Kansas Field Conference
June 4–6, 2013

South-Central Kansas

Oil Exploration, Water Allocation, and Range Management

Field Guide

Edited by Shane A. Lyle, Catherine S. Evans, Rex C. Buchanan, and Robert S. Sawin

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KGS Open-File Report 2013–3

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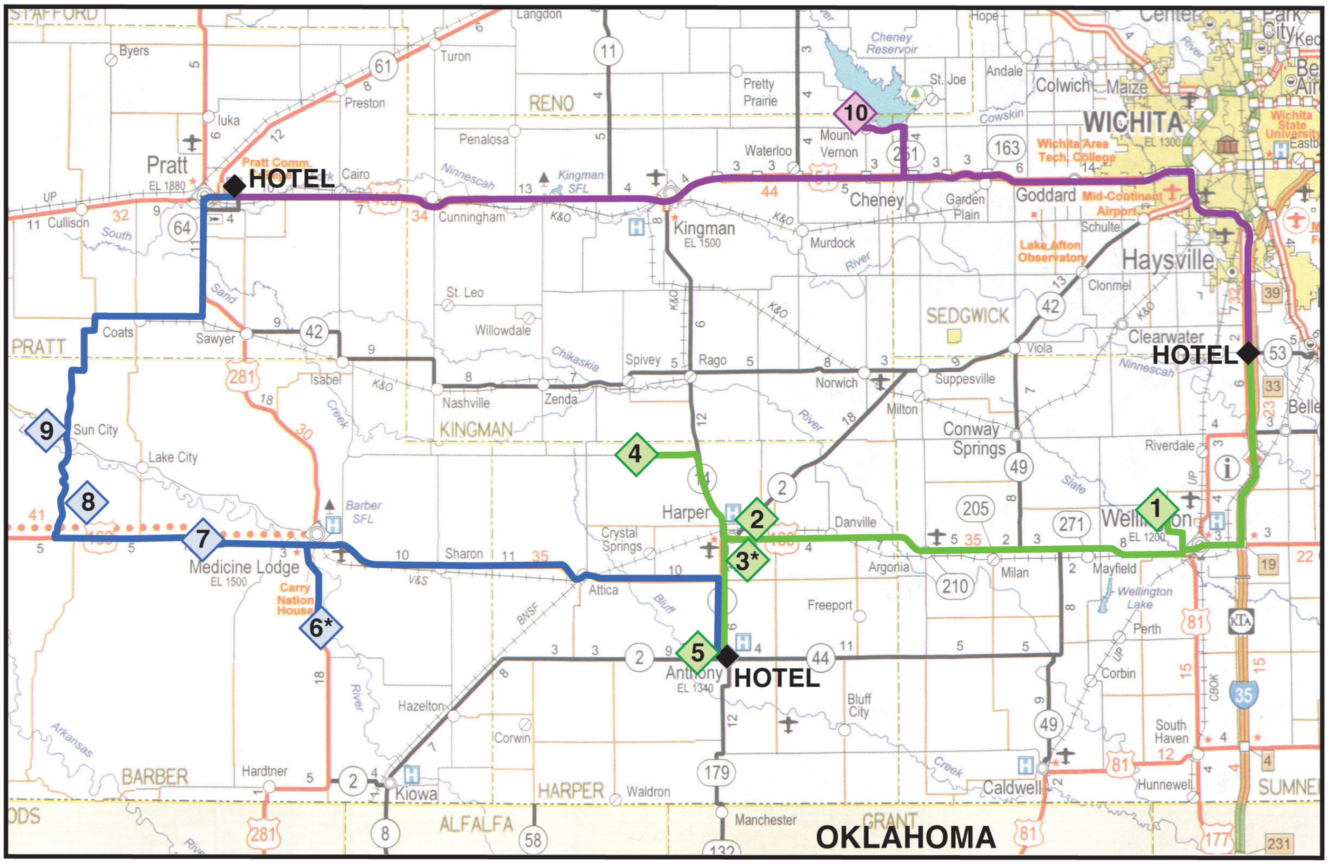

Day 1 Day 2 Day 3

* Site locations 3 and 6 are approximate. Final locations are dependent on petroleum field operations.

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South-Central Kansas

Oil Exploration, Water Allocation, and Range Management

June 4-6, 2013

Welcome to the 2013 Field Conference, co-sponsored by the Kansas Geological Survey (a division of the University of Kansas), the Kansas Water Office, the Kansas Department of Transportation, and the Kansas Department of Wildlife, Parks and Tourism. This marks the 19th year the Kansas Geological Survey (KGS), working with its co-sponsors, has taken decision-makers into the field to look at a range of the natural-resource issues facing the state. This year we're going to south-central Kansas, which is at the heart of complex water, energy, wildlife, and landscape issues of significant economic importance to the state of Kansas.

Although this area has long produced oil and natural gas, it recently became the center of an oil and gas play that rivals anything that has hit Kansas in the past 50 years. This activity is referred to as the Mississippian limestone play or, colloquially, the Mississippi lime. The combination of horizontal drilling, hydraulic fracturing, and traditional vertical drilling have made this play highly productive, to the point that Barber County is now the second-leading oil-producing county in the state. In addition to its economic impact, the play has also affected services and infrastructure, particularly roads and water supplies. As we've discussed in previous trips, water and energy are interconnected resources, and that is especially evident here, where water for hydraulic fracturing and drilling is in especially short supply.

First a word about the all-important geology that we'll encounter. For most of the trip, we'll be in the Red Hills physiographic region, a scenic area of butte-and-mesa topography unlike anything else in the state. The bedrock here is of Permian age, deposited at the bottom of a shallow embayment about 300 million years ago. Many of these rocks are stained red by iron oxide, thus the name Red Hills. They're also known as the Gypsum Hills because gypsum (along with other evaporates, like salt and anhydrite) was deposited at the bottom of the Permian bay. Gypsum caps many of the hills and, in the subsurface, has been dissolved, forming caves and sinkholes. Much of this area remains in native prairie, a mixture of tall and short-grass prairie, though the area is also sometimes called the Cedar Hills because of the preponderance of cedar trees; their encroachment on native prairie is something we will discuss. The geology, climate, land use, energy resources, water, and vegetation have made this a special place, one that is scenic, economically productive, and home to plants and animals—and natural-resource issues—that are unique to this part of the state.

In short, the Red Hills are a special part of Kansas, one that faces a range of natural-resource issues of long-term consequence, and the source of economic activity that has an impact on the entire state. By the time we finish on June 6, you should have a better understanding of the challenges and opportunities this area faces and of the people who are dealing with those challenges and opportunities.

Day 1

We'll spend the first morning looking at oil-field activity north of Wellington. In particular, we'll learn about the potential for use of carbon dioxide to produce additional oil from a mature Kansas field. The KGS, with funding from the U.S. Department of Energy and in cooperation with a number of partners (most notably Berexco, Inc., headquartered in Wichita), is developing a project to demonstrate the feasibility of CO_2 utilization and storage at this location. From here, we'll discuss some of the infrastructure and water issues posed by the Mississippian oil play. And we'll talk about the lesser prairie chicken, its management, and its effect on local energy projects, such as transmission lines. We'll end the day in Anthony, a town that has been especially affected by the recent increase in oil-field activity.

Day 2

The second day will offer an up-close look at oil production from the Mississippian and a discussion of drilling challenges, including the economics of the play. We'll hear from a number of operators active in this area, particularly Wayne Woolsey, the president of Woolsey Operating Company, who is generally credited with starting this play in Barber County. In the afternoon, we'll return to landscape issues, learning about The Nature Conservancy's Red Hills initiative; hearing from a local rancher about the challenges of rangeland management here; and having a discussion of red cedars and their control in the Red Hills. We'll also visit a Barber County institution: Buster's, in Sun City. We'll spend the night in Pratt and visit the Pratt offices of the Kansas Department of Wildlife, Parks and Tourism.

Day 3

Several of the issues covered on the final half-day deal with water. We'll get an update on Local Enhanced Management Areas (LEMAs), which we discussed in detail on last year's trip to northwestern Kansas, and we'll look at drought and water problems, especially related to Cheney Reservoir, one of the primary water sources for the city of Wichita.

About the Kansas Field Conference

Some issues are best understood by seeing them firsthand. The 2013 Field Conference gives policymakers the opportunity to see and experience some of the natural-resource issues that they grapple with. Participants have been selected to provide a range of legislative, government, education, and private-business expertise. Local and regional experts in natural-resource issues meet us at each site and describe the location and the issues related to it. The objective is to let participants see the results of their decisions and to talk with local, state, and federal governmental officials, environmental groups, business people, and citizens' organizations. The result should give participants a broader, more-informed perspective useful in formulating policies. In addition, the Field Guide you are holding provides background on sites and issues and serves as a handy reference long after the Field Conference is over.

During the Field Conference, participants are expected to be just that—participants. We want you to contribute to the discussion, to ask questions, and to otherwise join in on deliberations. **The bus microphone is open to everyone, and we encourage everyone to participate.**

Please remember that in the course of the Field Conference, we do not seek to resolve policy or regulatory conflicts. We do try to provide opportunities to familiarize policymakers with resource problems. By bringing together experts on energy and water, we hope to go beyond merely identifying issues. We want this combination of first-hand experience and interaction among participants to result in a new level of understanding of the state's natural-resource issues.

