of Geohydrology Support Services
- Franek Hasiuk, Associate Scientist
- Jennifer Raney, Research Project Manager
- Erin Seybold, Assistant Scientist
- Sam Zipper, Assistant Scientist
- Nikki Potter, Library Manager
- Andrew Connolly, Science Communications Specialist
- Sunday Siomades, Science Outreach Intern

Kansas Geological Survey
1930 Constant Avenue
Lawrence, KS 66047-3724
785-864-3965
www.kgs.ku.edu

Kansas Geologic Sample Repository
4150 W. Monroe Street
Wichita, KS 67209-2640
316-943-2343

Kansas Department of Transportation

The Kansas Department of Transportation (KDOT) is charged with providing a statewide transportation system to meet the needs of

Kansans. Its primary activities are road and bridge maintenance; transportation planning, data collection, and evaluation; project scoping, designing, and letting; contract compliance inspection of material and labor; federal program funding administration; and administrative support.

Kansas Department of Transportation
Dwight D. Eisenhower State Office Building
700 SW Harrison Street
Topeka, KS 66603-3754
785-296-3566
www.ksdot.org

Kansas Department of Wildlife and Parks

The Kansas Department of Wildlife and Parks (KDWP) is responsible for managing the state's living natural resources. Its mission is to conserve and enhance Kansas's natural heritage, wildlife, and wildlife habitats. Its responsibilities include protecting and conserving fish and wildlife and their habitats while providing for the wise use of these resources and associated recreational opportunities and providing public outdoor recreation opportunities through state parks, state fishing lakes, wildlife-management areas, and recreational boating on the state's public waters.

Kansas Department of Wildlife and Parks
Secretary
1020 S. Kansas Avenue, Rm 200
Topeka, KS 66612-1327
785-296-2281
www.ksoutdoors.com

Region 3 Office
1001 W McArtor
Dodge City, KS 67801
620-227-8609
www.ksoutdoors.com

Kansas Department of Agriculture

The Kansas Department of Agriculture (KDA) has a mission to support the agriculture sector in Kansas, including farmers, ranchers, food establishments, and agribusiness, and the consumers they serve. The KDA has several divisions, including the Division of Water Resources (DWR) and the Division of Conservation. The DWR regulates how water is allocated and used, the construction of dams and levees, Kansas's Groundwater Management District Act, and the state's interstate river compacts. It also coordinates the national flood insurance program in Kansas. The Division of Conservation works with the county conservation districts, organized watershed districts, and other special-purpose districts to improve water quality, reduce soil erosion and flood potential, conserve water, and provide local water supply.

Kansas Department of Agriculture
1320 Research Park Drive
Manhattan, KS 66506
785-564-6700

Kansas Water Office

The Kansas Water Office (KWO) is the water planning, policy, coordination, and marketing agency for the state. The KWO evaluates and develops public policies, coordinating the water-resource operations of agencies at all levels of government. The KWO administers the Kansas Water Plan Storage Act and the Water Assurance Act and advises the governor on drought conditions. The KWO develops the Kansas Water Plan, which addresses the management, conservation, and development of water resources in the state. The Kansas Water Authority, statutorily within and a part of the KWO, advises the governor, legislature, and director of the KWO.

Kansas Water Office
900 SW Jackson, Suite 404
Topeka, KS 66612-1249
785-296-3185
www.kwo.org

The Nature Conservancy

The Nature Conservancy is a global environmental nonprofit whose mission is to conserve the lands and waters on which all life depends. Founded in 1951, it has more than a million members and more than 400 scientists on staff and impacts conservation in 79 countries and territories. The Nature Conservancy has permanently protected 190,000 acres in Kansas, including five preserves that are open to the public: Little Jerusalem Badlands State Park, Cheyenne Bottoms Preserve, Konza Prairie, Tallgrass Prairie National Preserve, and Smoky Valley Ranch.

Kansas Field Office
The Nature Conservancy
PO Box 4345
Topeka, KS 66604
785-233-4400
Kansas@tnc.org

Acknowledgments

The following people helped make this an informative and successful field conference: Director Connie Owen and Assistant Director Matt Unruh, Kansas Water Office; Secretary Brad Loveless, Kansas Department of Wildlife and Parks; Deputy Secretary and Director of Environment Leo Henning, Kansas Department of Health and Environment; Secretary Mike Beam, Chief Engineer Earl Lewis, and Water Commissioner Mike Meyer, Kansas Department of Agriculture; Chief Geologist Kyle Halverson and Regional Geologist Neil Croxton, Kansas Department of Transportation; Executive Vice President Dana Wreath of Berexco LLC; and Water Resource Systems Manager Fred Jones, City of Lakin. Mark Schoneweis, KGS graphic designer, prepared the route map, and multiple KGS scientists contributed to the field conference guidebook, including Andrew Connolly, Brownie Wilson, Erin Seybold, Sam Zipper, Don Whittemore, Franek Hasiuk, Jennifer Raney, Rolfe Mandel, and Scott Ishman. Special appreciation goes to Julie Tollefson, KGS editor, for her extensive help editing and laying out the field guide. The KGS extends our appreciation to the presenters at each of the stops, without whom this conference would not have been possible.

Wednesday, June 7, 2023

3–5 p.m. Check in at registration desk at Hampton Inn & Suites
4002 W. Comanche St.
Dodge City, KS 67801

5–7:30 p.m. **Dinner Reception and Presentations**
Boot Hill Museum
500 W. Wyatt Earp Blvd.
Dodge City, KS 67801

Welcome
Jay Kalbas, Director, Kansas Geological Survey
Blair Schneider, Outreach Manager, Kansas Geological Survey

Keynote Presentation: "Conservation: It Takes a Village"
Justin Cobb, The Nature Conservancy, Kansas

7:30 p.m. **Boot Hill Distillery Private Tour and Tasting Room** (Optional)
Private tour for participants who purchased tickets with registration.
501 W. Spruce St.
Dodge City, KS 67801

NOTES

Thursday, June 8, 2023

7 a.m.	Breakfast provided at the Hampton Inn & Suites
7:50 a.m.	Check out of hotel and meet at bus in parking lot of Hampton Inn & Suites 4002 W. Comanche St. Dodge City, KS 67801
8 a.m.	Bus to Stop 1 U.S. Highway 160 Englewood, KS 67840
8:45 a.m.	**Stop 1: Big Basin Prairie Preserve** Brad Loveless, Kansas Department of Wildlife and Parks Justin Cobb, The Nature Conservancy Rolfe Mandel, Kansas Geological Survey
9:30 a.m.	Bus to Stop 2 11305 112 Road Fort Dodge, KS 66763
10:30 a.m.	**Stop 2a: Bus Tour of Hilmar Cheese Company** Joann Knight, Dodge City/Ford County Development Corporation
10:45 a.m.	Bus to Wright Park Shelter 71 N. 2nd Ave. Dodge City, KS 67801
11 a.m.	**Stop 2b: Hilmar Cheese Company Presentation** with lunch Joann Knight, Dodge City/Ford County Development Corporation Jeff Brock, Director of Engineering Site Development Mike Beam, Kansas Department of Agriculture Connie Owen, Kansas Water Office
Noon	**Stop 3: View of the Arkansas River** Earl Lewis, Kansas Department of Agriculture Sam Zipper, Kansas Geological Survey Bus to Stop 4 8993 County Road 13 Ingalls, KS 67853

12:30 p.m. **Stop 4: Playas in Gray County**
Scott Ishman, Kansas Geological Survey
Sara Baer, Kansas Biological Survey
Rolfe Mandel, Kansas Geological Survey

1:30 p.m. Bus back to hotel to pick up vehicles
Hampton Inn & Suites
4002 W. Comanche St.
Dodge City, KS 67801

Restroom stop available at hotel

3:50 p.m. Meet at bus in parking lot of Sleep Inn & Suites
1931 E. Kansas Plaza
Garden City, KS 67846

4 p.m. Bus to Stop 5
Intersection of West Lowe Road/North Kansas Nebraska Road
Sherlock, Kansas

4:30 p.m. **Stop 5: Index Well and Groundwater Modeling Programs**
Brownie Wilson, Kansas Geological Survey
Mike Meyer, Kansas Department of Agriculture

5:30 p.m. Bus back to hotel. Check in to hotel.
1931 E. Kansas Plaza
Garden City, KS 67846

6 p.m. Dinner on your own in Garden City

Big Basin Prairie Preserve

Andy Connolly

KEY FACTS

- Big Basin Prairie Preserve became a National Natural Landmark in 1978.
- Big Basin and Little Basin are sinkholes formed from the dissolution of salt and gypsum below the surface.
- The preserve converted farmland into a native mixed-grass prairie complete with its own herd of bison.
- St. Jacob's Well, at the bottom of Little Basin, is a spring-fed pool that has supported people for many centuries and has reportedly never been known to run dry.

At Big Basin Prairie Preserve (fig. 1), we stand at the edge of two physiographic regions of Kansas. To the east are the rolling Red Hills that cut across the south-central portion of the state. The Red Hills region's rugged butte-and-mesa topography was influenced by deposits of erosion-resistant gypsum. The soils, shales, siltstones, and sandstones in the region get their color from iron oxide (rust), which turns bright red when exposed to oxygen (fig. 2). To the west is the High Plains, which dominates the western third of Kansas. Higher and drier than the rest of the state, the High Plains formed from sediment eroded off the rising Rocky Mountains. Features of both of these regions are evident at Big Basin Prairie Preserve.

Big Basin Prairie Preserve protects roughly two-thirds of its namesake, Big Basin, a circular depression about one mile across and roughly 100 feet deep, as well as Little Basin to the east. Little Basin is 840 feet across and 35 feet deep. The western third of Big Basin is privately owned.

Based on the age of the rocks in its walls, geologists estimate Big Basin formed fairly recently (in geologic time, that is), probably within the last few thousand years. Its origin was

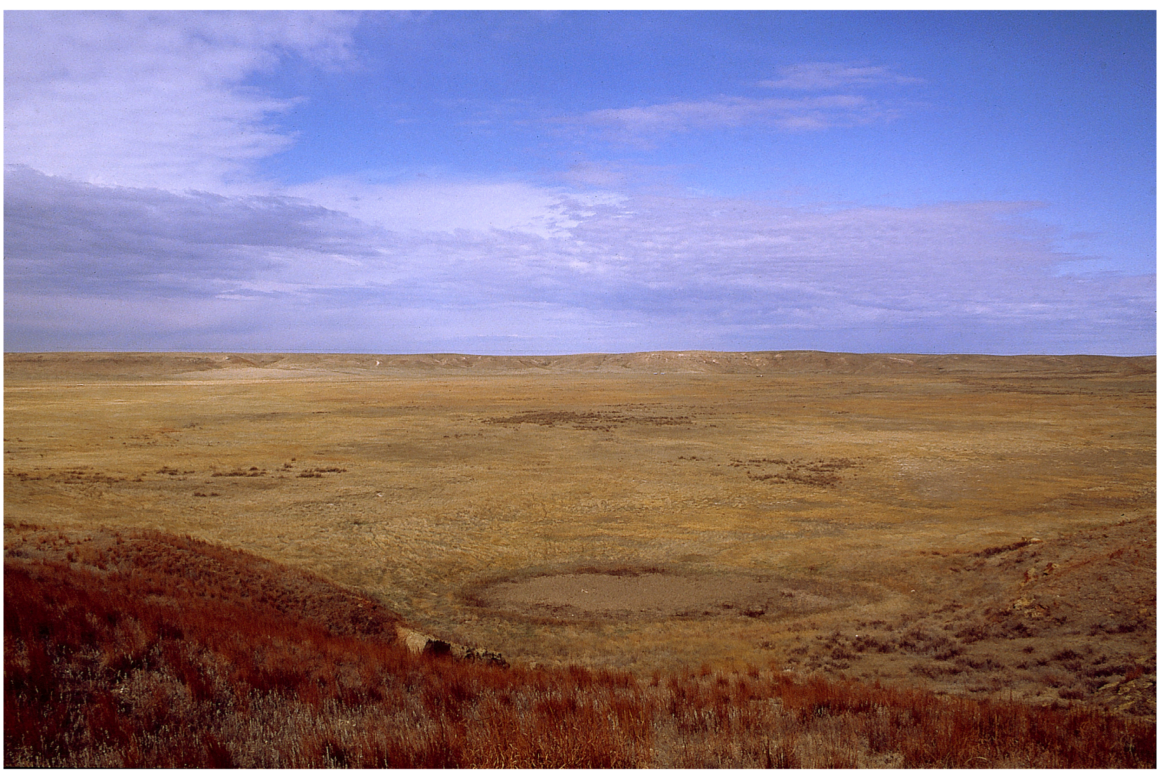

Figure 1. Big Basin in Clark County is a circular depression about one mile across and 100 feet deep.

a brief source of intrigue for geologists: crater or sinkhole? A research team from the University of Oklahoma tackled this question and concluded sinkhole was the likely answer.[1] The giant depression lacked characteristics of a meteor impact, such as disruption of rocks below the surface and along the rim, the research team determined. Instead, thousands of years ago, before the collapse, water flowed underground and slowly dissolved a large deposit of salt and gypsum crystals. Eventually, the dissolution created a large underground void and the entire surface collapsed, creating the sinkhole. Drilling in the area indicates that these eroding and collapsing events are still occurring.[2]

Figure 2. Flat-topped and irregularly shaped hills of red rock define the Red Hills region. Big Basin represents the western edge of the Red Hills physiographic region of Kansas.

Sinkholes in Kansas

Sinkholes can form slowly, dropping a few inches a year, or quickly dropping tens of feet per second. Most sinkholes, such as at Big Basin, are formed when groundwater dissolves an underground layer of salt or gypsum. The eventual dissolution causes the surface to sink. More than a quarter of the counties in Kansas have sinkholes ranging from smaller than a manhole to wider than a mile.

Sinkholes also can form from human activities, such as underground mining or oil and gas operations. A famous example is the Cargill sinkhole in Hutchinson. Because of local salt mining, a sinkhole formed overnight near the Cargill Salt company. In just 14 hours, it grew to 200 feet in diameter, leaving railroad tracks, still connected, suspended in air. The KGS uses seismic reflection techniques to study sinkhole formation and identify sinkhole-prone areas.

History of the preserve

The citizens of Clark County and The Nature Conservancy acquired land for Big Basin Prairie Preserve during the 1960s and 1970s for the purposes of conservation and enjoyment for future generations. In 1972, The Nature Conservancy sold the land to the Kansas Department of Wildlife and Parks with the stipulation that it should be managed as a preserve. In 1978, the preserve was designated a National Natural Landmark.[3]

One of the primary goals of the preserve was to restore the land to native prairie. Invasive species of weeds were removed, and farmland was converted to native grasses — big and little bluestems, blue grama, and others — and native plants, such as sagebrush, which serves as an important source of food for the pronghorn that roam the Red Hills.

The reintroduction of bison (fig. 3) further rejuvenated the land. Although once a dominant force of the American plains, bison numbers dwindled due to habitat loss and hunting. The now-thriving herd of bison, owned by the KDWP, plays an important role in maintaining the health and diversity of the prairie ecosystem.[4]

Figure 3. Bison, owned by the Kansas Department of Wildlife and Parks, roam Big Basin Prairie Preserve. Image by Wikimedia Commons (https://bit.ly/43oTJlr).

U.S. Highway 160-283 bisects Big Basin (fig. 4). A vehicle trail through the preserve is minimally maintained and includes two scenic overlooks toward Big Basin and parking at Little Basin. A foot path leads down through Little Basin to St. Jacob's Well, a 50-foot-wide, spring-fed pool that reportedly has never run dry (fig. 5). St. Jacob's Well, once a watering site for cowboys driving cattle up from Texas, served as an important source of hydration in a dry climate where water quickly evaporates. Archaeological evidence points to centuries of use by pre-Colombian people, Native American tribes, and pioneers (fig. 6).

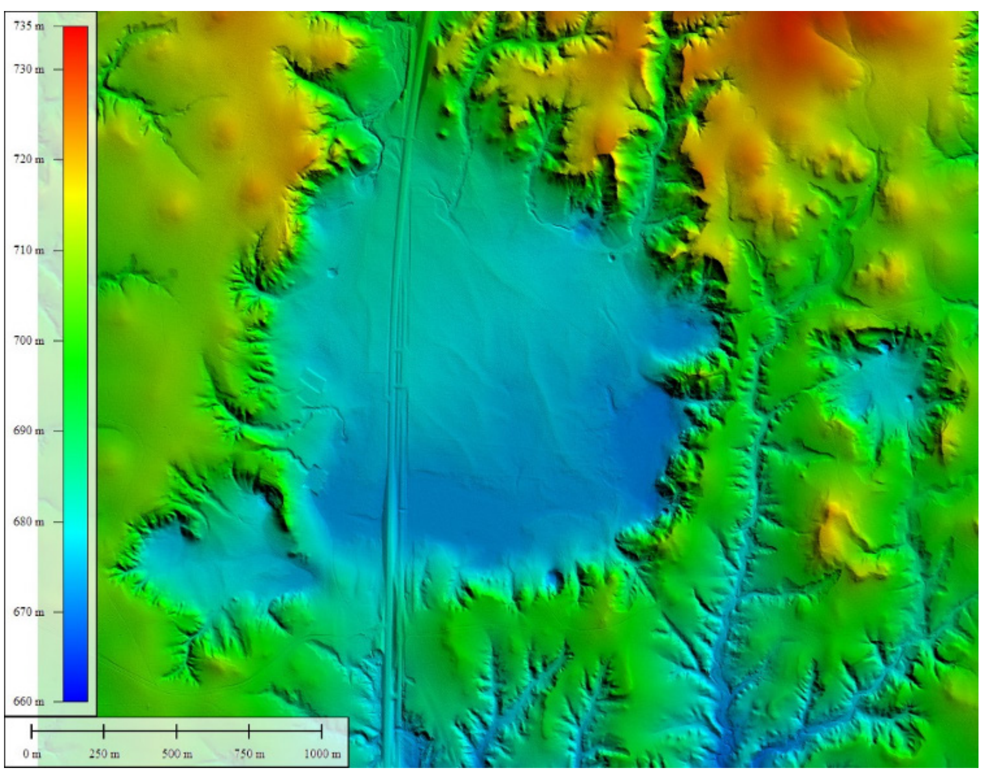

Figure 4. A shaded elevation map of Big Basin. Note U.S. Highway 283 bisecting Big Basin north to south. To the east is the much smaller Little Basin. Image from Wikimedia Commons (https://bit.ly/3MVH97Z).

Figure 5. St. Jacob's Well, located at the bottom of Little Basin. Despite centuries of use, the spring-fed pool has reportedly never run dry and has served as a frequent stop for people throughout history. Photo by Frank Thompson.

Figure 6. Historical photograph of St Jacob's Well taken between 1891 and 1903. Photograph by Francis Marion Steele.

The geology of Big Basin Prairie Preserve

The layers of rocks found along Big Basin's wall are Permian and Cretaceous in age. In geological terms, the time difference between these two rock layers — at least 100 million years—is called an unconformity. Why the lengthy age gap? Deposition, uplift, and erosion are common geologic processes. Other rock formations may once have topped the Permian layers but were eventually eroded away before a new set of rocks were laid down.

Figure 7. Gypsum is a common mineral found throughout the southern portion of the state. Large underground deposits of gypsum and salt gradually dissolved via groundwater, which eventually caused surficial collapse and the formation of Big Basin. Image by James St. John.

Gypsum is a common mineral found in the area (fig. 7). It's an evaporite, a mineral formed from the evaporation of water leaving behind crystals. During the Permian Period, some 255 million years ago, an inland sea covered Kansas. A portion of the sea was cut off and slowly evaporated. The evaporation left behind massive quantities of salt and gypsum that were eventually buried. Like salt, gypsum is soluble and dissolves in the presence of water.

Resources

[1] Richard R. Donofrio, *Big Basin, Kansas: Impact Crater or Sinkhole?* (EDGE Research Associate, June 2002). https://bit.ly/434ZC7S

[2] Donofrio, *Big Basin, Kansas: Impact Crater or Sinkhole?*

[3] The Nature Conservancy, *The Nature Conservancy in Kansas.* https://bit.ly/3WvlZkp

[4] Kansas Department of Wildlife and Parks, *Big Basin Prairie Preserve Wildlife Area*. https://bit.ly/3MTZ13a

CONTACTS

Brad Loveless
Secretary
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785-296-2281
Brad.Loveless@ks.gov

Region 3 KDWP Office
620-227-8609
1001 W. McArtor Rd
Dodge City, KS 67801-6024

NOTES

Hilmar Cheese Company

Press Release • May 5, 2021

KEY FACTS

- Hilmar Cheese Company, founded in 1984, is one of the world's largest producers of American-style cheese and whey products, with customers in more than 50 countries.
- The new plant is expected to create 247 new jobs and represents $460 million in capital investment.
- The company plans to use technologies and sustainable practices to promote carbon neutrality.
- The plant's wastewater will be used for crop irrigation and biogas production.

Hilmar Cheese Company to open new cutting-edge cheese and whey production facility in Dodge City, Kansas

HILMAR, CALIFORNIA — Kansas Gov. Laura Kelly and Hilmar Cheese Company, Inc. today jointly announced the company's decision to build a new state-of-the-art cheese and whey protein processing plant in Dodge City, Kansas.

Hilmar Cheese Company, founded in 1984, is one of the world's largest producers of high quality American-style cheese and whey products, with customers in more than 50 countries.

The new facility is expected to create 247 new jobs and represents $460 million in capital investment. The project is estimated to bring an additional $550 million in capital investment and 750 new jobs within a 50-mile radius of Dodge City by late 2023.

Hilmar Cheese Company CEO and President David Ahlem called Dodge City an "ideal choice" given its central location, critical existing infrastructure, proximity to the growing local dairy industry and business-friendly climate.

"Our first-class workforce and central location make Kansas one of the best places in the nation to do business," said Governor Laura Kelly. "It's great to see another major food manufacturer like Hilmar choose to put their trust in our state and Dodge City for their newest facility."

The state-of-the-art facility will showcase sustainable solutions. Hilmar Cheese Company is a leader in sustainable practices and has adopted the U.S. Dairy Stewardship Commitment and goal to achieve a Net Zero dairy industry by 2050.

"We want our plant to be as good for the environment as it will be for the local economy," Ahlem said. "We'll use technologies and sustainable practices to promote carbon neutrality."

Nick Hernandez, city manager, added, "One of the biggest advantages for both Hilmar Cheese Company and Dodge City is the cohesive nature of our sustainability efforts. They have a standing commitment to being stewards of the environment, much like Dodge City, and through this mutually beneficial partnership, we will be able to further utilize our wastewater for crop irrigation and biogas production."

The new facility will help Hilmar Cheese Company meet the growing demand of its customers and the marketplace for cheese and whey products worldwide. In addition to job creation, the plant will create opportunities for the Dodge City community, promote growth for Kansas dairy producers, and help Hilmar Cheese Company fulfill its purpose to improve lives.

Joann Knight, executive director of the Dodge City/Ford County Development Corporation, stated that the economic impact to the community "will be compounded substantially by the additional dairies, transportation and services that will be required to support the processing facility once operational as well as the impact that the construction phase will have on our region."

Kansas Governor Laura Kelly (center) participants in ground breaking ceremony for the new Hilmar Cheese Company plant at Dodge City.

The project has been a collaborative effort of many organizations. The Kansas Department of Commerce, Department of Agriculture, and Department of Transportation, the city of Dodge City, Ford County, Dodge City/Ford County Development Corporation, Black Hills Energy, Victory Electric, United Tel•Com, Dodge City Public Schools USD 443, Dodge City Community College, and area agricultural producers have helped bring the new business to the community.

"We greatly appreciate the warm welcome from the state of Kansas and the city of Dodge City officials whose values of integrity and excellence closely align with ours," Ahlem said. "Dodge City gives us many opportunities including a local and skilled labor force, a supportive and expanding agricultural region, and an excellent transportation network that allows us to easily reach our expanding markets.

"We're really happy with our decision and excited about becoming a part of this outstanding community."

Hilmar is expected to break ground on the facility in the summer of 2021 and be fully operational in 2024.

Hilmar Cheese Company was established in 1984 by 12 local dairy farm families in the Central Valley of California. The company added a state-of-the-art production facility in Dalhart, Texas, in 2007. Privately owned, the company currently employs more than 1,500 local residents of the two areas. The company offers great benefits, training and long-term career growth opportunities. Since its inception, Hilmar Cheese Company has been dedicated to processing high-quality cheese and whey products. It currently produces a variety of cheese including cheddar, monterey jack, pepper jack, colby, colby jack, and mozzarella. The whey is processed into whey protein products that are used as ingredients in many foods, including nutritional beverages and bars, and lactose, which is marketed internationally as an ingredient in confections and infant formula.

The company is also known as a strong community partner supporting local events, education and health care. Hilmar Cheese Company's annual scholarship program awards students of our employees, milk producers, and community scholarships to support continuing education. The company's California Visitor Center and the exhibits at the Texas XIT Museum are visited by thousands of students on field trips each year.

About Hilmar Cheese Company, Inc.

Hilmar Cheese Company, Inc. improves lives around the world by being a leading producer of wholesome dairy products. Founded in 1984, Hilmar Cheese Company and its division, Hilmar Ingredients, serve customers in more than 50 countries. State-of-the-art production facilities in California and Texas convert high-quality milk received from local independent dairy farms into a variety of nutritious cheese and whey ingredients. The company specializes in the production of cheddar and American-style cheeses utilized by private label and national brand companies worldwide. Its Hilmar Ingredients division manufactures and markets globally a wide range of whey protein and lactose products. Committed to continuous improvement, innovation and sustainability, Hilmar Cheese Company strives to make products that benefit all involved from our customers to our suppliers to our employees and communities. Together, we deliver the promise of dairy.

CONTACTS

Joann Knight
Executive Director
Dodge City/Ford County
Development Corporation
PO Box 818
Dodge City, KS 67801
620-227-9501 office
620-338-5101 cell

NOTES

STOP
3

The Arkansas River: A Historical Overview

Blair Schneider and Sam Zipper

Kansans depend on two major sources of water: groundwater and surface water. Groundwater is underground water that is generally found in the pore space of rocks or sediments and can be collected with wells, tunnels, or drainage galleries. Surface water is water that is found at the Earth's surface, such as in streams, rivers, and lakes. In southwestern Kansas, residents have had to shift from using a major surface water source, the Arkansas River (fig. 1), to primarily groundwater sources of water.

Many streams and rivers in Kansas are privately owned. Exceptions are the Kansas, Arkansas, and Missouri rivers, which are open to the public year-round. The Arkansas River is the sixth longest river in the United States at 1,469 miles and is the longest tributary in the Mississippi-Missouri system.[1] The river has flowed across the state for 10 million years, providing important economic contributions to Native American populations and current residents of Kansas. Among its many uses, it has served as a source of drinking water for humans and livestock and irrigation water for agriculture. It provides

KEY FACTS

- The Arkansas River is the sixth longest river in the United States at 1,469 miles long and is the longest tributary in the Mississippi-Missouri system.
- The river is a source of drinking water for humans and livestock and irrigation water for agriculture. It provides opportunities for fishing, hunting, and waterway travel.
- The river has transitioned from a perennial stream to a non-perennial stream due to the construction of irrigation canals in the late 1800s and the introduction of high-capacity irrigation wells for groundwater pumping.
- Colorado and Kansas ratified a compact in 1949 to help establish an equitable division of the Arkansas River water.
- KGS researchers have found that groundwater levels exert the most influence over when and where the river dries.

Figure 1. The Arkansas River in the spring at Garden City, circa 1870s–1890s. Photo: KansasMemory.org, Kansas Historical Society.

opportunities for fishing and hunting as well as waterway travel.

The Arkansas River enters western Kansas in central Hamilton County and exits the state in Cowley County in south-central Kansas. It flows over the High Plains aquifer region of southwestern Kansas and is subdivided into two units – the upper Arkansas River basin and the lower Arkansas River basin (fig. 2). This year's field conference will focus primarily on the issues in the upper Arkansas River basin, specifically the significant decrease in water quantity and water quality since the advent of irrigation (see Stop 6 — Groundwater Quality in the Upper Arkansas River Corridor for more about water quality).