In doing this, we attempt to present, as nearly as possible, all sides of contentious issues. Please know that the opinions presented during the Field Conference are not necessarily those of the KGS or Field Conference co-sponsors. Nonetheless, we do believe it is important for participants to hear various viewpoints on complex issues.

The Field Conference was begun in 1995 with the support of Lee Gerhard, then the Survey's director and state geologist. The Field Conference is modeled after a similar program of national scope, the Energy and Minerals

Field Institute, operated by the Colorado School of Mines. The KGS appreciates the support of Erling Brostuen, retired Director of the Energy and Minerals Field Institute, in helping develop the Kansas project.

The KGS Field Conference has been recognized by

- The National Institute of Standards and Technology as among 50 Best Practices for Communication of Science and Technology for the Public, 2001; and
- The Division of Environmental Geosciences of the American Association of Petroleum Geologists, which presented its Public Outreach Award to the Field Conference in 1998.

The KGS appreciates your attendance at this year's Field Conference and your willingness to share your insights for its improvements. Your input has helped make the Field Conference a model that has been adopted by other state geological surveys.

Sponsors

Kansas Geological Survey

The KGS is a research and service division of the University of Kansas. Its mission is to study the state's geologic resources and hazards and to report on them. The KGS is headquartered on west campus at KU and has a branch office in Wichita, the Wichita Well Sample Library. Much of the KGS focus is on energy, water, and a better understanding of the state's surficial and subsurface geology. By statutory charge, the KGS role is strictly one of research and reporting. The KGS has no regulatory functions.

KGS staff participating in the 2013 Field Conference include the following:

- Shane Lyle, Senior Research Assistant, Geology Extension
- Cathy Evans, Writer/Editor, Public Outreach
- Bob Sawin, Senior Research Associate, Public Outreach/Stratigraphic Research
- Rex Buchanan, Interim Director
- Dave Newell, Associate Scientist
- Lynn Watney, Senior Scientist

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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. In addition to dealing with roadways for automobile traffic, KDOT is responsible for other modes of transportation, including aviation, rail, and bicycles/pedestrians. The current secretary of KDOT is Mike King, president of King Enterprise Group, Inc., of McPherson, a general contractor serving the oil/gas/industrial markets in Kansas and adjoining states. Bob Henthorne, who will also speak on the trip, is KDOT's chief geologist.

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Kansas Department of Wildlife, Parks and Tourism

The Kansas Department of Wildlife, Parks and Tourism is responsible for managing the state's living natural resources. Its mission is to conserve and enhance Kansas' natural heritage, its wildlife, and its habitats. The Department works to assure future generations the benefits of the state's diverse living resources; to provide to the public opportunities for the use and appreciation of the natural resources of Kansas, consistent with the conservation of those resources; and to inform the public of the status of the natural resources of Kansas to promote understanding and gain assistance in achieving this mission. The Department's responsibility includes protecting and conserving fish and wildlife and their associated habitats while providing for the wise use of these resources and providing associated recreational opportunities. The Department is also responsible for providing public outdoor-recreation opportunities through the system of state parks, state fishing lakes, wildlife-management areas, and recreational boating on all public waters of the state.

This cabinet-level agency is administered by a Secretary of Wildlife, Parks and Tourism and is advised by a seven-member Wildlife and Parks Commission. Robin Jennison is the Secretary of Wildlife, Parks and Tourism. Steve Adams is the department's Natural Resource Advisor, and Jim Pittman is the small-game program coordinator for the department.

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Kansas Water Office
The mission of the Kansas Water Office (KWO) is to provide the leadership to ensure that water policies and programs address the needs of all Kansans. 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, the Kansas Weather Modification Act, and the Water Assurance Act. It also reviews plans of any state or local agency for the management of water and related land resources in the state. The KWO advises the Governor on drought conditions and coordinates the Governor's drought-response team. The KWO develops the Kansas Water Plan, which is revised periodically and addresses the management, conservation, and development of water resources in the state. The Water Plan is approved by the Kansas Water Authority, a 13-member board whose members are appointed, along with 11 nonvoting *ex officio* members who represent various state water-related agencies. Besides approving the Water Plan, the Authority approves water-storage sales, federal contracts, administrative regulations, and legislation proposed by the KWO. Much of the input for the Water Plan comes from 12 Basin Advisory committees composed of volunteer members from each of the state's drainage basins. During this year's Field Conference, we will be in the Lower Arkansas and Cimarron river basins. Tracy Streeter is the Director of the KWO.

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Supporting Organizations and KGS Staff
The KGS and Field Conference co-sponsors would like to acknowledge the help of other organizations, agencies, and companies that have contributed to the Field Conference,

in 2013 and in previous years. In particular, Larry Biles, head of the Kansas Forest Service at Kansas State University, and David Barfield, Chief Engineer at the Division of Water Resources, Kansas Department of Agriculture, have provided useful insights, made presentations, and helped with logistics. In addition, Brad Loveless of Westar Energy, Raney Gilliland of the Kansas Legislative Research Department, Steve Adams of Kansas Department of Wildlife, Parks and Tourism, and Earl Lewis of the Kansas Water Office provided advice about topics and locations to address.

Many people from the KGS and other organizations also contributed information to this field guide, including David Newell, Jennifer Raney, Lynn Watney, and Tony Layzell of the Kansas Geological Survey; Robert Henthorne and Amy Link of the Kansas Department of Transportation; Brad Loveless of Westar Energy; Clare Gustin of Sunflower Electric Power Corporation; Ken Brunson and Ruth Palmer of The Nature Conservancy; Larry Biles and David Burchfield of the Kansas Forest Service; Larry Price and Deon van der Merwe of Kansas State University; and Susan Metzger, Earl Lewis, and Susan Stover of the Kansas Water Office. Julie Tollefson, KGS editor, edited and laid out the field guide; Julie Bogle, KGS assistant to administration, compiled the biographical information; and Mark Schoneweis, KGS graphic designer, provided assistance with the locator map in the front of the field guide and several illustrations.

Tuesday, June 4, 2013

6:00 a.m.	Breakfast at Woodfire Grille, Kansas Star Casino, Mulvane (breakfast served as early as 6 a.m. but starting time is informal)
7:15 a.m.	Conference Overview *Rex Buchanan*, Interim Director, Kansas Geological Survey
8:00 a.m.	**Bus leaves Hampton Inn & Suites, Mulvane, for Site 1**
	Bus Session – Agricultural Land Use Assessment – Woodland and Riparian Property Tax Rates at Risk *Larry Biles,* State Forester, Kansas Forest Service *Robin Jennison,* Secretary, Kansas Department of Wildlife, Parks and Tourism
8:30 a.m.	**SITE 1** – CO_2 Enhanced Oil Recovery and Storage in Kansas, Wellington Oil Field *Rex Buchanan,* Interim Director, Kansas Geological Survey *Lynn Watney,* Senior Scientific Fellow, Kansas Geological Survey *Dana Wreath,* Berexco, Inc.
9:30 a.m.	Bus to Wellington
9:40 a.m.	Restroom break – Worden Park, Wellington
10:00 a.m.	Bus to Site 2
10:30 a.m.	**SITE 2** – Safety and Highway Maintenance Cost Attributed to Truck Traffic, Harper *Mike King,* Secretary, Kansas Department of Transportation *Rick Miller,* Pavement Management Engineer, Kansas Department of Transportation
11:00 a.m.	**SITE 3** – Bus Tour of County Infrastructure and Socioeconomic Aspects of Oil Development, Harper County *Al Roder,* Harper County Administrator
12:00 p.m.	Lunch – Fence Post Supper Club, Harper
1:00 p.m.	Bus to Site 4
	Bus Session – Update on the Proposed Listing of the Lesser Prairie Chicken as a Threatened Species *Robin Jennison,* Secretary, Kansas Department of Wildlife, Parks and Tourism *Jim Pitman,* Kansas Department of Wildlife, Parks and Tourism

1:15 p.m.	**SITE 4 –** Energy Transmission Route Siting and Habitat Mitigation, East Substation – Flat Ridge II Wind Farm *Brad Loveless,* Director, Biology and Conservation Programs, Westar Energy *Stuart Lowry,* President and CEO, Sunflower Electric Power Corporation
2:00 p.m.	Bus to Site 5 Bus Session – Legislative Update: Limited Transfer Permits *David Barfield,* Chief Engineer, Kansas Department of Agriculture, Division of Water Resources
2:30 p.m.	**SITE 5** – Anthony City Lake
2:30 p.m.	Restroom Break, Anthony City Lake
3:00 p.m.	State Water Plan Fund Summary *Tracy Streeter,* Director, Kansas Water Office
3:30 p.m.	Anthony Lake Conditions and Dredging Initiative *Larry Claflin,* Mayor of Anthony *Phillip Truby*, Anthony City Council
4:00 p.m.	Fracking Water Supply: Recycling and Reuse *Robert Stanberry*, Shell Oil Company
4:30 p.m.	Bus to Hotel(s), Cobblestone Inn & Suites and Anthony-area hotel(s)
6:00 p.m.	Bus to Supper - Anthony Municipal Hall, Anthony Hog Heaven BBQ
7:30 p.m.	Return to Cobblestone Inn & Suites and Anthony-area hotel(s)

CO_2 Enhanced Oil Recovery and Storage in Kansas

The U.S. Department of Energy (DOE) has funded several Kansas Geological Survey (KGS) projects to evaluate the use of private industry sources of carbon dioxide (CO_2) for enhanced oil recovery (EOR) and CO_2 storage in southern Kansas. The purpose of the government–industry collaboration is to evaluate the use of CO_2 injection for the recovery of trapped oil in depleting oil fields in southern Kansas, while also studying whether CO_2 can be permanently sequestered even deeper underground in the saline Arbuckle Group aquifer. The projects consist of field-scale studies at the Wellington Field in Sumner County and the Cutter Field in Stevens County, a 33-county regional study, and the selection of a depleted oil field in the Chester/Morrow sandstone play in southwest Kansas for a feasibility study of CO_2-EOR and sequestration. The KGS-led CO_2 sequestration projects have received nearly $21.5 million in cooperative agreement funding from the DOE.

The KGS and its industry and government partners also provided millions of dollars in cost-share contributions, such as drilling and engineering personnel, equipment, facilities, discounted service, geochemical analysis, geologic modeling, and computer simulation.

Carbon Dioxide

CO_2 is a natural and essential component of the atmosphere, but it is also a greenhouse gas—a byproduct of fossil fuel emissions from vehicles and stationary sources such as electric, cement, ethanol, and fertilizer plants—that has been considered a cause of climate change. There is a scientific consensus that increased greenhouse gases can contribute to increased temperatures and other changes in regional climate patterns. CO_2 is of particular concern because it is increasingly produced through human activities. If current trends continue, the United States will emit 6.8 billion tons of CO_2 by 2030, a 16% increase over 2006; Kansas

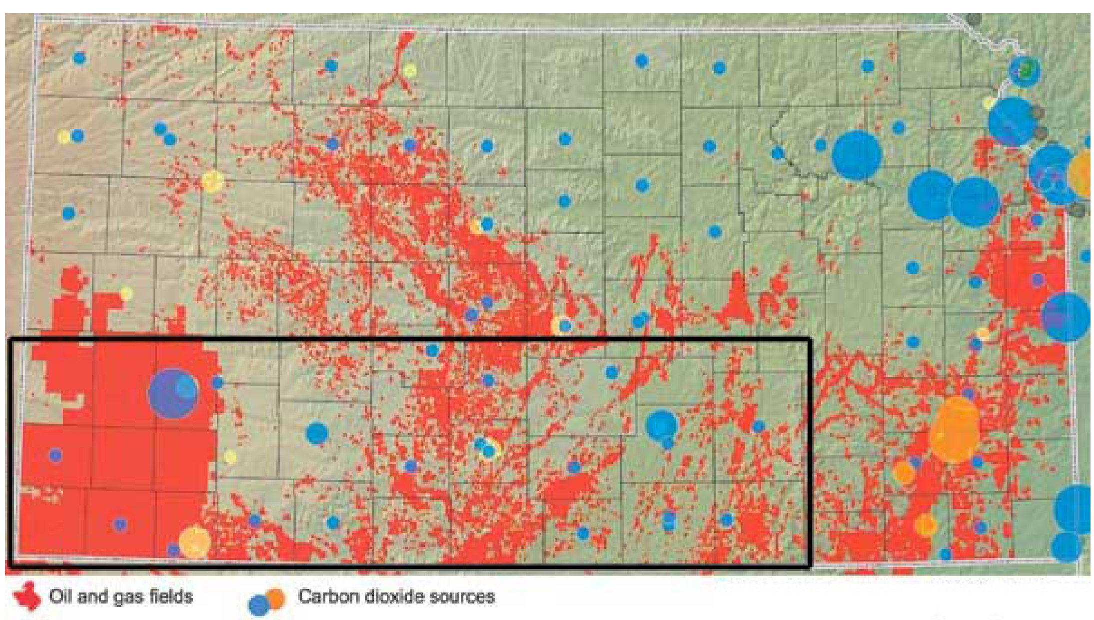

Figure 1—Documented stationary sources of CO_2 and evaluated potential geological storage sites. Stationary sources include power-generation facilities, refineries, cement kilns, and ethanol plants. The black box outlines the area that the KGS and partners are studying for potential storage of CO_2. Map created from NatCarb (2008) database.

CO_2 emissions would be 89.5 million tons by 2030 (U.S. DOE, 2008).

In Kansas, coal-fired electrical power plants, refineries, cement plants, and ethanol plants are the most common stationary sources of CO_2 (fig. 1). CO_2 produced from many Kansas stationary sources, however, is impure. That is, it is mixed with other gases, which makes it harder to use. Currently, CO_2 is captured in Kansas only at a few facilities that produce high-purity CO_2. However, work is underway to reduce costs and energy requirements to make the isolation of CO_2 from impure sources feasible on a commercial scale.

Enhanced Oil Recovery

Because the state has had a long history of oil production, a great deal is known about its subsurface geology and vast amounts of geologic data are available. Even in Kansas fields that are declining after decades of production, significant amounts of oil remain trapped in the pore space of underground rocks. Many known oil reservoirs appear to be candidates for EOR with CO_2. KGS scientists estimate that Kansas oil reservoirs have 750 million additional barrels that could be recovered through CO_2-EOR (Byrnes, 2000). At the same time, the process would sequester significant quantities of CO_2 in the oil reservoir. Kansas shares geological formations with Oklahoma, where commercial CO_2 floods are proven and are serviced by existing and planned CO_2 pipeline infrastructure.

In the EOR process, CO_2 is injected through a well to force out trapped oil. CO_2 pumped into a reservoir dissolves into the oil, reducing the oil's viscosity and making it easier to recover (fig. 2). Small amounts of CO_2 that come back to the surface with the oil can be captured and re-injected to help produce more oil. Much of the CO_2, however, remains sequestered in the reservoir. CO_2 is already being used commercially and experimentally to enhance oil recovery in a number of locations in the country, most notably in west Texas. Sequestration of CO_2 in saline aquifers is also being tested throughout the United States, with larger tests in Texas and Illinois.

Wellington Field CO_2-EOR and Sequestration

The Wellington project is a field-scale study that will test the feasibility of CO_2-EOR and

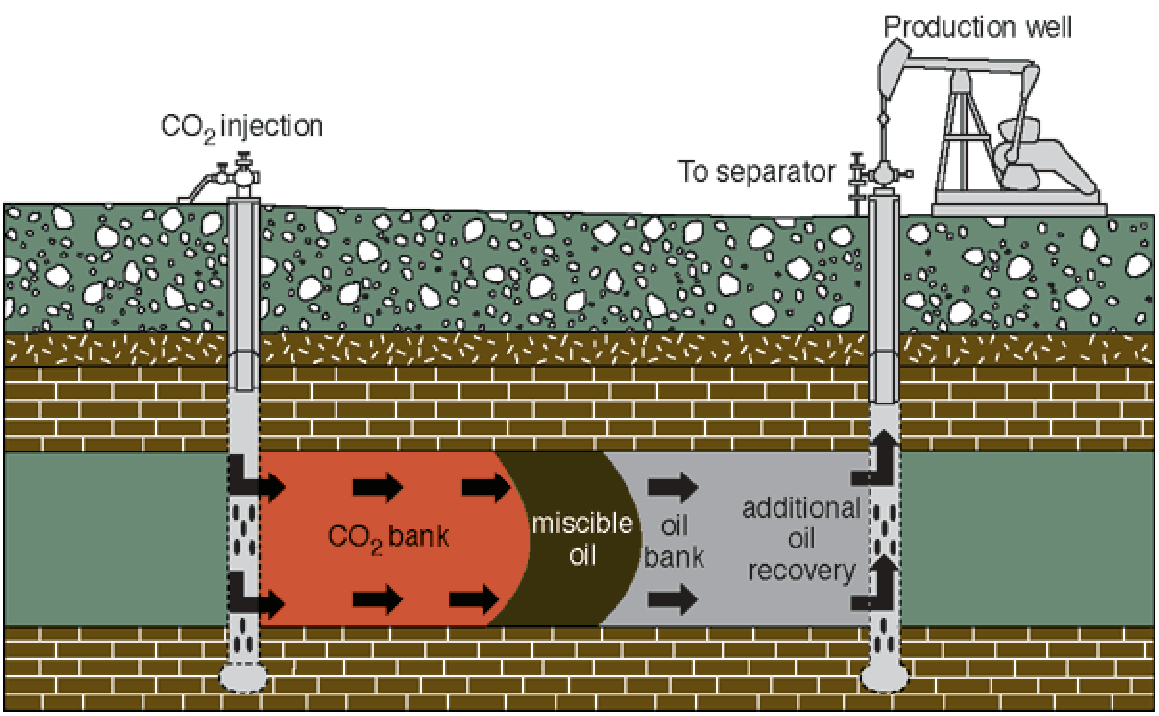

Figure 2—Carbon dioxide flooding (Kansas Geological Survey).

CO_2 sequestration at the Wellington Field in Sumner County. Pilot study activities at the field are being carried out through industry partner Berexco, which is assisting in acquiring seismic, geologic, and engineering data for analysis. The major goals of the Wellington project are small-scale injections of CO_2—approximately 30,000 metric tons into the Mississippian-age oil reservoir and about 40,000 metric tons into the Arbuckle saline aquifer below the oil reservoir (fig. 3). CO_2 will be injected to force out trapped oil in a Mississippian dolomite reservoir about 3,600 feet deep in the nearly depleted Wellington Field. The Arbuckle Group is a porous sequence of rocks about 5,000 feet deep at the Wellington Field. Saline water in the Arbuckle is unfit for human consumption and is separated from shallower freshwater aquifers by thousands of feet of impermeable rock. Impermeable rock and shale units overlie the oil reservoirs and trap CO_2 underground, safely and permanently. A suite of different monitoring technologies and wells, tailored to the site-specific geology, will verify CO_2 containment at the site.