Canals, irrigation, and John Martin Reservoir

In the early and mid-1800s, an abundance of water flowed through the banks of the Arkansas River year-round (fig. 3), except occasionally in the fall months above the confluence of it and the Little Arkansas River. That began to change, though, in the late 1800s. From 1880 to 1905, local businessmen and farmers constructed a total of 12 irrigation canals to divert water from the Arkansas River to irrigate corn and sugar beet fields (figs. 4–5). One of the largest attempts to bring water to southwest Kansas was the construction of a 96-mile-long canal that took two years to dig, known as the Soule Canal (fig. 6). It

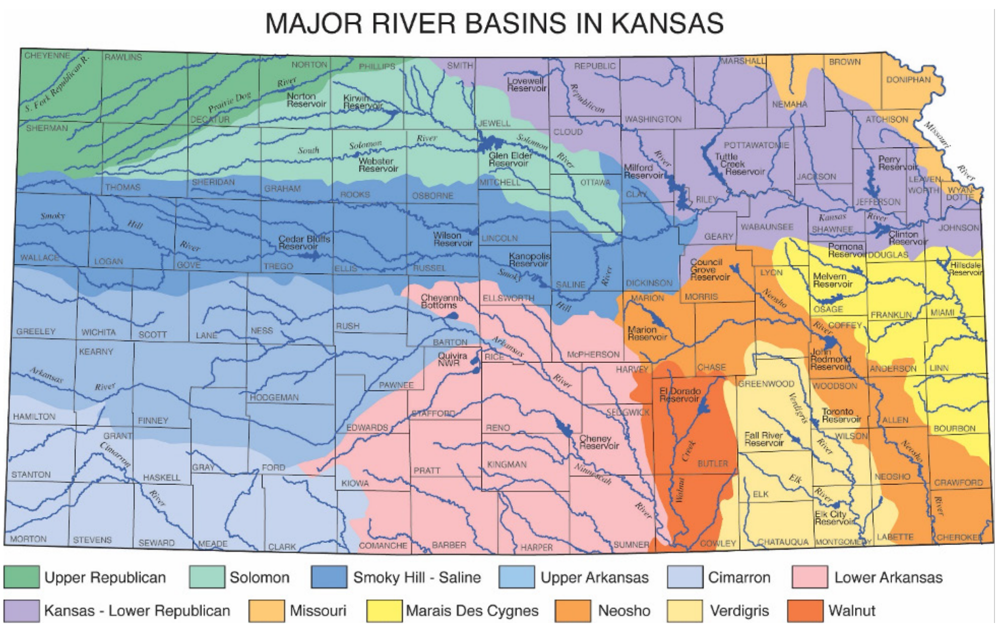

Figure 2. The major river basins in Kansas. The upper Arkansas River basin is shown in medium blue, and the lower Arkansas River basin is shown in pink.

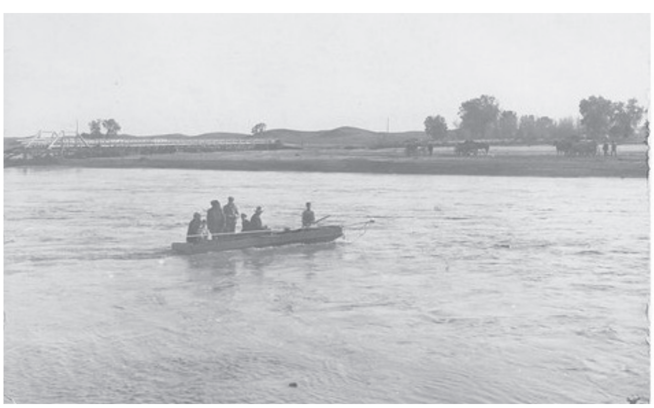

Figure 3. The Arkansas River at Syracuse, circa 1905–1909. Photo: KansasMemory.org, Kansas Historical Society.

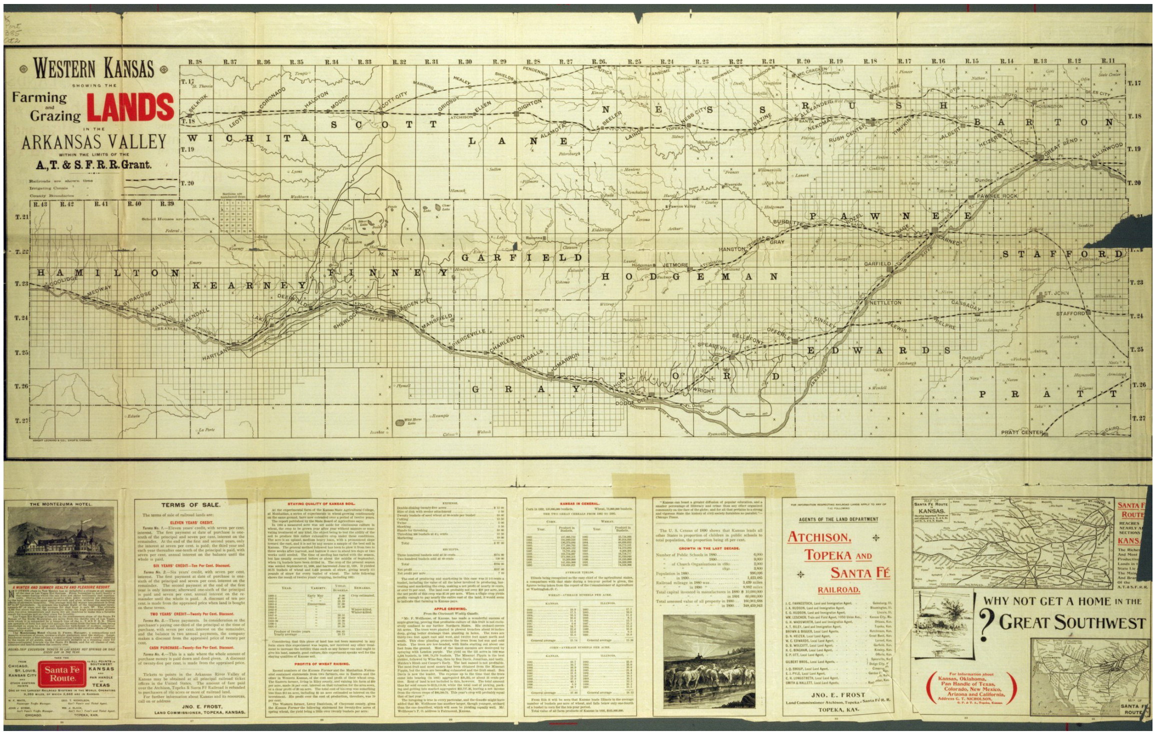

Figure 4. Atchison, Topeka and Santa Fe Railroad Company map of farming and grazing lands in the Arkansas River valley, 1892. Photo: KansasMemory.org, Kansas Historical Society.

was constructed by the Eureka Irrigation Canal Company but failed within five years after the diversion dam flooded out, and it is known today as Soule's Folly.[2] These canals diverted water north and south of the Arkansas River beginning east of Lakin and west of Garden City, with the intent to irrigate 5,000 to 100,000 acres of cropland.[3] Within a few years after the construction of the canals, a study in this region reported that the Arkansas River was no longer actively flowing in the summer months from June to October in the Garden City area.[4]

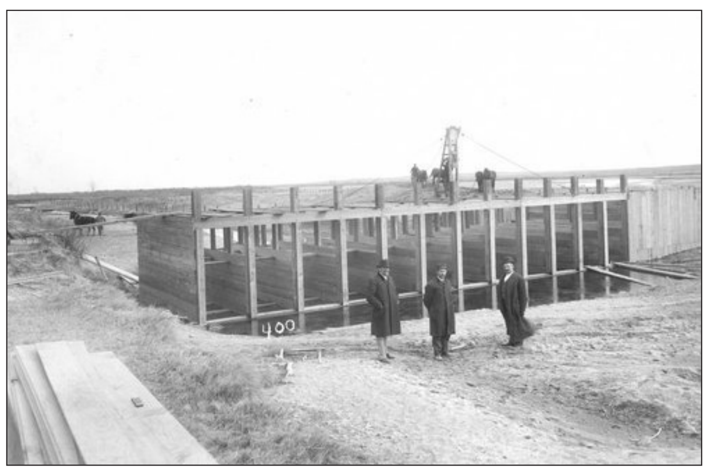

Figure 5. Headgate to the Great Eastern Ditch at the Arkansas River in Finney County circa 1900–1910. Photo taken by Francis Marion Steele and made available by KansasMemory.org, Kansas Historical Society.

At the beginning of the 20th century, a new technology emerged that contributed to the decline in water flow in the Ark. The introduction of high-capacity irrigation wells (fig. 7) allowed farmers to tap the High Plains aquifer, an immense source of groundwater that could be extracted at depths of less than 20 feet. Originally, farmers pumped groundwater to supplement the water available within the Arkansas River. Now, almost a quarter of the way into the 21st century, the majority of the water used to irrigate farmland in southwest Kansas comes solely from the groundwater in the High Plains aquifer.

Figure 6. The Soule Canal — Soule's Folly — in Ford County, circa 1883–1885. The canal stretched from Ingalls across Gray and Ford counties to Coon Creek in Edwards County. Photo: KansasMemory.org, Kansas Historical Society.

Figure 7. Center-pivot irrigation system.

A third factor contributing to the diminishing water supply in the Arkansas River was the development of the John Martin Reservoir near Lamar, Colorado, in 1943. The reservoir was constructed to control floods and support the water resources in the Arkansas River basin.[5] By the 1970s, the Arkansas River at Lakin was dry all year, except when the reservoir released water. In 1984, Kansas sued Colorado for taking too much water out of the river in violation of the Kansas-Colorado Arkansas River Compact. Ratified by Colorado, Kansas, and Congress in 1949, the compact aims to do the following:

A. Settle existing disputes and remove causes of future controversy between the states of Colorado and Kansas, and between citizens of one and citizens of the other state, concerning the waters of the Arkansas river and their control, conservation and utilization for irrigation and other beneficial purposes.

B. Equitably divide and apportion between the states of Colorado and Kansas the waters of the Arkansas river and their utilization as well as the benefits arising from the construction, operation and maintenance by the United States of John Martin Reservoir Project for water conservation purposes.[6]

The Arkansas River today

Today, Arkansas River water flows in from Colorado but dries up west of Garden City. Stream drying is common across western Kansas. Figure 8a shows the rivers and streams in Kansas that transitioned from perennial to non-perennial flow since 1961. Figure 8b shows the average daily discharge, or rate of streamflow, in the Arkansas River at two gage locations.[7] The gage at Coolidge (blue) shows relatively stable inflows across the state line from Colorado, while the downstream Dodge City gage (red) shows the transition in the 1970s to intermittent flow downstream. This change is attributed to the combination of diverting the water into the irrigation canals and increased groundwater pumping rates in Garden City that ultimately disconnects the inflows from Colorado, which are controlled by the Arkansas River Compact, from reaching downstream of Garden City.

Streamflow research at the Kansas Geological Survey

Scientists at the Kansas Geological Survey are working to understand what factors influence when and where streamflow

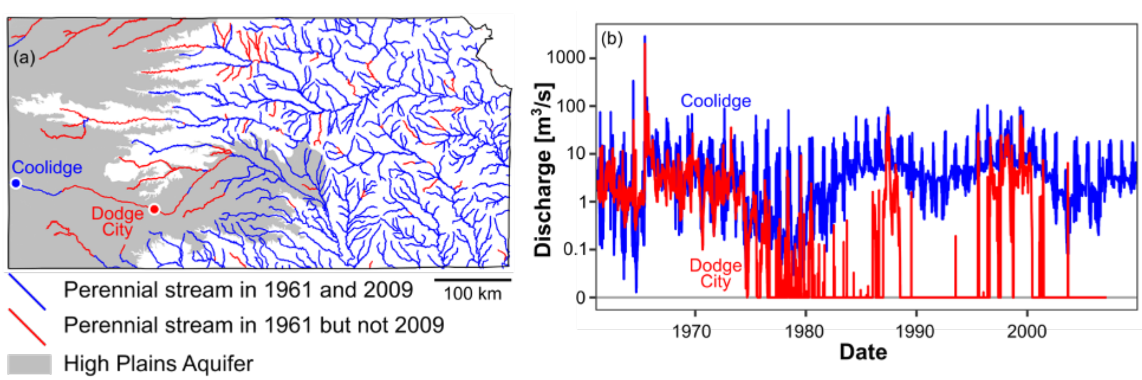

Figure 8. (a) Kansas's major stream network, showing transitions from perennial to non-perennial between 1961 and 2009. Map modified from data used in the Kansas High Plains Aquifer Atlas (http://www.kgs.ku.edu/HighPlains/HPA_Atlas/index.html) and based on data collected and interpreted from the Kansas Surface Water Register (Kansas Department of Health and Environment, 2013). (b) Comparison of daily discharge near the Colorado border (Coolidge gage) and downstream (Dodge City).[8]

occurs in non-perennial streams across the state, including in the Arkansas River. Farther downstream, near Larned, the Arkansas River regularly shifts between multiyear flowing and dry conditions. Through long-term studies of the Arkansas River, KGS researchers have found that groundwater levels exert the most influence over when and where the Arkansas River dries. When groundwater levels rise above the streambed, flow in the river is maintained. When groundwater levels drop, the river is at risk of drying when precipitation is insufficient to support flow. Groundwater levels respond to both human actions (such as pumping and surface water diversions) and climate conditions (such as droughts and wet periods), exemplifying the interconnected nature of groundwater resources, rivers and streams, and water management practices.

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STOP
4

Playas in Kansas

Rolfe Mandel, Blair Schneider and Scott Ishman

KEY FACTS

- Playas are being investigated for their natural potential recharge sources to the High Plains aquifer.
- Playas provide numerous ecosystem services, such as providing habitat for wildlife, increasing biodiversity, and sequestering carbon.
- Playas are one of the most recognized water resources in the High Plains of Kansas and can range in size from 3 to 20 meters deep.
- There are more than 22,000 playas across 43 western Kansas counties.
- Radiocarbon dating suggests that many of these depressions formed over the past 11,000 years.

Playas are recognized as one of the most vital water resources on the High Plains, a point that will be emphasized during this field conference. Playas are natural recharge sources to the High Plains aquifer, which means that they can provide water to the aquifer below as the water they hold seeps into the ground. Playas also provide numerous other ecosystem services, such as providing habitat for wildlife, increasing biodiversity, and sequestering carbon.[1, 2] Playas — shallow, relatively round, closed depressions, with diameters ranging from a few meters to several kilometers — are common in western Kansas (fig. 1).[3] Most of these depressions are less than 3 meters deep, but some of the larger ones are as much as 15 to 20 meters deep. In their natural state, playas receive water only from precipitation and runoff. Although playas may remain dry for months or years during drought, they can fill quickly and hold water for weeks, months, or years when precipitation is high.[4] Hence, it is not surprising that these dynamic features in the landscape are referred to as playas, which is Spanish for "beach."

Figure 1. Aerial view of a playa filled with rainwater in Lane County. Photo: Bill Johnson.

Playas in western Kansas

More than 22,000 playas cover more than 81,000 acres in 43 western Kansas counties.[5] Scott, Thomas, Lane, Cheyenne, Finney, and Sherman counties have the most playas per county, with their numbers ranging from the highest of 2,116 in Scott County to 1,373 in Sherman County. More than half are in Scott, Lane, and Finney counties. In total acreage, Finney and Meade counties lead with about 8,036 and 6,921 acres of playas, respectively.[6]

The formation of playas has been attributed to many different causes, including wind deflation, solution subsidence, water erosion, and wallowing of buffalo. Some of the playas have low, silty, crescent-shaped dunes called lunettes on the eastern side of the basins, formed when sediment was blown out of the playas. Also, there is recent evidence that some playas formed when small, intermittent streams were blocked by sand dunes, forming ponds behind the dune dams. Radiocarbon dating of the buried soils in playas suggest that many of these depressions formed over the past 11,000 years.[7] Many slowly filled with sediment until a period of inten
in about 7,000 years ago, and w
deepened the playa basins over
years. This period was followe
sedimentation punctuated by sc
in the playas, which continues t
springs, playas have attracted g
people over at least the past 13,

Winger archaeological site, a Late Paleoindian bison bone bed contained in playa fill on the High Plains of southwestern Kansas, is a case in point.[9] Lunettes on the southeast side of playas also have yielded archaeological finds, supporting the idea that these dunes likely provided shelter from northwesterly winds.