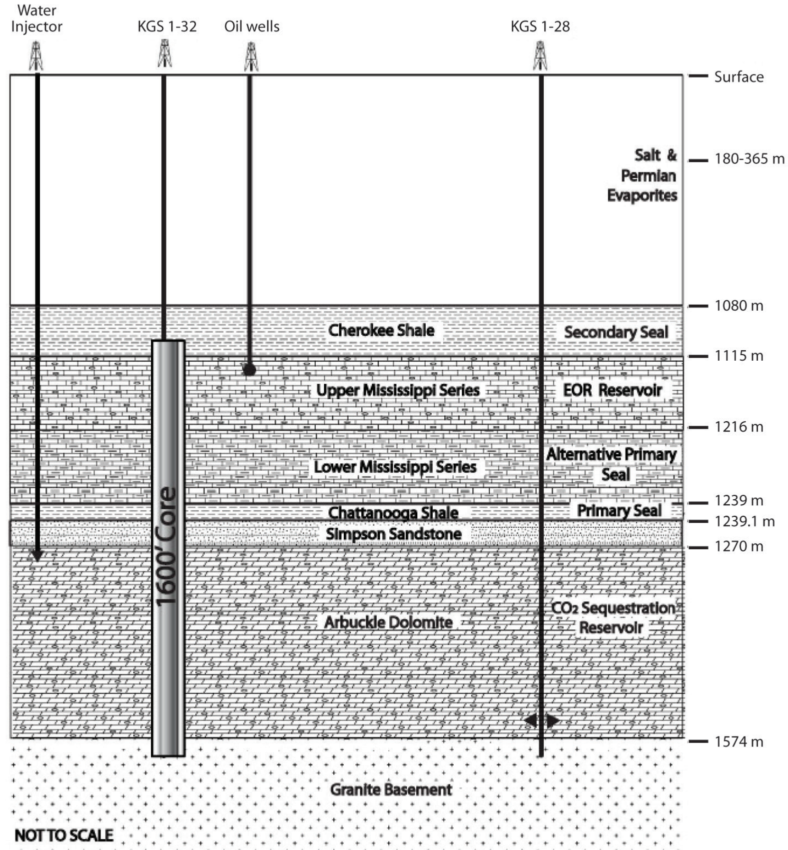

Figure 3—Conceptual model of the EOR reservoir in Mississippian-age rocks and CO_2 sequestration reservoir in the Arbuckle Group aquifer (Kansas Geological Survey).

CO_2 for the project will be transported from the Abengoa Bioenergy Corporation's ethanol plant near Colwich. Project funding will install compression, chilling, and transport facilities at the ethanol plant for truck transport to the injection site. This will be the first time CO_2 emitted during industrial activities has been captured and stored long-term underground in Kansas.

The goals of this research are to advance EOR and the practice of CO_2 sequestration in the Midcontinent through characterization and modeling; evaluate best practices for monitoring, verification, and accounting; optimize methods for remediation and risk management; provide technical information and training to enable future projects; and facilitate discussions on issues of liability and risk management for operators, regulators, and policymakers. The research will also provide data and technical support for oil and gas producers using EOR methods and spur business development for companies seeking locations with the geologic capacity to sequester industrial quantities of CO_2.

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Assessment of Pavement Conditions on Roads Used to Transport Drilling Equipment

Horizontal drilling in combination with hydraulic fracturing is becoming more commonly used to explore for oil and gas in southern and western Kansas, particularly in an area centered on Harper, Barber, and Comanche counties. The processes related to this method of exploration and the production of energy resources require a great deal of equipment and materials, which can result in increased truck and heavy-equipment traffic on highways near drilling and production sites. Given the potential for road damage, the Kansas Department of Transportation (KDOT) has begun gathering data to evaluate the highway conditions where significant drilling is already underway, or is expected, to determine whether roads are already showing increased wear and to set a baseline for future comparison.

Since 1983, KDOT has collected pavement-condition data that can be used to help make decisions about highway maintenance. Several manual and automated methods for collecting data served the state well over the years, and numerous national studies rated the state's road pavements as among the best. However, those methods of collecting pavement-condition data were time consuming, somewhat subjective, and posed risks to both the traveling public and the KDOT staff assessing the roadways. To help alleviate the risk and to more easily and efficiently collect data, KDOT purchased a Pavement Data Collection System from Mandli

Figure 1— The Pavement Data Collection System van. The boxes mounted on top are the Laser Crack Imaging System cameras that make images of the pavement and elevation measurements. The elevation measurements provide a transverse profile of 4,000 points across a 14-foot lane. Two laser profilometers are mounted through the hitch to collect data used to compute smoothness in each wheelpath.

Communications of Madison, Wisconsin, in June 2012.

The Pavement Data Collection System consists of a van, hardware and software to automate the processing of the data, and software to view the images and data collected. The van includes forward-looking cameras, downward-looking line-scan cameras illuminated with lasers, downward-looking laser measurement devices, two wheelpath profilers, and an inertial measuring unit (for pitch, roll, and yaw) (fig. 1). This equipment is integrated through on-board computers to allow for data on pavement smoothness measurements, rutting, faulting, and cracking to be collected at about 60 miles per hour (fig. 2).

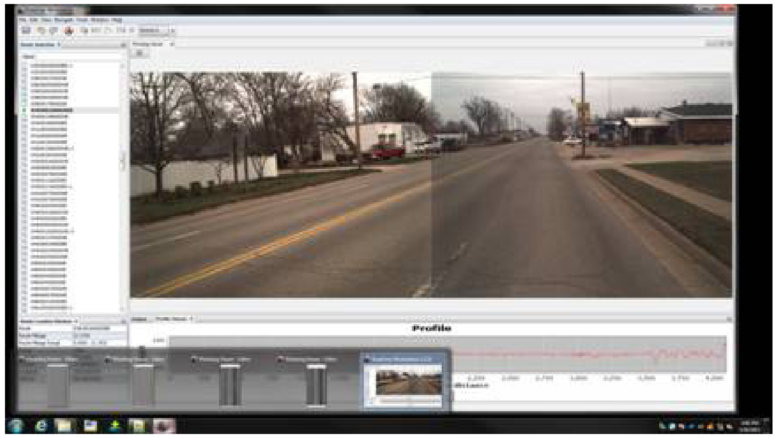

Figure 2—Images from the forward-looking cameras showing the route.

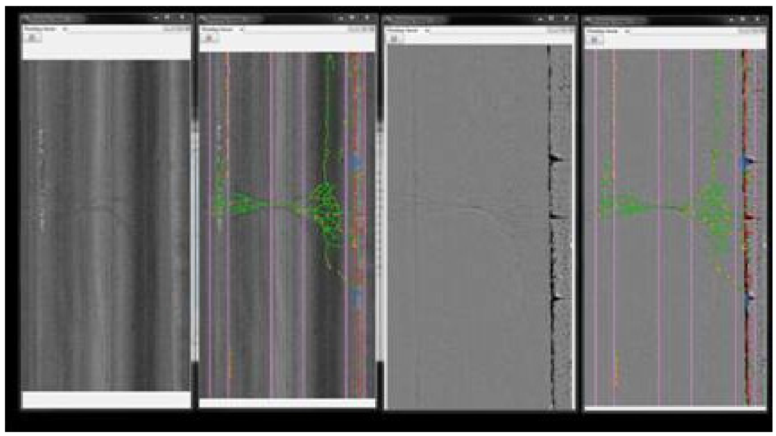

Figure 3—Four images of the same strip of pavement, from left to right: a scan-like image; pavement cracks color enhanced by software (e.g., green lines represent cracks 3-mm to 6-mm, or about 1/8- to 1/4-inch, wide); the topography of the pavement with black lines representing holes; and software analysis of the topography.

In the spring of 2012, before the purchase of the data-collection system, KDOT had collected pavement-condition data on highways in areas where horizontal drilling operations were underway or anticipated. At that point, the highways, which were being used to carry equipment related to drilling and production, appeared to be holding up well. A few routes were experiencing greater than normal increases in roughness and/or rutting in the areas around where oil and gas production were heavy, but there was no evidence of widespread damage that could be linked to the oil and gas activities. KDOT will continue to monitor highway conditions near drilling and production sites, if deemed appropriate.

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County Infrastructure and Socioeconomic Aspects of Oil Development

Development of energy resources can initiate regional employment, infrastructure, and industrial development, which can have great impact on the socioeconomic structure of a region. Often, however, towns and counties are not able to keep pace with the rate at which these changes occur in a "boom" cycle of oil production, resulting in housing shortages, inadequate roads, and other infrastructure needs.

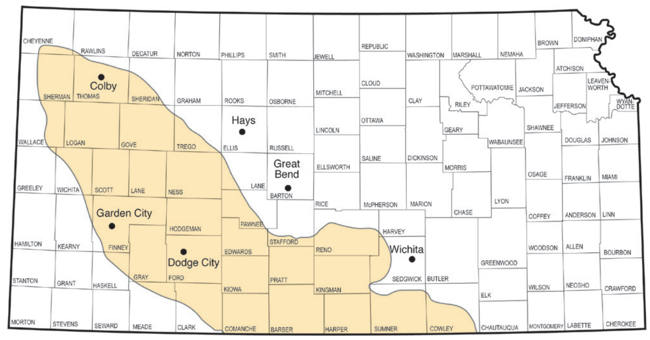

Figure 1—Boundary of the Mississippian limestone play in Kansas (KCC, 2013).

The full scope of future oilfield development in the Mississippian limestone play in Kansas is unknown. Commercial petroleum companies are evaluating approximately 34 counties for potential oil exploration. As of April 2012, 12 counties (Barber, Clark, Comanche, Ford, Harper, Hodgeman, Kingman, Kiowa, Ness, Reno, Sherman, and Sumner) were experiencing various stages of petroleum activity related to the play. Barber, Comanche, and Harper have the most producing, "spudded" (wells that have just started drilling), and permitted wells.

Development of the Bakken shale in North Dakota is a benchmark example that Kansas and other oil producing states have used to address the socioeconomic challenges associated with rapid petroleum development. Municipalities and county governing bodies are on the leading edge; their effectiveness is contingent on experience, fiscal resources, and planning capability to develop zoning and ordinances to manage the demands of increased traffic, population workforce, and housing.

Horizontal drilling, itself, minimizes the footprint of oil and natural gas extraction. The practice allows for increased distance between well pads, reducing the required number of access roads and well pads to complete a well. However, an average Bakken horizontal well requires 2,024 truck trips during the drilling phase.

Skilled labor for oil and gas exploration and production is limited. Petroleum companies meet their workforce requirements by importing labor from regional and national market resources and rotating skilled employees between project fields. The sudden influxes of a transient workforce and truck traffic have significant local impact.

An influx of oil workers and heavy truck traffic can stretch a local community's capacity to provide adequate roads, housing, emergency services, health care, and more. Potential impacts to municipal and local governments are further described in the next section.

Local Impact

Road infrastructure is a major challenge. Traffic volume and road capacity design varies greatly among county, state, and federal highways (fig. 2). Well pads are located in disparate locations and increase the amount of truck traffic onto rural roads not designed for high-volume truck traffic.

Because of low-density population in south-central Kansas, fewer households and rental housing space are available. Oil development leads to significant local population increases, causing housing shortages.

Figure 2—Many roads in the area of the Mississippian limestone play are unpaved and not built to withstand heavy truck traffic.

Rural ambulance and fire departments typically rely on volunteer departments that already have a heavy workload. Increased emergency service calls strain the volunteer system. Increased workload and a workforce shift to lucrative petroleum-related jobs contribute to loss of personnel, making retention of volunteer departments more difficult.

Regional health-care services are designed for a sparsely populated and large rural area. A shortage of primary care doctors and long distances to critical access hospitals increase health risks and mortality rates.

Similarly, the law enforcement system is designed for low population, rural areas. Increased crime rates tend to coincide with increased population, regardless of industry or business. Traffic-related violations also increase along with increased volume of truck traffic.

Continuing drought has strained municipal public water supply in an already arid portion of the state. Water infrastructure and treatment facilities serving many small, rural communities require modernization and upgrades to meet demands for their present population base. Water utilities often have small customer bases and do not generate enough revenue to upgrade their water infrastructure systems. Increased water demand and usage with the influx of oil workers will increase the rate of water system failure and maintenance costs.

Large, portable diesel generators often power initial oil drilling. A transition from exploration to production may increase the demand for electrical infrastructure to serve higher-than-designed electric loads. Exploration uncertainties make it difficult for electric co-ops to adequately anticipate the demand and impact to the regional power grid.

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Electric Transmission and Petroleum Energy Demand

Hydraulic fracturing and horizontal drilling in the Mississippian limestone play have led to new oil and gas exploration in Kansas (fig. 1). New oil and gas wells, petroleum infrastructure (e.g., pipelines, water treatment facilities, gas processing plants, etc.), along with growing population, increase demand for localized energy delivery. In North Dakota, a recent study by the North Dakota Industrial Commission forecasted an 88% increase in total electric demand between 2012 and 2017, mainly related to the oil boom in the Bakken shale play. South-central Kansas is also facing increased electric demands in connection with exploration of the Mississippian limestone play.

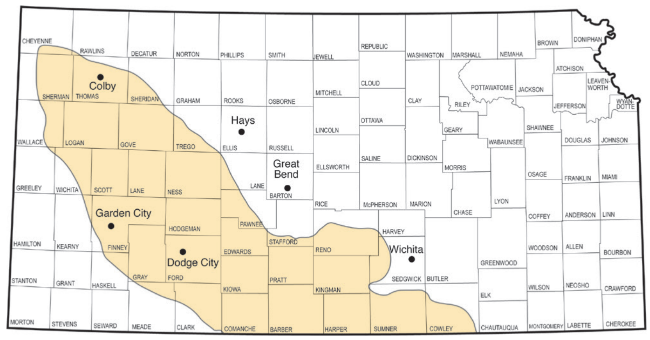

Figure 1—Boundary of the Mississippian limestone play in Kansas (KCC, 2013).

During initial exploration and drilling activities, oil companies can use diesel generators to drill and complete wells, but production pumps used to produce oil and dispose of salt water often require large amounts of power. The actual power demand varies, but, as an example, one section with three wells and a water disposal well in Oklahoma require almost one megawatt of power, roughly enough electricity for 1,000 homes.

Oil leases are often developed near metro areas to reduce the cost required to connect wells to the power grid with new distribution lines. Some of the larger oil companies, such as SandRidge Energy Inc., often build their own

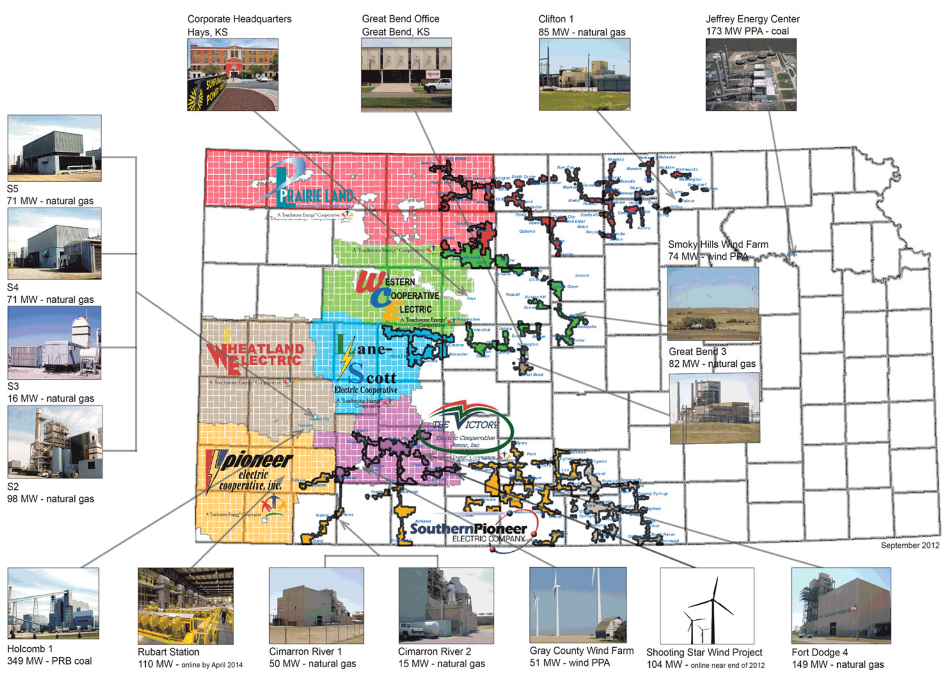

Figure 2—Sunflower Electric Power Corporation and Mid-Kansas Electric Company, LLC electric transmission system (Sunflower, 2013).

substations and distribution lines that connect to existing or planned transmission lines. In Kansas, early exploration and development of the play has generally followed the rural, co-op power grids that serve western Kansas (fig. 2).

Very rural areas don't have large load demands, but oil development can rapidly increase the regional power requirements. A sudden increase in demand for new transmission capacity can create planning and design complications for rural co-ops, which have designed their grids based on anticipated loads over a 20-year planning period.

Any new line, substation, or large user must be balanced with the larger, regional power grid. Changes that affect the regional grid must be approved by the Southwest Power Pool, which regulates the electricity grid in Kansas and six other states. Regional studies and the permitting process can sometimes take years to complete, while an oil lease typically requires exploration and production to be completed within three years.

New infrastructure design is based on historic trends of electric use or load. These trends are easily skewed by sudden and drastic changes, such as new petroleum development, and can lead to unnecessary build out of transmission infrastructure. Over construction is a fiscal risk to rural co-ops with small customer bases. In the absence or decline of petroleum energy demand, a co-op's revenue stream may not be large enough to pay for the capital expenditure of new transmission capability.

In south-central Kansas, the geology of the Mississippian limestone play compounds the uncertainty of forecasting an electric load. The play's reservoir characteristics vary over relatively short distances, and its extent is not yet defined. Although the historical electric load requirements associated with vertical well development is understood, a comparable history of electrical load growth with horizontal drilling doesn't exist.