Playas and aquifer recharge

Playas often occur in flat, semi-arid regions where evaporation rates are high, all of which contribute to the playa hydroperiod, or the period of time that a playa is ponding water. The hydroperiod is variable over time and unique to each individual playa. Sediment that has accumulated in the playas tends to have a high content of expansive clay, which helps retain water, thereby creating wetland conditions (fig. 2). However, when the playas become dry, large, deep cracks form in the clayey deposits. Those cracks may provide paths for water to percolate into the underlying sediments, resulting in significant increases in groundwater recharge rates to the High Plains

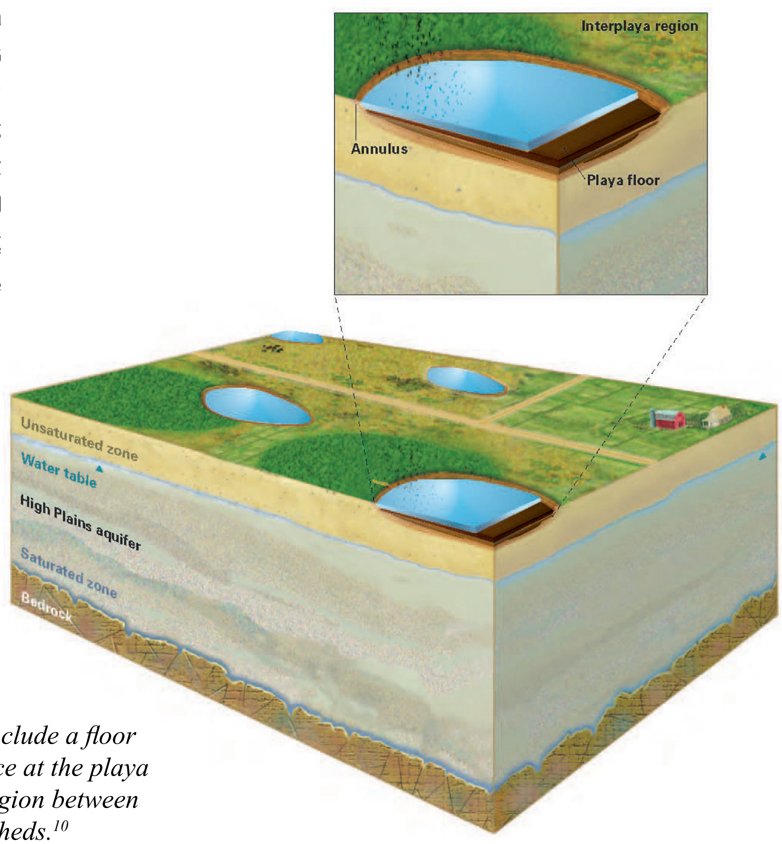

Figure 2. Playa features include a floor and annulus (sloped surface at the playa margin). The interplaya region between playas includes the watersheds.[10]

aquifer at the playas in comparison to the surrounding landscape.[11, 12] Extreme rainfall events can lead to more ponding in the playa and increase the amount of water that seeps below the subsurface.

Playas and KGS research

Scientists at the KGS are collaborating with the University of Waterloo, Kansas Biological Survey, and the University of Minnesota-Mankato to study the interaction between agriculture and playas to improve understanding of how farming playas affects recharge rate and associated issues. This research is significant because 80% of the more than 22,000 playas in western Kansas have been plowed and planted over. Farming often increases playa sedimentation, which reduces the volume of water a playa basin can hold as well as changing the soil structure. The goal of this project, funded by the U.S. Environmental Protection Agency and the Kansas Water Office, is to measure whether the effects of farming reduce recharge rates to the High Plains aquifer.

Researchers selected 15 playas within Groundwater Management District 1 boundaries (see fig. 3) for this study. KGS and KBS scientists are analyzing water chemistry and soil samples and inventorying plant and animal life in and around each of these playas. They are also collecting cores, or sections of rock and sediment obtained by drilling, from selected playas to determine sediment depth and soil structure. Finally, they will measure how much water is transferred from the playa to the aquifer using chemical tracers and specialized equipment.

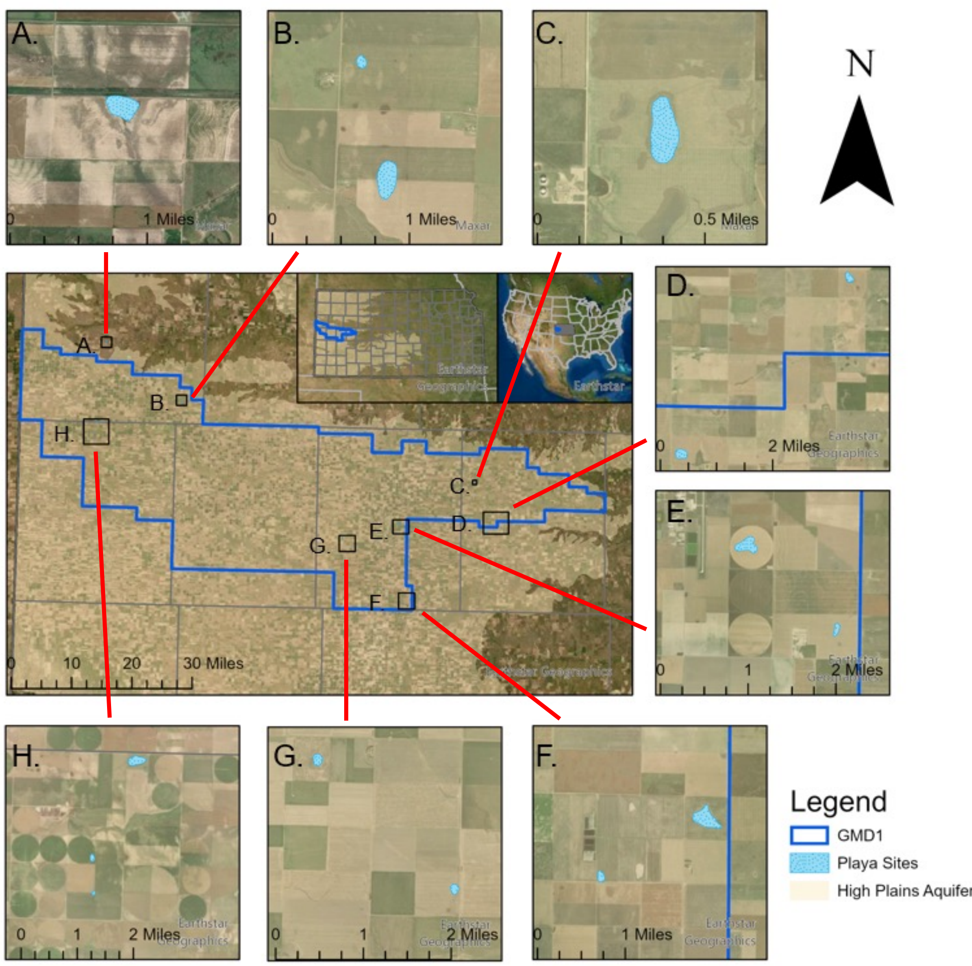

Figure 3. Playas selected for study within Groundwater Management District 1 boundaries.

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STOP 5

Kearny-Finney Index Well Program, Q Stable, and Groundwater Modeling

Andy Connolly and Brownie Wilson

KEY FACTS

- The Ogallala aquifer, the main source of water for irrigation across western Kansas, has seen a drastic decrease in water levels since the 1960s.
- The Kansas Geological Survey and the Department of Water Resources measure roughly 1,400 wells once a year to record water levels in central and southwest Kansas aquifers.
- The High Plains Aquifer Index Well program, started in 2007, provides continuous water-level data from 32 wells across western and south-central Kansas.
- Measurements at the Kearny-Finney Index Well indicate pumping reductions of 12–34% are needed to stabilize water levels in the area.

Every day, roughly 90% of the water used by Kansans comes from aquifers. In some areas, the future of these sources of water is in question, especially in areas where the pumping of water for irrigation and other uses exceeds the rates of natural recharge, resulting in significant decreases in water levels. It cannot be overstated how important aquifers are for Kansas. A recent study by Kansas State University estimated that the High Plains aquifer in Kansas alone is worth almost $4 billion of economic production. To better understand the conditions within the aquifers at both regional and local scales, the state relies on an extensive network of wells that are measured annually (fig. 1) or equipped with sensors to continuously observe water levels throughout the year. This stop highlights one of these continuously monitored wells, the Kearny-Finney Index Well.

Water in Kansas

The precipitation map of Kansas (fig. 2) reveals a substantial difference in the amount of rain received across the state. The extreme southeast corner of the state gets more than 40 inches

Figure 1. A KGS scientist measures water levels in western Kansas.

of rain annually but the western edge, which lies within the rain shadow of the Rocky Mountains, gets less than 20 inches.

This difference in rainfall means that where Kansans get their water — for drinking, irrigation, and other uses — varies, too. Most eastern Kansans get their water from surface sources, such as rivers, lakes, and the like (fig. 3). Higher precipitation amounts relative to evaporation rates allow for the greater potential to collect water at the surface. In contrast, in the semi-arid regions of the state, surface water supplies are more limited. As a result, western and south-central Kansans are more likely to get their water from underground sources in the form of aquifers.

Aquifers are underground layers of porous and permeable rock or unconsolidated sediment (such as sand and gravel) that hold water. To be classified as an aquifer, a body of rock or sediment must be able to yield a significant flow of water that is of high enough quality for use through a well or natural spring. The largest aquifer in Kansas is the High Plains aquifer (HPA), which in its entirety covers parts of eight states (fig. 4). The Ogallala portion of the HPA

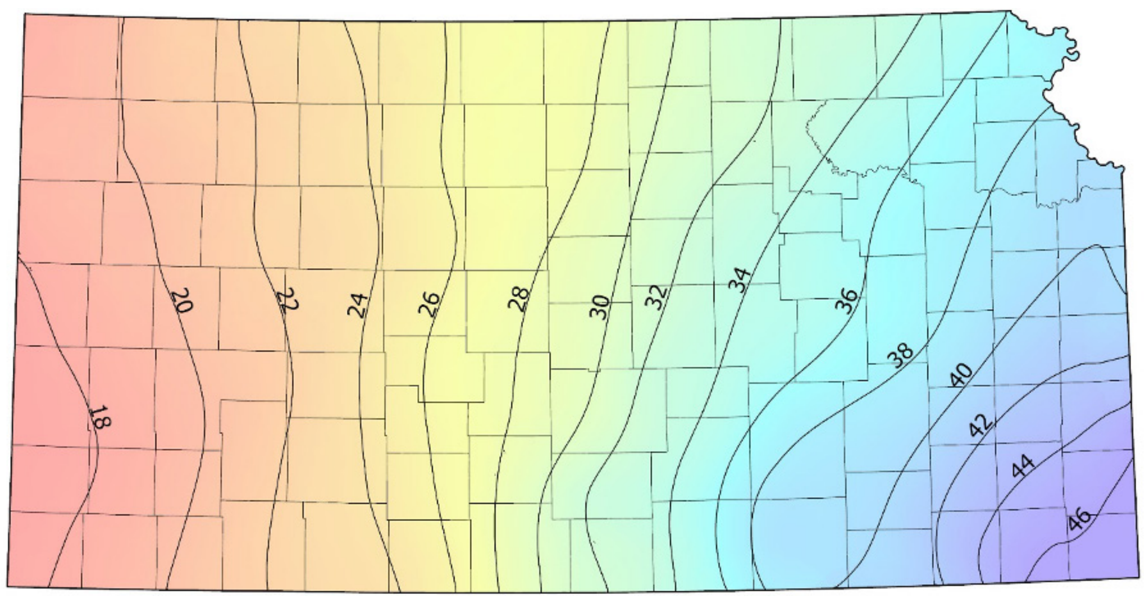

Figure 2. Normal precipitation (average from 1991 to 2020) map of Kansas. On average, the western third of the state receives less than half the amount of precipitation of southeast Kansas. Map created from data provided by the Kansas State Weather Data Library.

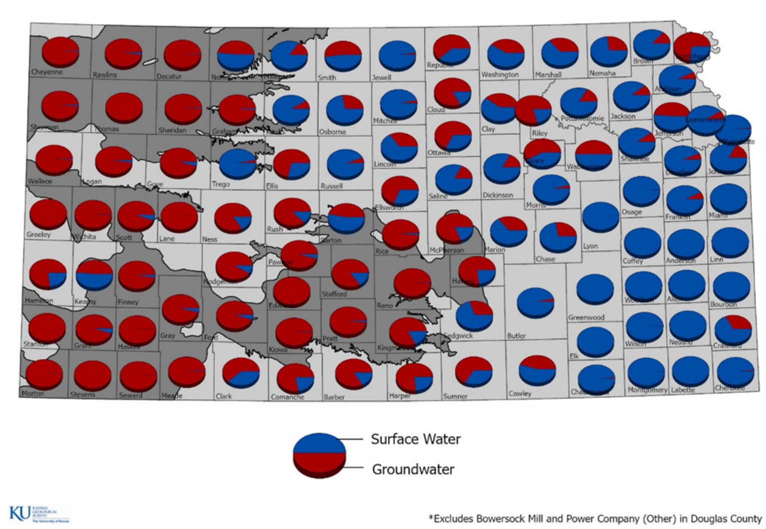

Figure 3. Proportion of the average amount of reported water usage, by county and water source, from 2012 to 2021. Blue represents surface water sources, and red represents groundwater sources. The primary extent of the High Plains aquifer, shown in dark gray, covers the western third and south-central portions of Kansas and is the primary groundwater source for most of those overlying counties.

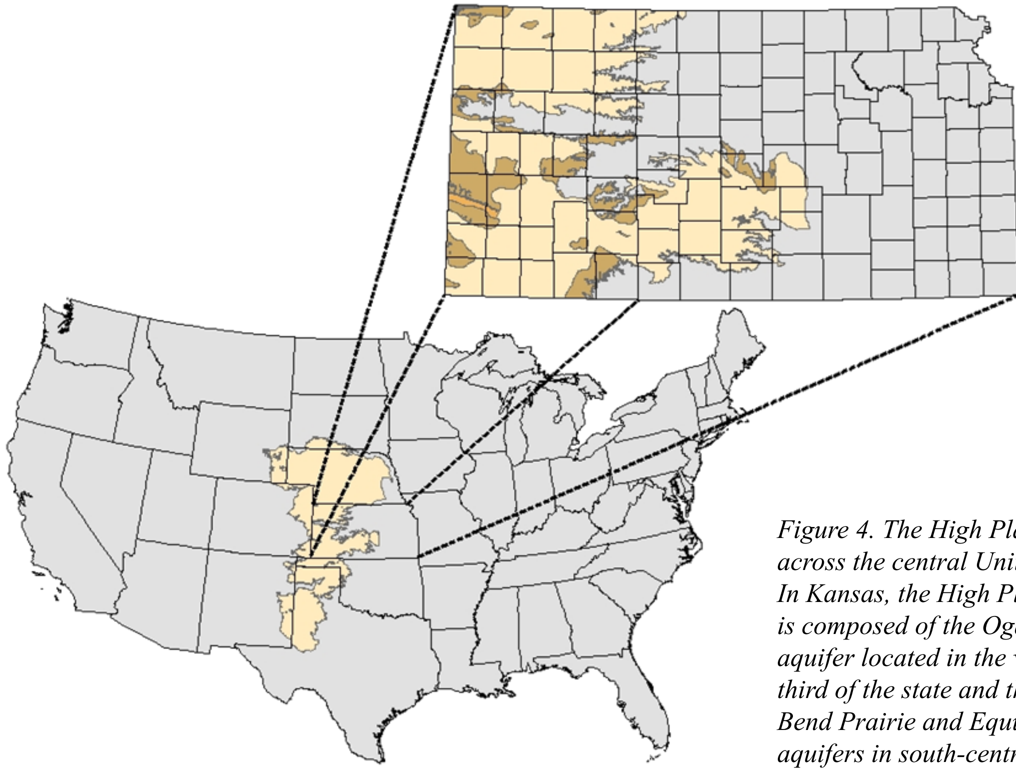

Figure 4. The High Plains aquifer across the central United States. In Kansas, the High Plains aquifer is composed of the Ogallala aquifer located in the western third of the state and the Great Bend Prairie and Equus Beds aquifers in south-central Kansas.

is located in the western third of our state and has been used as the primary source of water for many western Kansans for generations. However, limited rainfall and higher rates of groundwater pumping in the area mean the Ogallala aquifer is typically in a state of water-level declines. Studies of the Ogallala estimate that on average, the aquifer receives less than an inch of water per year from precipitation that infiltrates deep enough below the surface, a process known as "recharge." In many western Kansas areas, the aquifer loses more than a foot of water per year from pumping. Since the advent of widespread irrigation in the middle of the last century, huge portions of the area have seen significant drops in water level (fig. 5).

Index Well Program

To monitor water levels across the state, the Kansas Geological Survey and the Department of Agriculture, Division of Water Resources, have measured roughly 1,400 wells every year since 1996. These depth-to-water measurements are taken using steel or electric-tapes, which we will demonstrate at this stop. The annual measurements in this network allow scientists, policymakers, and people who rely on the aquifer's waters to understand regional changes in it over time. All data are available online through our WIZARD database (https://geohydro.kgs.ku.edu/geohydro/wizard/).

In an effort to obtain data at more local scales throughout the year, the KGS initiated the High Plains Aquifer Index Well Program in 2007. The program provides continuous water-level readings from select wells in south-central and western Kansas. Funded primarily through the Kansas Water Plan, the program started with just three wells (blue triangles in fig. 6) but has since grown to 32 with the latest two added this year. Sensors in the index wells measure the water level every hour and send the data in real time to the KGS website, where it is stored and can be accessed by the public (https://www.kgs.ku.edu/HighPlains/OHP/index_program/index.shtml).

A key aspect of the index well program is its ability to track seasonal changes. Water levels typically decrease the fastest during the summer irrigation and growing months and then recover over the fall and winter. By

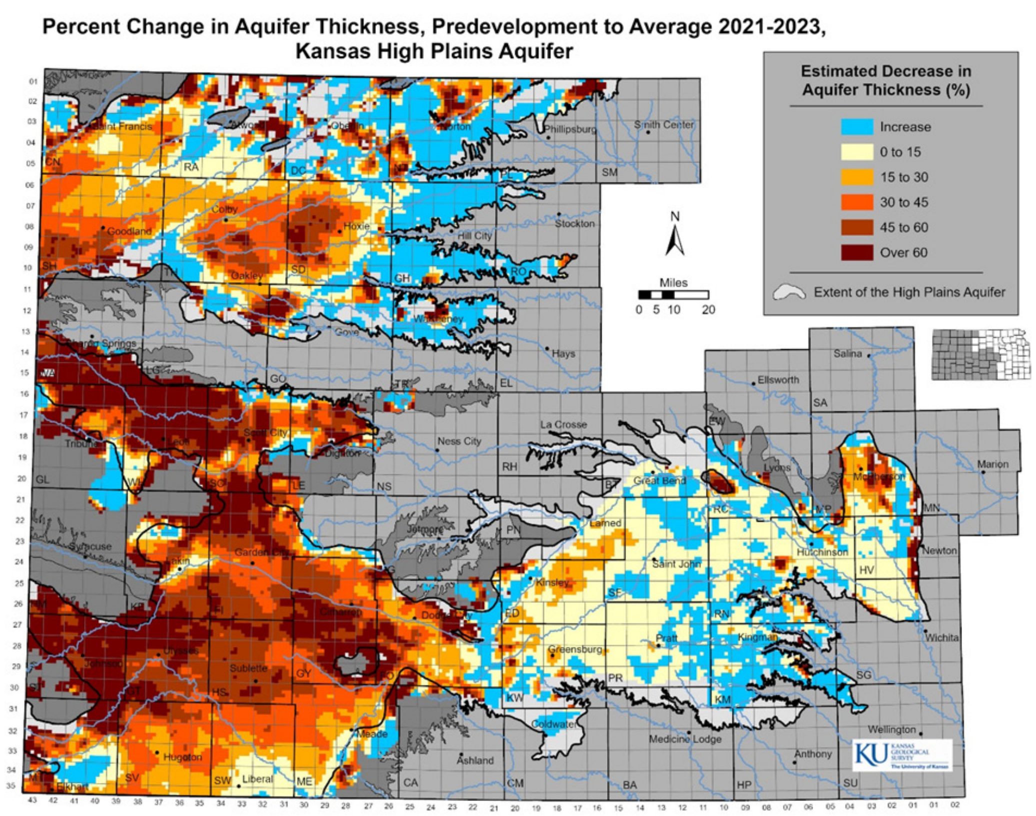

Figure 5. Changes in water levels across western Kansas from predevelopment (typically groundwater conditions in the 1940s to early 1950s) to the average 2021–2023.

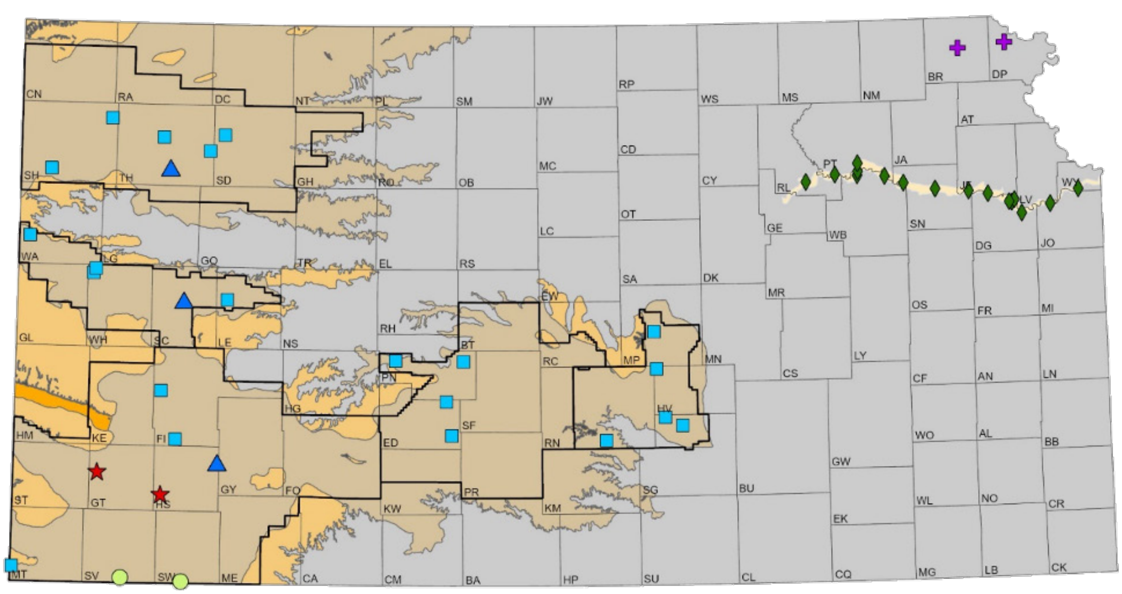

Figure 6. Location of index wells across Kansas. The three dark blue triangles indicate the first index wells established in the High Plains aquifer in 2007. Since that time, additional index wells (light blue squares, red stars, and light green circles) have been added to the High Plains aquifer index well program. Dark green diamonds represent index wells installed in the Kansas River alluvial aquifer, and purple crosses are index wells added to the glacial drift aquifers in northeast Kansas.

studying many years' worth of data, we can see how local climate conditions, soil quality, and water usage affect the water level in real time.

The rate at which water levels in the Ogallala index wells recover suggests the net inflows, defined as all the water flowing in and out of the aquifer during the non-pumping season, is remarkably consistent. This finding led scientists and researchers from the KGS to develop a simple, data-driven method called "Q Stable" to rapidly assess aquifer characteristics. Based on the relationship between groundwater usage and water-level change, Q Stable allows us to quickly assess the aquifer's response to changes in pumping.

The Kearny-Finney Index Well lies in a part of southwest Kansas where groundwater usage from the Ogallala-High Plains aquifer is supplemented by surface water that is delivered to fields through a series of canals. The Q Stable analysis of the area, based on conditions from 2013 to 2022 (fig. 7), reveals that 97% of the changes in water levels can be explained statistically by changes in reported groundwater usage. The analysis determined that to stabilize water levels for the next decade or two, pumping would need to be reduced by roughly 12% of the average of the amount pumped annually over the past 10 years. Under the drought conditions experienced in 2022, pumping reductions of 34% would be necessary to stabilize water levels.

Groundwater models

Numerical groundwater flow models are sophisticated computer programs that attempt to simulate portions of the hydrologic cycle, such as water-level changes in an aquifer. Unlike the Q Stable process, which groups inflows and outflows into a single variable, groundwater models represent the components of the water budget individually. A water budget is similar to a household financial budget. It takes into account factors such as recharge from the land surface, irrigation return flows (excess irrigation water that infiltrates back into the aquifer), evapotranspiration, and gradient flows (water flowing underground) in and out of the aquifer, to name a few. Once a model has been calibrated — its components tested and adjusted to be consistent with known, measurable values — it becomes a

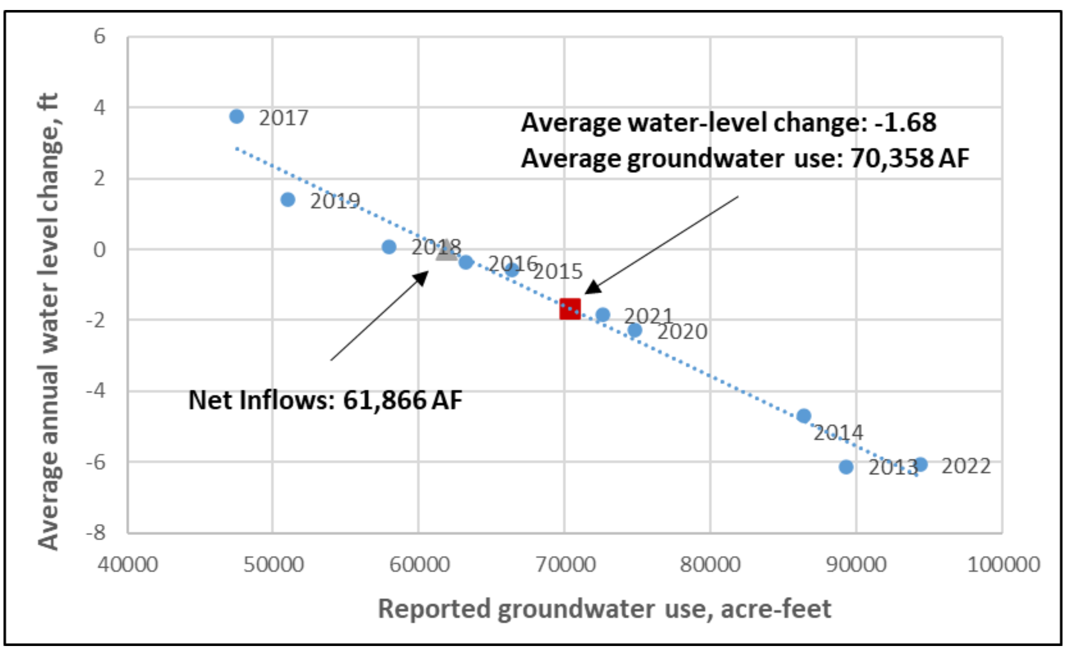

Figure 7. Average water-level change (feet) compared to the amount of annual water use for the area around the Kearny-Finney Index Well. The red square represents the average water level from 2012 to 2022, and the olive-gray triangle represents net inflows.

powerful tool to run "what if…." scenarios. Using a groundwater flow model, water managers can measure an aquifer's response to such things as water conservation proposals, variations in streamflow, and climatic changes.

The KGS is in the process of updating a groundwater model for southwest Kansas to simulate conditions in the Ogallala-High Plains aquifer and portions of the underlying Dakota aquifer (fig. 8). Funded by the Kansas Water Office and Southwest Kansas Groundwater Management District 3, the model consists of a grid of 60,000 cells, each 0.5 by 0.5 miles in size, that are coded with values that represent complex aquifer characteristics: land surface elevations, bedrock depths, pumping demands, aquifer properties, changes in precipitation. As the model runs through a series of six-month time steps, it simulates the various inflows and outflows to the aquifer and then computes water-table elevations (fig. 9).

Models are only as good as the data that go into them. Data are often complex and detailed, with some elements being easy to quantify (precipitation, for example) while others (such as recharge) have inherent levels of uncertainty. Once developed, models are fantastic tools for water management but understanding their strengths and weaknesses is key to the proper use.