Key Habitat

Kansas contains many unique habitats and wildlife populations. Depending on their location, wind energy projects and transmission lines may cause habitat loss, fragmentation,

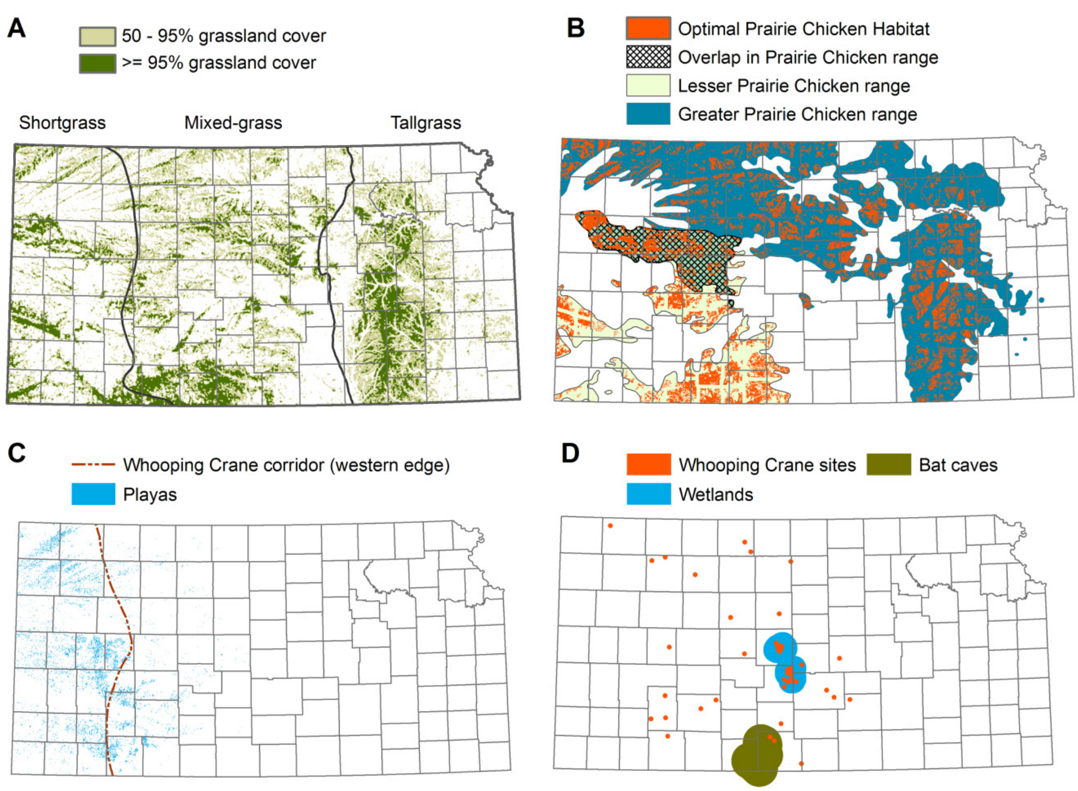

Figure 3—Key habitats in Kansas (Obermeyer et al., 2011).

and wildlife mortality. Obermeyer et al. (2011) identified the general location of key habitat areas in Kansas that are susceptible to energy infrastructure development. These include un-fractured prairie landscapes, playas, wetlands, and Red Hills cave complexes (fig. 3). Through project and site-specific biological assessments, the U.S. Fish and Wildlife Service or the Kansas Department of Wildlife, Parks and Tourism (KDWPT) identify other areas as containing threatened and endangered species habitat or occurrences.

Figure 4—Male lesser prairie chicken displaying during mating season. Photo courtesy Larry Lamsa.

Figure 5—Whooping crane. Photo courtesy Brad Loveless.

Because these landscapes have experienced significant reductions across the Great Plains, they are unique habitat types. Native prairie landscape provides habitat for indicator species such as the lesser prairie chicken (fig. 4). Playas, Cheyenne Bottoms (the largest U.S. interior wetland) and Quivira National Wildlife Refuge make up one of the most important fly-over sites for migratory shore birds and provide habitat for imperiled species like the whooping crane (fig. 5). In the Red Hills, dissolution of the evaporate mineral gypsum forms cave complexes that provide critical bat colonies habitat.

Habitat Mitigation

In Kansas, critical habitats are defined as habitats known or likely to support viable populations of listed threatened or endangered species (T&E). Kansas statute requires a KDWPT permit for an action (e.g., transmission line construction) that affects a listed T&E species. Critical habitats are identified by field assessments and project review by qualified biologists. KDWPT and the permit applicant cooperatively develop a permit, which is incorporated into proposed project plans. Permitted actions provide sufficient mitigating or compensating measures to assure protection of either critical habitat, listed species, or both as conditions require.

Habitat mitigation includes:

1. Avoiding and minimizing impacts during the planning stages.
2. Rectifying the impact by repairing, rehabilitating, or restoring the affected environment.
3. Compensating for the impact by replacing or providing substitute resources or environments.

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Anthony City Lake

Anthony City Lake was built in 1935 as a Works Progress Administration (WPA) project during the Great Depression to provide water and flood control for the City of Anthony. The lake, now dry due to recent drought, also provided a variety of recreational activities, including boating and fishing.

The original water storage volume of the lake was 951 acre-ft (fig. 1). As with many lakes in Kansas, it has filled with sediment over time and now has a reduced water storage capacity.

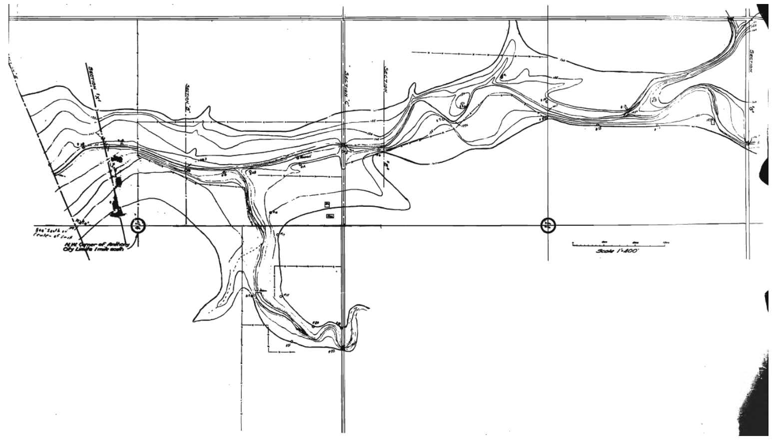

Figure 1—Anthony City Lake original construction and design plans (Black & Veatch).

Bathymetric Survey and Lake Dredging

In 2010, the Kansas Biological Survey (KBS) conducted a bathymetric survey of the lake and found the storage volume had declined to about 495.5 acre-ft, a capacity loss of about 47 percent (fig. 2). Sediment that has accumulated in the lake consists mainly of clay and silt. The calculated mean annual sedimentation rate is about six acre-ft per year, a relatively low rate compared to other Kansas reservoirs. The calculated sediment volume that has accumulated since the lake was constructed is 735,000 cubic yards. A City of Anthony assessment of the sediment volume is even higher, about 1.5 million cubic yards. Three fishing piers were constructed on the east lake bank and repaired with riprap sides in 1990. Sediment

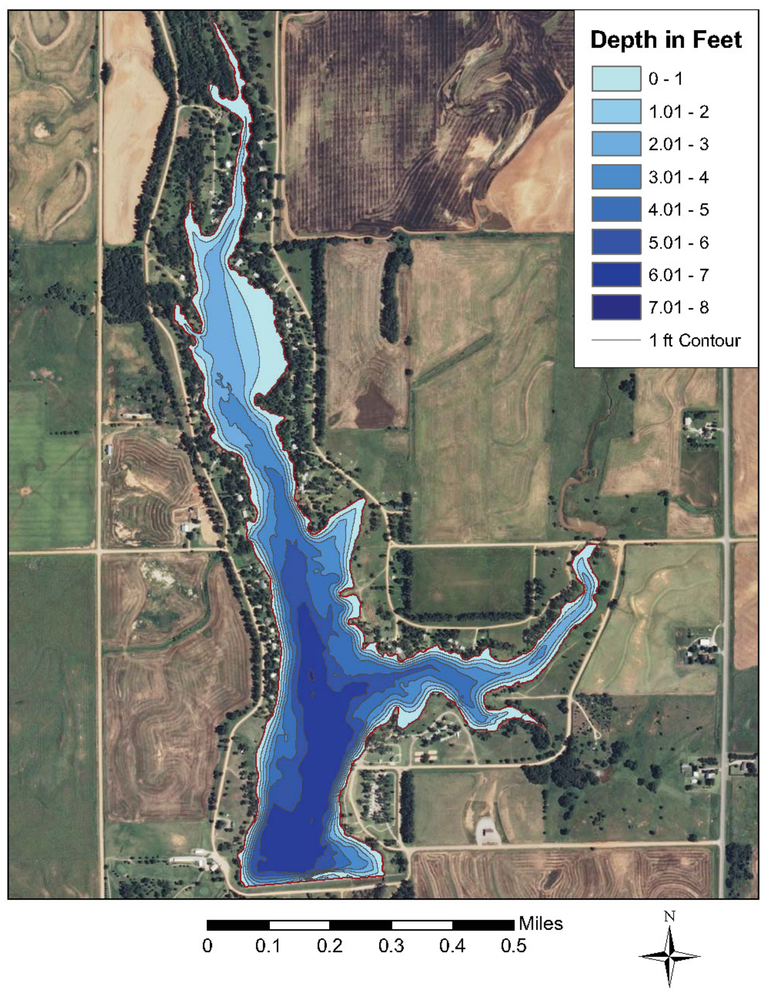

Figure 2—Anthony City Lake bathymetric survey reservoir depths (KBS, 2010).

excavated during the construction of the piers may account for the sediment volume disparity between the KBS and City of Anthony sediment studies.