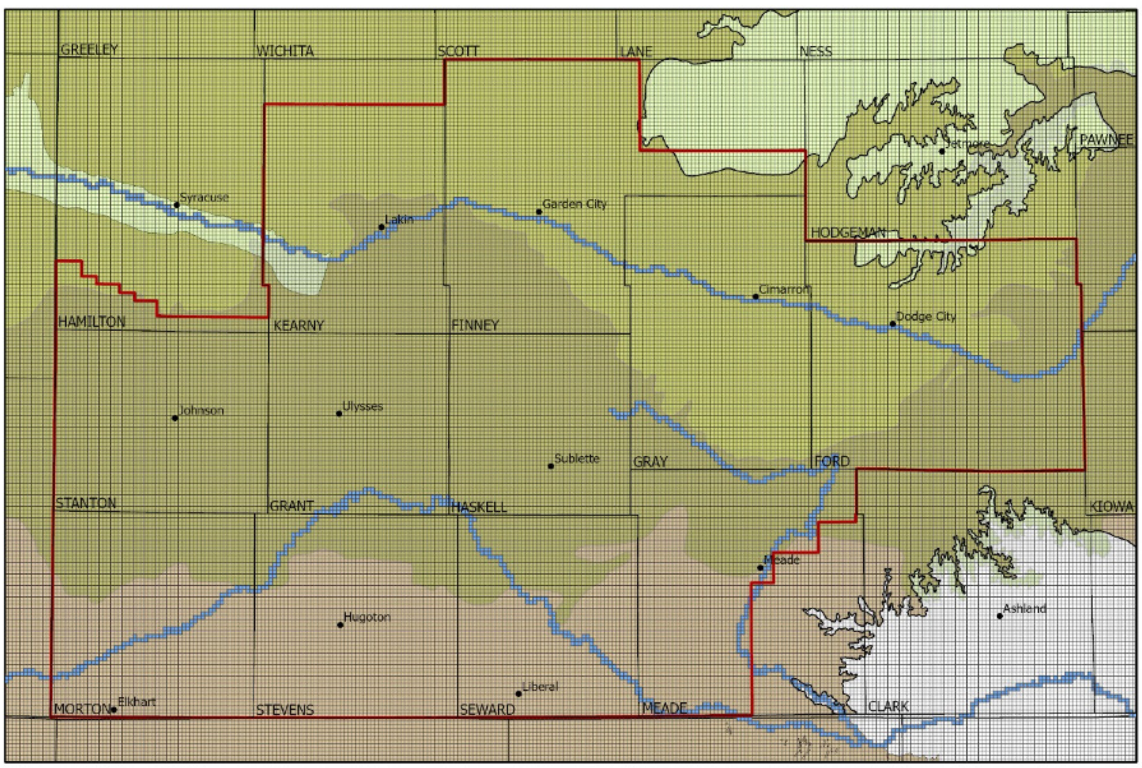

Figure 8. Study area for the Southwest Kansas Groundwater Management District 3 model. The focus of the project is on the Ogallala-High Plains aquifer and the hydrologically connected, underlying Dakota aquifer shown in darker green.

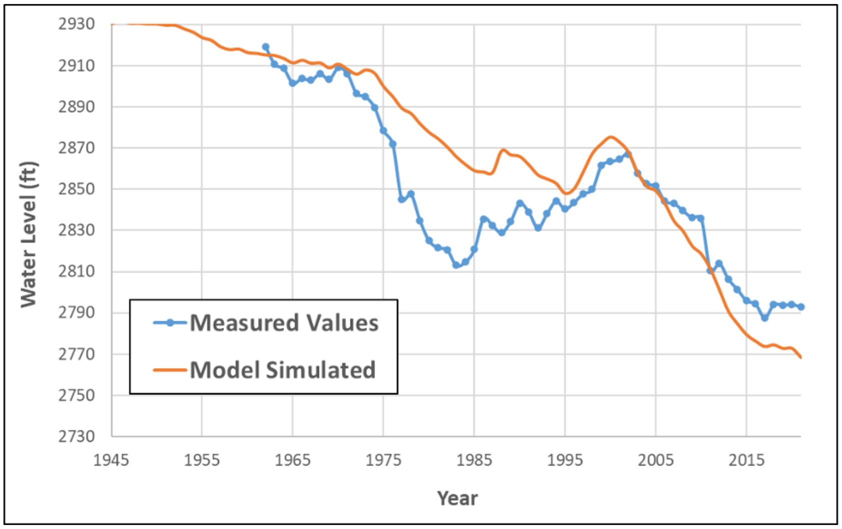

Figure 9. Preliminary results of simulated water levels from the GMD3 model (still under construction) for a well located in sec. 17, T. 23 S., R. 43 W., in Finney County.

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NOTES

Friday, June 9, 2023

7 a.m. Breakfast provided at the Sleep Inn & Suites

8 a.m. Check out of hotel and meet at bus

8:30 a.m. Bus to Lakin Water Treatment Facility
1590 Road 160
Lakin, KS 67860

9 a.m. **Stop 6: Lakin Water Treatment Facility**
Fred Jones, Water Resource Manager, Garden City
Erin Seybold, Kansas Geological Survey

10 a.m. Bus to Patterson Well Site
791 Road 250
Lakin, KS 67860

Restroom stop in Lakin

Bus Talk: Climate Effects on Transportation and Safety
Neil Croxton, Kansas Department of Transportation

10:30 a.m. **Stop 7: Patterson Well Site**
Brett Blazer, Berexco
Franek Hasiuk, Kansas Geological Survey
Jennifer Raney, Kansas Geological Survey

12:30 p.m. Bus to Sleep Inn & Suites Hotel
Lunch on Bus

1:30 p.m. **Stop 8: Panel Discussion on the "Future of Water in Western Kansas"**
Moderator: Brownie Wilson
Panel members:
Katie Durham, Groundwater Management District 1
Mark Rude, Groundwater Management District 3
Shannon Kenyon, Groundwater Management District 4
Leo Henning, Kansas Department of Health and Environment
Matt Smith, Playa Lake Joint Venture
Jay Kalbas, Kansas Geological Survey
Earl Lewis, Kansas Department of Agriculture

2:30 p.m. End of field conference

NOTES

Groundwater Quality in the Upper Arkansas River Corridor

Blair Schneider, Don Whittemore, and Erin Seybold

STOP 6

KEY FACTS

- The Arkansas River is very saline, which has resulted in more than a century of contamination of the alluvial aquifer and the High Plains aquifer in southwest Kansas.
- The Kansas Geological Survey has been studying the rising concentrations of uranium in the Arkansas River water since the 1970s.
- The most recent mineralization study revealed high concentrations of sulfate north and south of the Arkansas River in Lakin and Garden City.
- The KGS study identified high concentrations of uranium north of the river in Garden City.
- The city of Lakin constructed a $6.6 million water treatment plant in 2013 to address uranium contamination.

In addition to the issue of diminishing flow in the Arkansas River in western Kansas (see Stop 3 — The Arkansas River: A Historical Overview), the river water that crosses the border from Colorado into Kansas presents another challenge for those who rely on it for irrigation and human consumption: contamination. The river water is saline, which means it has a high amount of dissolved salt or ion contents in the water. This saline water has resulted in more than a century of contamination of the alluvial aquifer and the High Plains aquifer in southwest Kansas. For the last several decades, the water crossing the border also has contained a uranium concentration that exceeds the maximum contaminant level (MCL) of 30 micrograms per liter for public supplies of drinking water. To address this serious issue, the Kansas Geological Survey and the Kansas Department of Health and Environment have worked together to study the extent of the contamination, and the city of Lakin constructed a 400,000 gallon underground reservoir to capture contaminated water and dispose of it safely through a deep underground injection well.

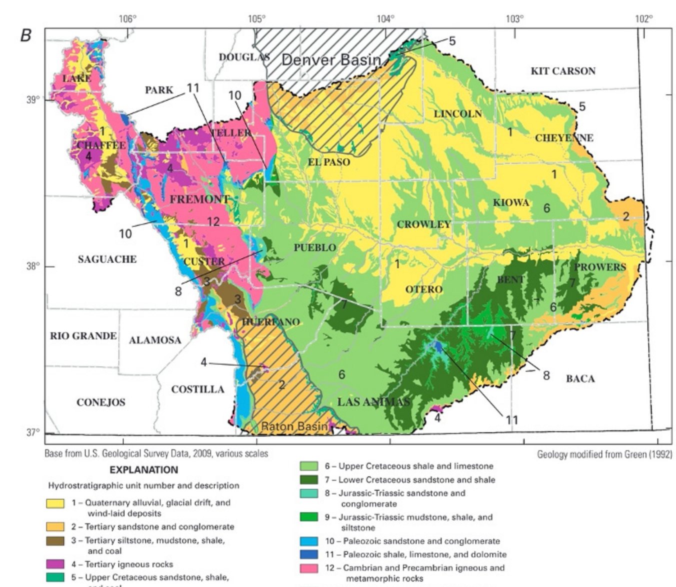

Figure 1. Surface exposure of bedrock units in the Arkansas River basin in Colorado.[1] The Arkansas River weathers rocks in units 5–7 (green colors), which releases uranium and sulfate that are naturally contained in those rocks.

Where does the contamination come from?

Two main types of contamination have been studied in this region: sulfates and uranium. The main source of the contaminants is natural, the result of weathering of the bedrock the river basin cuts through. The bedrock consists of shales and chalky limestone that contain minerals and sulfides, which release uranium and other elements into the water (fig. 1). The natural release of these contaminants alone, however, would not lead to the significantly elevated concentrations of uranium and sulfates we see in the Arkansas River today. An additional anthropogenic, or manmade, source contributes to the higher levels. Water use practices in Colorado and Kansas, starting with the diversion of water into ditches for irrigation, lead to evapotranspiration of water, leaving behind higher concentrations of sulfates and uranium in the soils and remaining surface water. When this water infiltrates the aquifer, higher concentrations affect groundwater, too. Pumping of groundwater from wells that already contain high levels of sulfates further concentrates the level of contaminants at the surface (fig. 2).

Results of the most recent KGS mineralization study

The most recent mineralization study completed by the KGS builds off previous KGS studies in the 1970s and 1990s. These studies have focused on river and groundwater quality in the upper Arkansas River corridor and were partially funded by the Kansas Water Plan. The results of the most recent study were published in a Kansas Geological Survey open-file report this year and are publicly available on the KGS website.[2] The major objectives of the new study were to determine the current input of saline concentrations in the Arkansas River water, determine the current distribution of sulfate and uranium concentrations in groundwater in the upper Arkansas River corridor, and assess factors that control the distribution of these contaminants. The results found that the mean annual concentrations of uranium exceed 30 micrograms per liter, with higher concentrations in years with more streamflow (fig. 3). As part of the study, the KGS analyzed water samples from 330 domestic, public water supply, irrigation, stock, and observation wells. Results of the analyses found the highest concentrations of uranium around the Garden City area (fig. 4). Sulfate concentrations were highest in the area around Lakin, where there is substantial ditch irrigation and diversion of water to irrigation canals. The sulfate concentrations are distributed north and south of the river corridor. The uranium results show areas of high concentration predominantly on the north side of the river around Lakin and Garden City. Wells closer to the river channel have higher sulfate and uranium concentrations, and at some well locations, uranium and sulfate concentrations increase at greater depths in the aquifer.

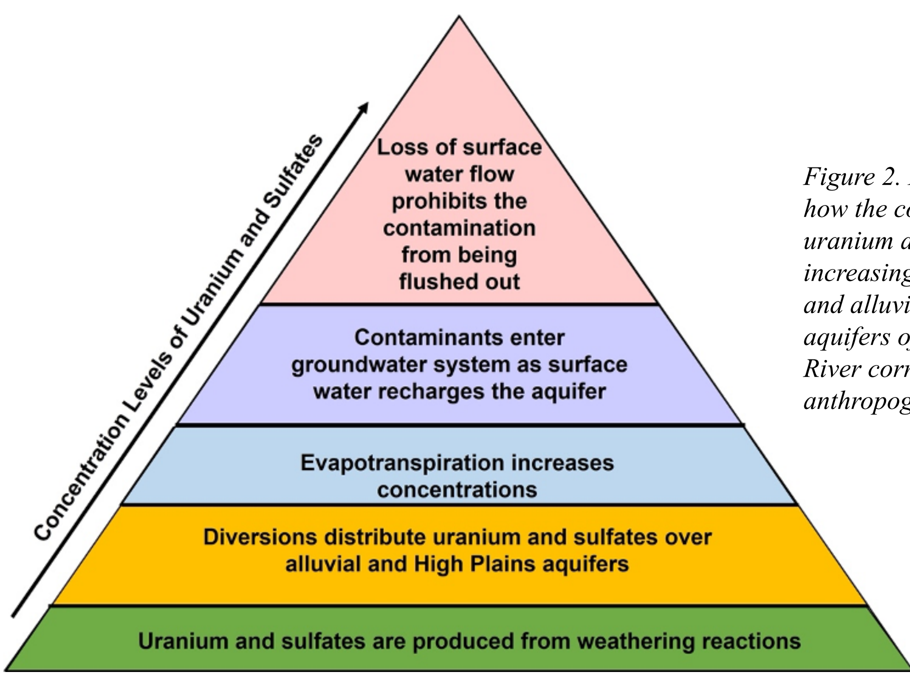

Figure 2. Model demonstrating how the concentrations of uranium and sulfate are increasing in the river water and alluvial and High Plains aquifers of the upper Arkansas River corridor in Kansas due to anthropogenic activities.

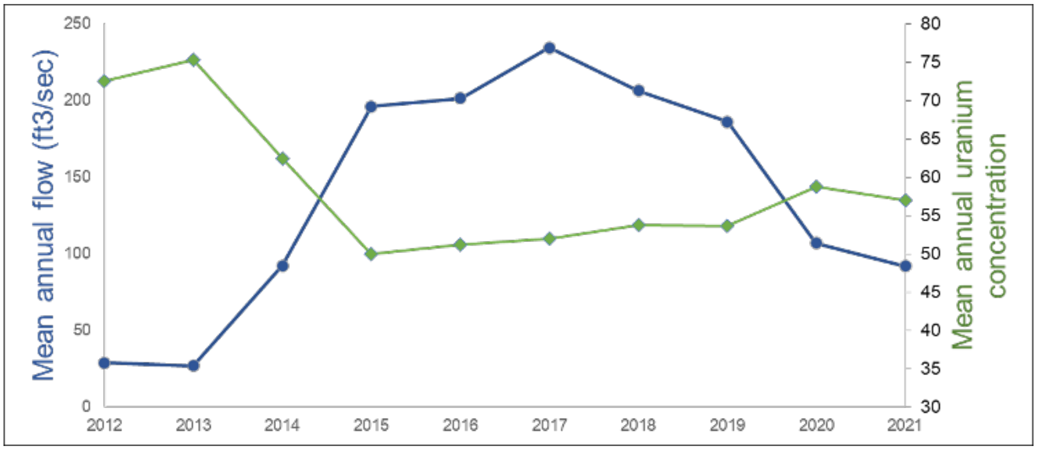

Figure 3. Mean uranium concentration levels from 2012 to 2021 in green and mean annual flow rates of the Arkansas River over the same time period in blue.

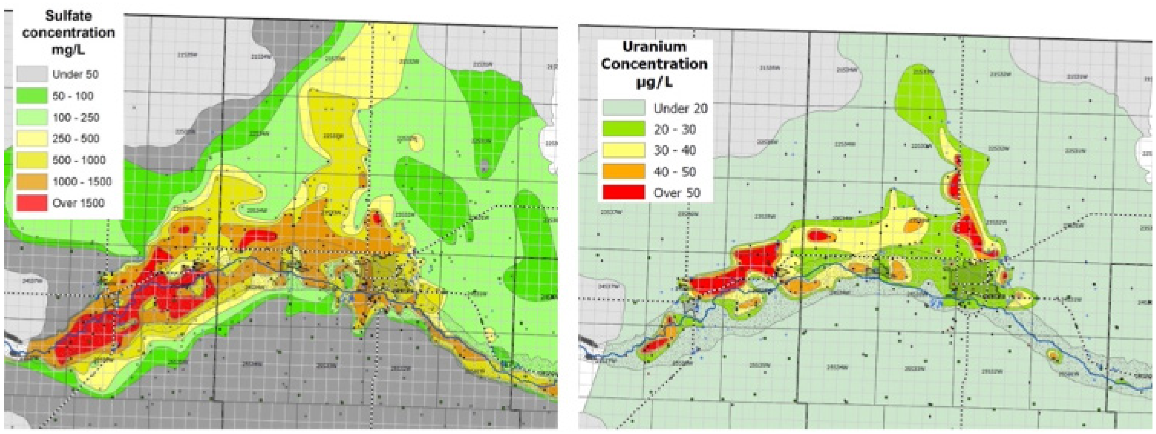

Figure 4. Sulfate (left) and uranium (right) concentration results in the High Plains aquifer in Kearny and western Finney counties. Yellow, orange, and red indicate high concentrations.

A new treatment plant in Lakin

Lakin has dealt with water hardness issues and higher sulfate concentrations for years but not to an extent that required a water treatment plant. That changed in the last decade, however, when water testing began to reveal uranium concentrations ranging from 32 to 38 micrograms per liter, higher than the Environmental Protection Agency's maximum contaminant threshold for public drinking water supplies. In 2004, the EPA's final rule on radionuclides in drinking water capped uranium at 30 micrograms per liter to avoid toxic effects to an individual's kidneys. The city of Lakin had two options: find a new source of water or build a plant to treat the contaminated water. Recognizing that the city might not be able to find a reliable source of water elsewhere, officials chose to build a treatment plant. The total cost of this project was more than $6.6 million dollars and was funded in part by the U.S. Department of Agriculture.

Several water treatment technologies can be used to address uranium contamination.[3] Ion exchange technologies use synthetic resins to capture the negatively charged ions in uranium and replace them with safer ions, such as chloride. Line softening further supports ion exchange technologies by attaching a drain line to the resin filter so that the captured ions don't build up. Membrane technologies, such as reverse osmosis and nanofiltration, physically remove contaminants from water by forcing the water at high pressure through semi-permeable membranes. Coagulation technologies use an adsorptive media treatment that passes the contaminated water through a media bed to capture the inorganic compounds. The city chose to move forward with membrane technology treatments because that technology can address the water hardness and high sulfate concentrations that the city faces, in addition to removing the uranium.[4]

Though the treatment process results in substantial amounts of usable water, filtered contaminants are concentrated in a smaller amount of water — "reject water" — that must then be disposed of appropriately. One major component of the new water treatment plant was figuring out what to do with the reject water. First, the city constructed a two-compartment underground storage tank with a total capacity of 400,000 gallons. The reject water that comes out of the membrane systems is sent directly to the underground storage tank. Next, the city worked with the Kansas Department of Health and Environment to permit a Class V injection well that was installed to a total depth of 6,400 feet. The water from the underground storage tank is injected deep underground through this injection well into the Arbuckle Group, where it doesn't endanger other sources of drinking water. Since the construction of this treatment plant in 2013, water quality has improved significantly in the city of Lakin.

Resources

[1] L. D. Miller, K. R. Watts, R. F. Ortiz, and Tamara Ivahnenko, *Occurrence and Distribution of Dissolved Solids, Selenium, and Uranium in Groundwater and Surface Water in the Arkansas River Basin from the Headwaters to Coolidge, Kansas, 1970–2009* (U.S. Geological Survey Scientific Investigations Report 2010–5069, 2010), 59 p.

[2] D. O. Whittemore, E. C. Seybold, B. B. Wilson, J. J Woods, and J. J. Butler, Jr., *Assessment of Groundwater Mineralization in the Upper Arkansas River Corridor* (Kansas Geological Survey Open-File Report No. 2023-21 2023). https://www.kgs.ku.edu/Publications/OFR/2023/OFR2023-21.pdf

[3] D. Zerr, *Uranium in City's Water Causes Lakin to Install Treatment Plant* (The Kansas Lifeline, Kansas Rural Water Association, 2012, p. 34–38).

[4] Zerr, *Uranium in City's Water Causes Lakin to Install Treatment Plant.*

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How Climate Change Is Impacting KDOT Infrastructure

Climate change has KDOT's attention. While not currently using Federal Highway Administration climate tools, changing climate conditions are incorporated into the agency's design process.

- The amount and the intensity in rainfall at any particular location comes into play in KDOT design and planning:
    - Hydraulic parameters are studied periodically and updated parameters are used in our design of culverts.
    - The University of Kansas recently studied rainfall intensity tables. As a result, western Kansas's value was reduced while values to the eastern half of the state continue to increase.
    - KDOT's bridge staff uses USGS monitoring gages to help understand the flow characteristics of Kansas streams.
    - KDOT is using more 2-D hydraulic analysis to look at flows for a bridge site across the entire floodplain rather than only at the particular channel.
    - The Bridge and the Geotechnical sections are monitoring the degradation of stream bed elevations occurring in some of our major rivers.
- Due to concerns about "d-cracking," a 660 specification for aggregates was added for increased freeze-thaw testing requirement to aid in the longevity of our pavements.

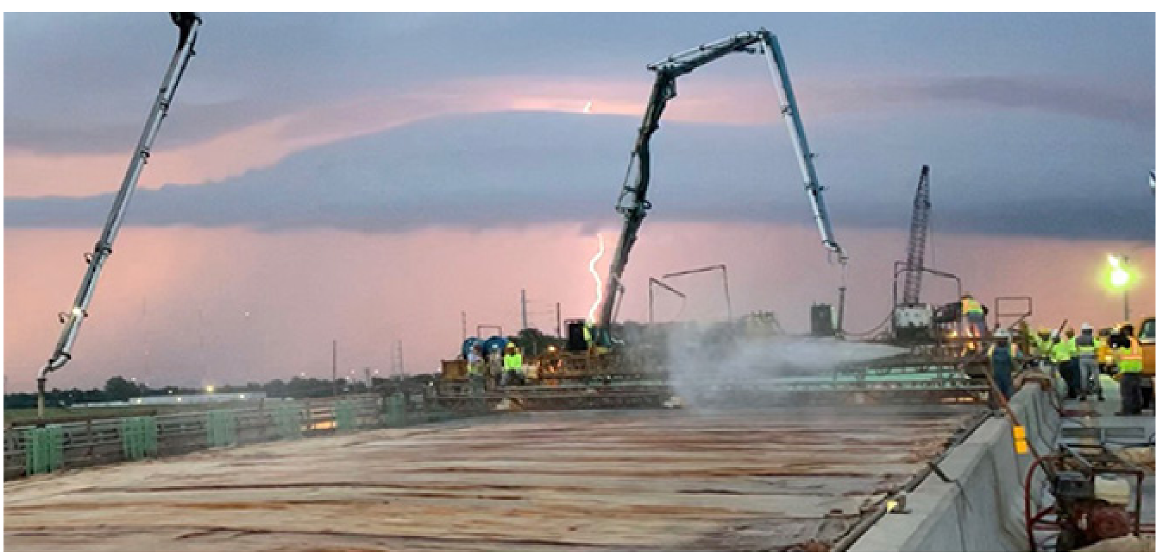

Photo from the I235green project website showing KDOT workers pouring over a new bridge above the Little Arkansas River in Wichita. A strike of distant lightning can be seen in the background.

D-cracking refers to deterioration due to freezing and thawing of properly proportioned, air-entrained concrete made with aggregate susceptible to freeze/thaw damage.

- KDOT intends to implement the MEPDG (Mechanistic-Empirical Pavement Design Guide) to monitor pavement conditions and to include environmental variables in the design process.
- For temperature and wind, KDOT has traditionally based designs on the extremes we see here in Kansas. Climate change is not projected to affect those extremes, though it may affect the averages.
- Development of a Resilience Improvement Plan is underway with the help of a consultant. It will include a vulnerability assessment of all state highway assets.

Many recent projects incorporate the above modifications. One example is Interstate 235 reconstruction over Broadway in Wichita: www.235green.org.

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Patterson Oil Field

Franek Hasiuk, Jenn Raney, and Dana Wreath

STOP 7

KEY FACTS

- Oil production and brine injection at the Patterson field are done through wells designed to protect usable groundwater.
- Oil production from Patterson field pays approximately $700,000 in taxes annually.
- Oil is produced from a thin sandstone at a depth of approximately 4,950 ft by injecting brine to push it to the surface.

Although we all may use oil and oil-derived products daily, we may not be as familiar with the sources of those materials or how they are brought to market. At this stop, we will discuss how an oil field works as the first in a long series of steps that result in gas at your local filling station or plastic containers on your store's shelves. In addition, we will discuss how oil production and water injection wells are designed to protect groundwater and related topics.

Patterson field background and geology

The Patterson field was discovered in October 1941, with the drilling of the Gates O. Patterson Unit 1-23 well, located in the southeast quarter of sec. 23, T. 22 S., R. 38 W., in Kearny County (fig. 1). (Gates and Ethel, his wife, are buried in the Syracuse Cemetery in Hamilton County.) In its first full year of production, 1942, it produced 32,148 barrels of oil (fig. 2). In 2022, the field produced 105,056 barrels. The field produces from the Morrow Sandstone reservoir rock (Pennsylvanian-aged, about 315 million years old) at a depth of about 4,750 feet below the surface. Its average oil quality is 34° (light and sweet). Porosity

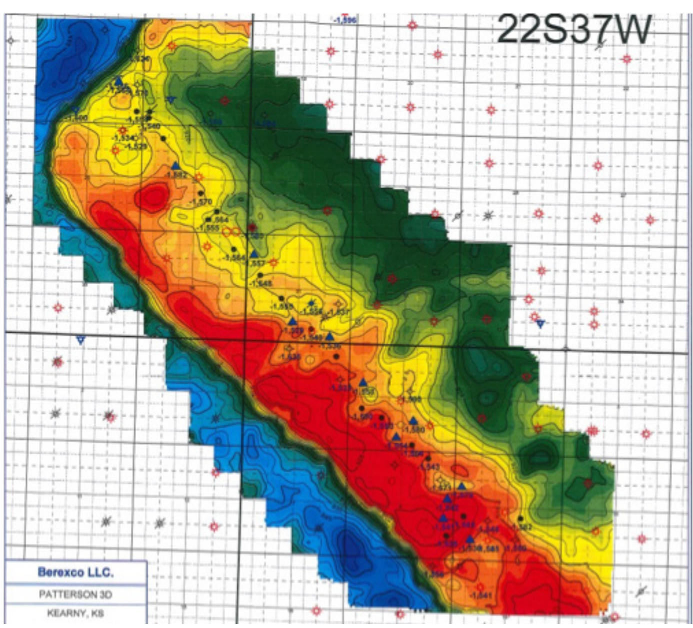

Figure 1. Topographic map of the top of the oil-producing horizon at Patterson field.

Definitions

Light vs. heavy crude: This relates to how dense the oil is. Light crude looks more like vegetable oil (or even gasoline). Heavy crude is like tar and can actually be heavier than water. Lighter crude, like the 34°API crude at Patterson, is more valuable because it's easier to refine.

Sweet vs. sour crude: This relates to its sulfur content. Sweet crude tastes sweet. Sour tastes sour. (Literally the old prospectors would taste it!) Sweeter crude is more valuable because it's easier to refine.

Porosity: How much of a rock is open space. Higher porosity reservoirs mean there can be more fluid in them, and thus they are more valuable. The oil reservoir at Patterson averages 19% porosity, so 19% of the reservoir rock volume is void space where oil can be stored.

Permeability: How fast you can move fluids through a rock. Higher permeability reservoirs mean you can pump fluids into/out of them faster, and thus they are more valuable. The oil reservoir at Patterson averages 670 millidarcies permeability, which is very good for an oil reservoir.

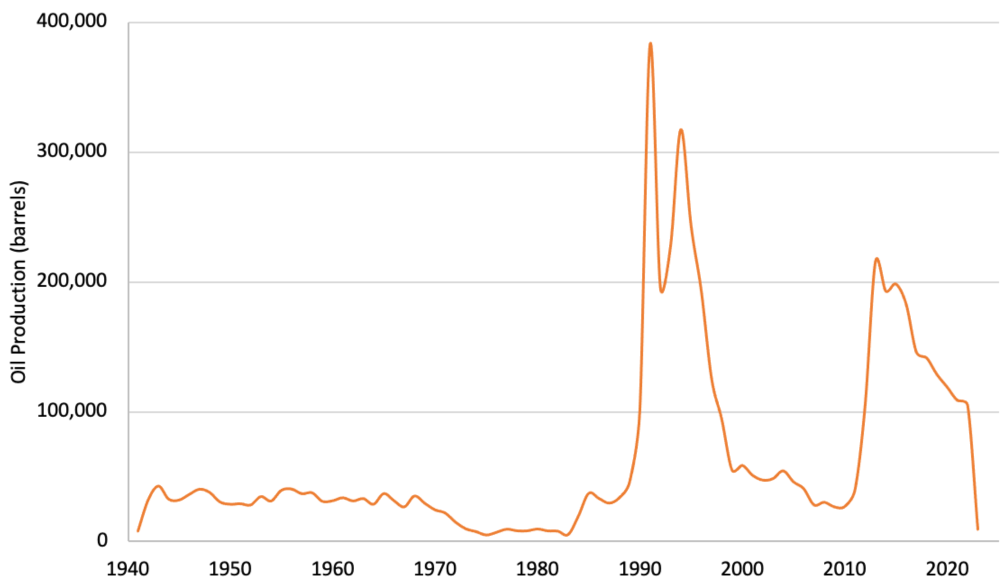

Figure 2. Production at the Patterson field since 1966. The uptick in 2009 coincided with the modern waterflood system being initiated.

averages 19% and permeability averages 670 millidarcies. The salinity in the water in the Morrow Sandstone is about 142,000 parts per million (four times the salinity of seawater, thus undrinkable). Reservoir temperature is 121°F. Taken together, these rock and crude properties make Patterson field a good oil field.