In 2012, the city cooperated with a petroleum service company, Select Energy Services, to excavate sediment from a portion of the lake in exchange for a commercial water supply agreement. The amount of sediment removed is difficult to quantify, but the Kansas Water Office (KWO) estimates that 10,000 cubic yards were excavated from two areas of the lake. In 2013, the city received bid proposals from several dredging companies to complete the lake dredging project. Cost estimates for removal of approximately 1.5 million cubic yards of sediment are about $3.50 per cubic yard, or $5,250,000 total. Additional engineering studies identified several suitable parcels of land near the lake for sediment disposal.

Harper County Water Supply

Harper County has experienced a rapid expansion of horizontal drilling and hydraulic fracturing. In 2010, 67 wells were spudded (drilling begun), none of which were horizontal. In 2011, 11 of the 44 new wells were horizontal and in 2012, 62 of 108 new wells were horizontal. With this rapid drilling expansion, public water suppliers began to assess how much water could feasibly be allotted to the oil and gas industry without causing local public water supply problems. Compounding the water supply concerns, Harper County has experienced drought conditions since the summer of 2011.

Harper County relies primarily on smaller alluvial aquifers and limited stream flow for its water supply. Although Harper County is meeting its current water supply demands, this supply is somewhat limited relative to other arid counties in Kansas that may possess thicker sequences of the High Plains aquifer or larger river systems with thicker alluvial aquifers. The Chief Engineer of the Kansas Department of Agriculture's Division of Water Resources (DWR) established a dual review system of Designated Unit Areas (DUA) and safe-yield evaluation for water-right development in south-central Kansas. New water rights applications are first evaluated

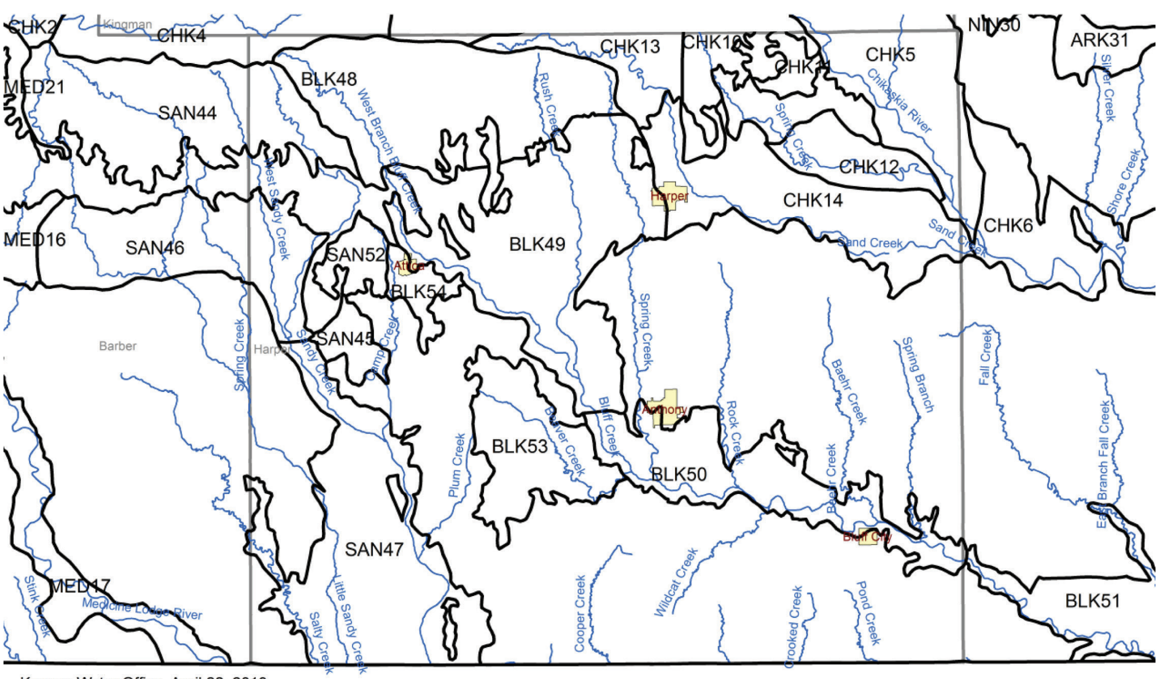

Figure 3—Designated Unit Areas (DUAs) in Harper County around the cities of Anthony and Harper (KWO, 2013)

for water availability based on a specific DUA water budget that considers the change in aquifer storage (fig. 3). If water is available, the application is then evaluated for safe yield within a 2-mile circle around the proposed point of diversion (water well).

Harper County Water Use

Harper County appears to have a sufficient water supply under the current level of demand (fig. 4). The county has an annual authorized quantity of about 6,802 acre-ft of appropriated or vested water rights (i.e., irrigation, municipal, industrial, recreational, stock water, and domestic), almost 90% of which is from groundwater. The reported water use is typically below the authorized quantity. In 2011, the county used about 3,755 acre-ft.

However, the use of recently issued short-term permits (temporary, term, or basin term) for industrial use (i.e., hydraulic fracturing) puts the area at potential risk if a significant portion of the short-term allocations (about 10,177 acre-ft) are fully invoked in the future.

Most short-term permits are not evaluated for safe yield or DUA water budgets. Term permits appropriate water for a specified time; if the time specified is less than five years, then no safe yield or DUA evaluation is conducted. Basin-term permits appropriate up to 100 acre-ft of water annually from streams within a specific basin per calendar year. Temporary permits are for water uses of less than six months (typically 90 days for oil and gas wells). DWR can process temporary permits much faster than term permits. In 2012, the Chief Engineer of DWR raised the temporary permit cap from one million to four million gallons annually, a quantity needed for horizontal drilling and hydraulic

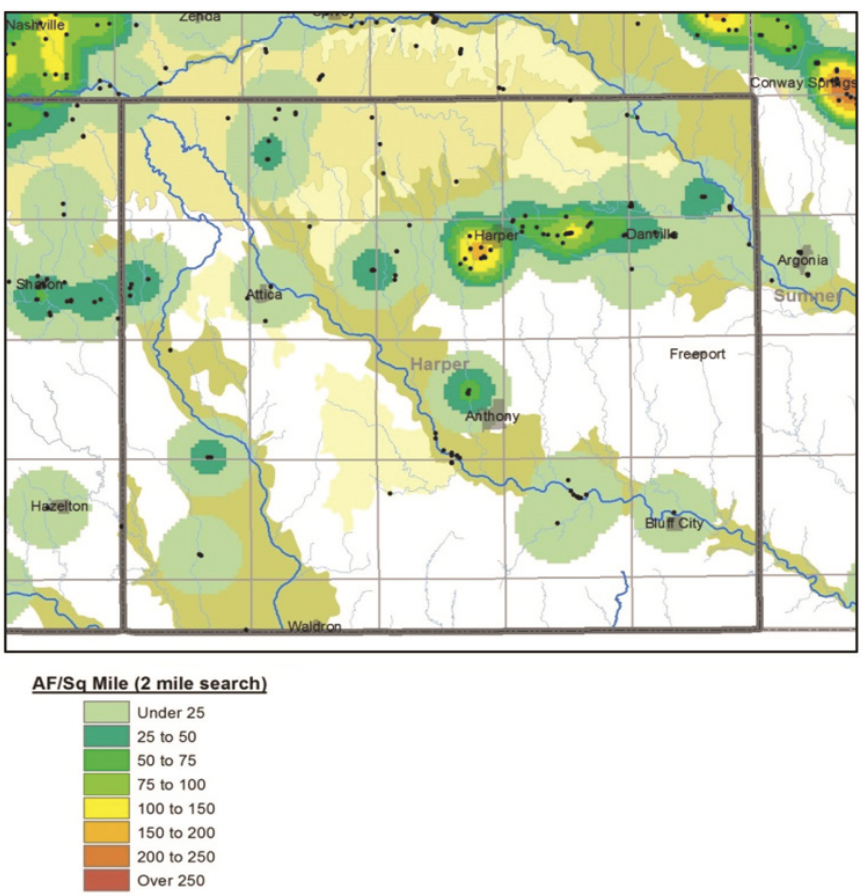

Figure 4—Reported water use density, average 2010 to 2011, for Harper County. Total water use has increased around and to the east of Harper's and Anthony's well fields. Both well fields are located in close proximity to each other near Harper (Kansas Geological Survey).

fracturing. Unlike term and basin-term permits, annual water-use reports are not required for temporary permits, although metering of water use on horizontal wells is required and the user must submit a report if asked.

Consumptive use that exceeds the DUA water budget and safe-yield analysis might occur in some areas if both the annual water use (3,755 acre-ft) and the authorized short-term quantity (about 10,177 acre-ft) were used. Under this extreme scenario, the consumptive use (about 13,932 acre-ft) exceeds the annual appropriated and vested rights in the county (about 6,802 acre-ft). However, to date, less than 5 percent of the short-term permit authorizations have been reported used.

A new type of short-term permit, the limited transfer permit, was signed into law on April 17, 2013. The intent of this permit is to provide the capability to offset short-term water uses from pre-existing water users in targeted areas where declines or potential impairments are a concern, yet keep the application process simple so processing times can still meet industries' needs. The new law will allow DWR to adopt rules and regulations to ensure that no increase of consumptive use would occur under new permits. Limited transfer permits will likely be issued for one year and up to four million gallons of water use. Non-consumption would be accomplished by an offset of water use from an existing water right. If the water right is for groundwater, the use of water can be transferred to another well within the same source of supply within 2 miles. If the water right is for surface water, the use can be transferred to another point of diversion within the same surface-water system.