Berexco purchased the field in 1990, and a waterflood (a type of enhanced oil recovery technique) commenced in 2010. Shale rocks that overlie the Morrow Sandstone act as seal rocks, keeping the oil in the Morrow Sandstone.

Patterson oil production paid approximately $700,000 in combined ad valorem and severance taxes in 2022 on total revenue of approximately $9,500,000. About 7% of revenue goes to taxes before any expenses are paid. Three to four employees work at Patterson at one time depending on how much work is going on in the field.

Bringing oil to the surface

In the early years of the Patterson field, oil was produced by means of the natural pressure in the reservoir—this is called primary production. Perhaps 20% of the field's oil was produced in this manner. Oil production naturally wanes as pressure depletes (like popping open a soda can). At Patterson, reservoir pressure dropped from 1,147 pounds per square inch at discovery to about 50 psi before waterflooding began. To get additional oil, secondary production — increasing the pressure in the reservoir layer to drive more oil to the surface — is initiated. At Patterson, secondary production takes the form of re-injecting brine that is co-produced with the oil in a process called a "waterflood." Figure 2 shows the significant increase in production that occurred in 2009 after developing Patterson's waterflood. This secondary production is projected to be able to liberate up to 45% of the oil at Patterson. Later, tertiary production can involve injection of carbon dioxide, surfactants (such as soap), polymers, or a combination of these to improve production. The KGS has employed U.S. Department of Energy funding to study carbon dioxide injection at the Patterson field. Secondary and tertiary production methods can sometimes be lumped together under the term enhanced oil recovery.

Constructing wells to protect groundwater

Three things that every oil well must do are protect the local environment or people, ensure the health and safety of the drilling crew, and find oil. As sparsely populated as the area around Patterson field is, the chief concern in well construction is the protection of the High Plains aquifer that runs over the field. The aquifer is 200–300 feet thick and lies at a depth of approximately 250 feet below the surface. Though this may seem deep, the oil being pumped at Patterson is about 4,750 feet deep (fig. 3). The Hugoton gas field as well as thick salt layers lie between the layer from which Patterson gets its oil and the High Plains aquifer.

Building an oil well is like nesting a series of pipes and tubes inside each other like Russian nesting dolls, while filling the spaces between some of them with cement.

The first hole is 12¼ inches in diameter, drilled to a depth of about 1,640 feet, into which is placed 8⅝ inch diameter steel surface casing. Cement is injected down the center of the casing and up the outside (between the casing and the bare rock or soil) to form a protective barrier between the interior of the well and the native rock. At Patterson, this steel and cement are the first barrier protecting the High Plains aquifer.

Next, a 7⅞ inch hole is drilled to total depth (the maximum depth of the well), which is about 5,000 feet. Into that is inserted a second string of steel casing, this time 5½ inches in diameter. Another batch of cement is injected down this casing and up its outside to bond with the native rock as well as the previous steel casing above 1,640 feet.

Finally, a string of 2⅞ inches of steel production tubing through which the oil will be pumped to the surface is inserted.

When in production, groundwater is protected from oil flowing to the surface first by the steel production tubing, then by the 5½ inch steel casing, then by cement job no. 1, then by 8⅝ inch steel casing, and finally by cement job no. 2. The original hole was 12½ inches in diameter, and the final tube is 2⅞ inches, leaving a roughly 5-inch cement-steel-plastic sandwich preventing the oil from mingling with usable groundwater.

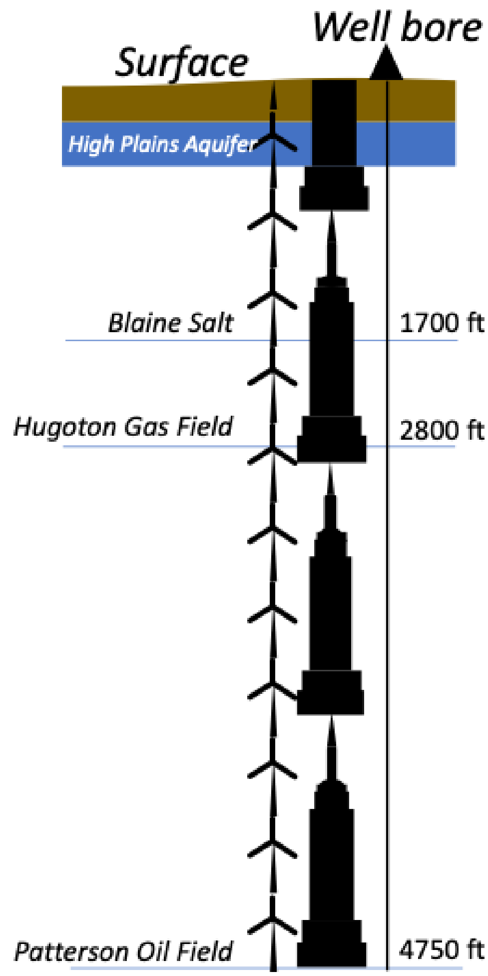

Figure 3. Relative scale of Patterson oil field compared to the High Plains aquifer, the Hugoton gas field, and the heights of a wind turbine (430 ft) and the Empire State Building (1,450 ft).

Types of oil field equipment

The infrastructure for producing oil is obvious in many parts of Kansas. At this site, we will see the three major types of surface oil field infrastructure (fig. 4):

- Brine injection well, where co-produced brine is reinjected to sweep oil to the producing wells.
- A tank battery and surface facilities, where oil and co-produced fluids such as brine are separated and held—the oil for market and the brine for reinjection.
- Oil producing well, with its moving pumpjack (also known as a nodding donkey, beam pump, or thirsty bird) that brings oil to the surface.

a
b
c

Figure 4. Types of oilfield equipment seen at the Patterson field stop: (a) brine injection well, where co-produced brine is reinjected to maintain reservoir pressure; (b) tank battery and surface facilities, where oil and co-produced fluids such as brine are separated and held—the oil for market and the brine for reinjection; and (c) oil producing well, with its moving pumpjack (also known as a nodding donkey, beam pump, or thirsty bird) that brings oil to the surface.

This equipment makes an oil production and water injection system as seen in fig. 5. The fluid pumped out of the oil production well is part oil and part brine. At the surface facilities, these are separated. The oil is sent to market (mostly via pipeline to the CHS Refinery in McPherson), and the brine is reinjected to both maintain pressure in the oil reservoir and to push more oil to the oil production wells.

Enhancing oil recovery with CO_2

CO_2 is often thought of as a byproduct of energy production, industrial processes, or other similar activities. It can even be the byproduct of opening a can of Coca-Cola. However, one company's byproduct can become another one's feedstock. With recent interest in reducing CO_2 emissions to the atmosphere, there has been renewed interest in storing CO_2 deep underground. The federal government enacted tax credits in 2016 (and sweetened them in the 2022 Bipartisan Infrastructure Law) to encourage private sector investment in technologies that can reuse or reinject CO_2. These so-called "45Q" tax credits have spurred significant activity in North Dakota, Wyoming, Louisiana, Texas, and other states where large CO_2 producers are interested in taking advantage of these tax credits to improve the economics of their operations. In Kansas, major sources of CO_2 — coal-fired power plants and ethanol distilleries, for example — are studying options for CO_2 injection. In addition, Kansas oil and gas producers have been interested in the possibility of using CO_2 to improve oil recovery, improving economics and reducing the CO_2 footprint of that fossil fuel production.

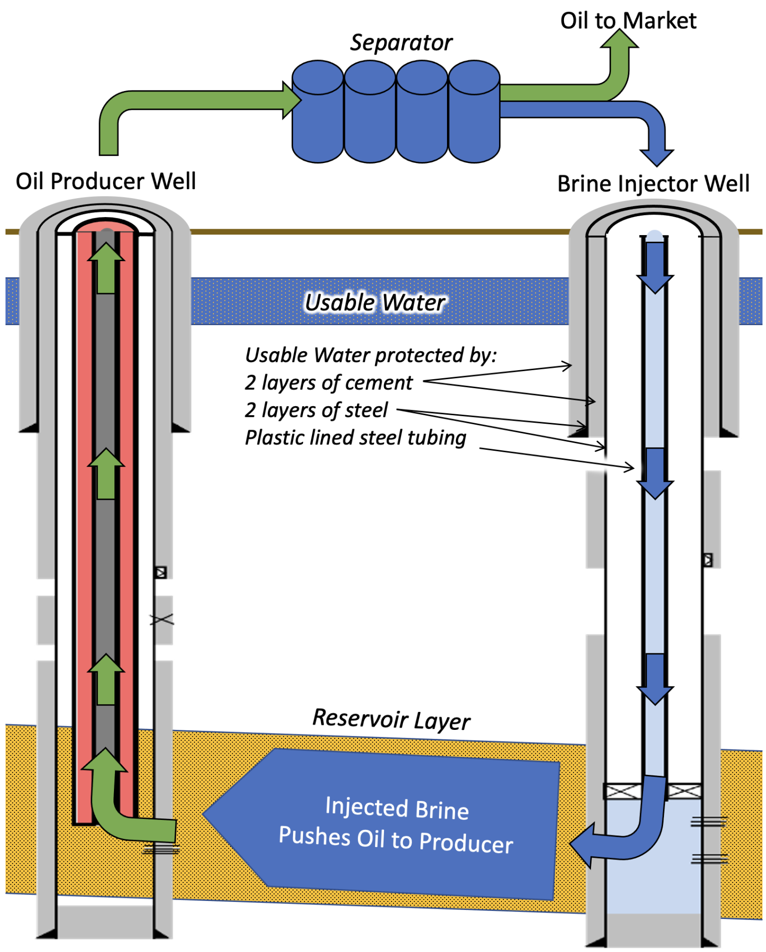

Figure 5. Schematic of oil production, separation, and water injection system at Patterson field.

Numerous KGS studies over the last 20 years have shown that the same geology that traps oil and natural gas in many deep underground layers across Kansas would also be suitable for CO_2 injection. In total, this field of redirecting CO_2 emissions for beneficial uses or storage is called "carbon capture, utilization, and storage" (CCUS).

Carbon dioxide is produced by a lot of human activities. Generally, we can describe these as "point source" and "non-point source." Point-source production refers to large producers of carbon dioxide—coal-fired power plants, refineries, chemical plants, ethanol distilleries, and the like— where large amounts of CO_2 are produced from essentially single sources. "Non-point source" refers to activities that include a lot of small CO_2 sources. For these, think of burning gas or diesel in a car or truck or emissions from livestock. Due to economies of scale, it is generally considered more economically attractive to capture CO_2 from point sources but to switch to non-CO_2 emitting technologies for non-point sources. For cars, this could involve using battery-electric motors, and in agriculture it could mean developing new breeds or feeds that result in less CO_2 production.

Previous KGS CCUS research

The KGS has had a research program dedicated to assessing the potential for CCUS in Kansas for about 20 years. This work has involved statewide and regional studies, computer database and web mapping development, economic modeling, focused studies at individual sites targeted for potential carbon dioxide injection, and even carbon dioxide test injection. Much of this work has leveraged state funds obtained through grants from the U.S. Department of Energy (USDOE).

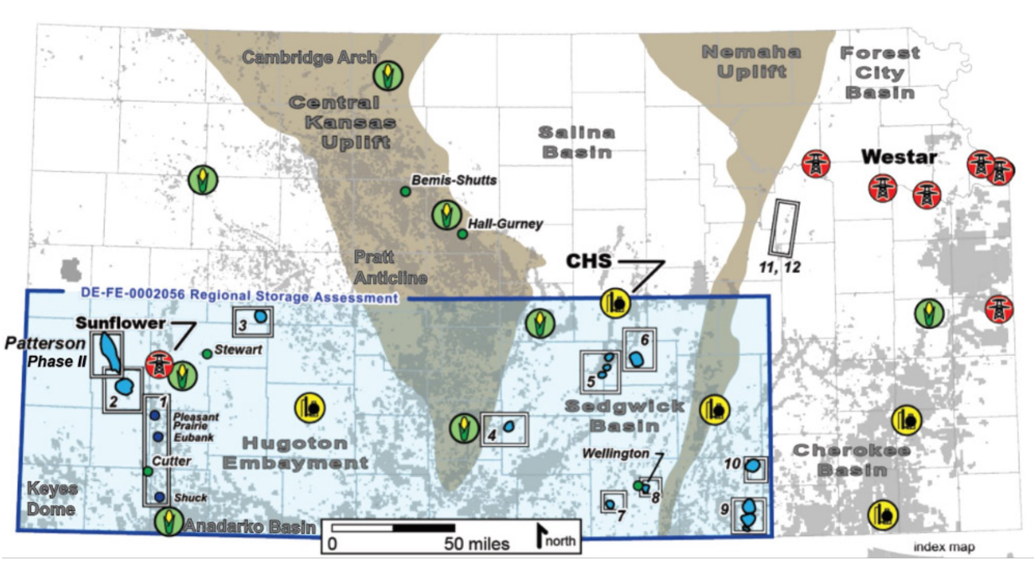

Figure 6. Kansas map showing the location and general regional structural province of the Patterson field discussed in the study, various industrial carbon dioxide sources, and other possible carbon dioxide injection sites in Kansas evaluated during previous KGS CCUS projects (numbered 1–12).[1]

The KGS in collaboration with Berexco and Battelle completed a detailed CCUS study at Patterson (fig. 6) in 2021 as part of a USDOE-funded project that showed Patterson would be a good site to store CO_2 and to use CO_2 for enhancing oil recovery. Approximately 26 square miles of new 3-D seismic data were acquired in July 2019. Seismic imaging is a lot like CAT scans or MRI imaging done in hospitals. It allows geologists to see into the earth, make 3-D models of the layers deep underground, and identify folds, faults, and other features. Once surveyed, two wells were drilled that showed reservoir and seal rocks were high enough quality to support CO_2 injection. One interesting feature observed in the seismic results was a buried river valley up to 250 ft deep similar to other incised valleys identified previously at Pleasant Prairie South, Eubank, and Shuck oil fields in southwest Kansas.

Resources

[1] Y. E. Holubnyak, M. Dubois, T. Bidgoli, D. Wreath, L. Watney, S. Stover, D. Newell, F. M. Fazelalavi, A. Hollenbach, J. Jennings, and C. Steincamp, *Integrated CCS for Kansas (ICKan) Final Technical Report (No. DOE-ICKan-29474)* (Kansas Geological Survey, University of Kansas Center for Research, 2018).

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