The Cities of Anthony and Harper, the two largest cities in the county, have their well fields in close proximity to each other (fig. 4). The DUA within which their well fields lie (CHK14 in fig. 3) as well as the DUA immediately to the east are both areas of high water-use density. The cities are considering asking the Chief Engineer to designate those DUAs as areas for limited transfer permits.

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KANSAS GEOLOGICAL SURVEY
The University of Kansas

Hydraulic Fracturing of Oil and Gas Wells in Kansas

Daniel R. Suchy and K. David Newell
Kansas Geological Survey

Introduction

Hydraulic fracturing is a method of enhancing oil and gas recovery from wells by injecting water, sand, and chemicals into rock formations under very high pressure to fracture the rock and release trapped hydrocarbons. It has been used in the industry for decades, but questions have arisen concerning possible environmental problems associated with the practice, particularly suspected contamination of potable ground water and rivers and streams in certain areas. Currently the practice is regulated by the states, with rules varying from state to state. Some people, however, are asking for increased Federal regulation to govern its use (The Editors, 2011). This publication will discuss hydraulic fracturing, how it is used, how it is regulated, especially in Kansas, and possible environmental issues. Terms in **boldface type** are defined in the glossary at the end of the circular.

History of Hydraulic Fracturing

The first experimental hydraulic fracturing treatment in the United States took place in 1947 in the Hugoton gas field in Grant County, Kansas (fig. 1). It was done on a small scale to bypass pore space near the wellbore in the oil-bearing rock formation that was clogged by **drilling mud** during drilling operations (Montgomery and Smith, 2010). In 1949 a patent was issued to the Halliburton Oil Well Cementing Company, which then performed the first two commercial fracturing treatments in Oklahoma and Texas. At that time the engineering was simple and unsophisticated. Since then, significant advances have been made in materials and techniques, fracture modeling, fracturing fluids, and the types and amount of equipment needed (fig. 2). Today over 60% of all oil and gas wells drilled worldwide are fractured, with more than 50,000 **fracture stages** completed annually (Montgomery and Smith, 2010). In Kansas, over 57,000 wells have been hydraulically fractured since that first "frack job" in 1947 (KCC, 2011; fig. 3), and an estimated 90% of the wells drilled in Kansas over the next decade will be fractured (McCoy, 2011). Fracture stimulation has not only increased individual well production, sometimes manyfold, but also has increased estimated recoverable reserves of oil in the United States by 30% and gas reserves by 90% (Montgomery and Smith, 2010). Many oil and gas fields would not be economically viable without it.

Alongside advancements in hydraulic fracturing, horizontal drilling has become increasingly important in the past decade or so. In contrast to conventional vertical drilling, horizontal drilling begins vertically, then, at a given depth, turns gradually in

The first experimental hydraulic fracturing treatment in the United States took place in 1947 in the Hugoton gas field in Grant County, Kansas.

Figure 1—First experimental fracturing job conducted in 1947 by Stanolind Oil in the Hugoton gas field of southwestern Kansas utilizing "1,000 gallons of naphthenic-acid and palm-oil- (napalm-) thickened gasoline" . . . "and sand from the Arkansas River" (from Montgomery and Smith, 2010, p. 2).

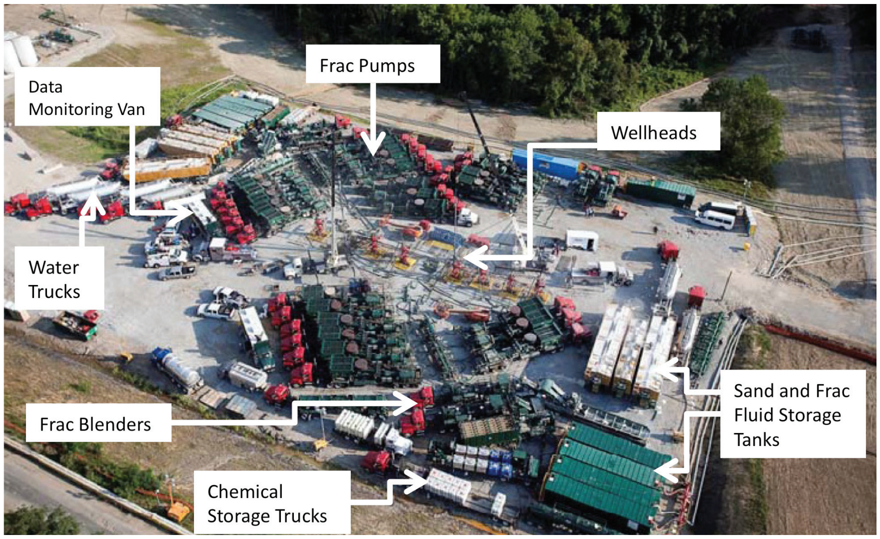

Figure 2—A very large, staged hydraulic fracturing job performed recently on a Marcellus Shale multi-well pad in Pennsylvania (modified from U.S. DOE and NETL, 2011, p. 6). Large numbers of trucks and equipment and voluminous quantities of fracturing fluids are needed to carry out an operation such as this. Fracking operations in Kansas normally are not done on such a large scale.

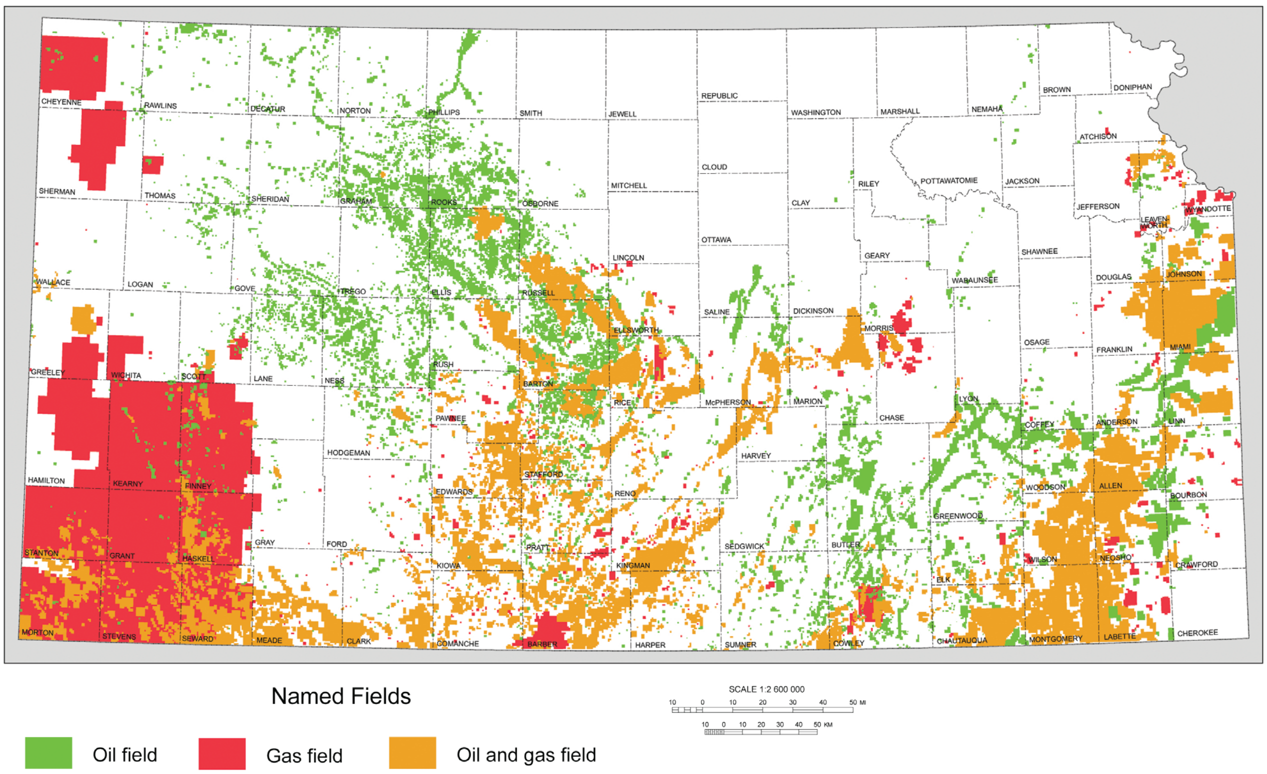

Figure 3—Over 430,000 oil and gas wells have been drilled in Kansas since the late 1800s. Of the roughly 244,000 wells drilled since 1947, over 57,000 of those wells have been hydraulically fractured.

a horizontal direction, in which the borehole proceeds for a long distance through a single formation. Coupling hydraulic fracturing with horizontal drilling has been instrumental in turning previously uneconomical and unconventional plays, such as **shale gas** (fig. 4), **tight gas sandstone**, and **coalbed methane**, into highly productive projects. A fundamental consequence of this recent coupling is that the scale of hydraulic fracturing operations has increased immensely in the last few years (fig. 2).

Hydraulic Fracturing Technology

Hydraulic fracturing, also known as hydrofracturing, hydrofracking, fracking, or fracing, enhances the recovery of oil and gas from wells by fracturing formation rocks to release the hydrocarbons, allowing them to flow more easily through the rocks to the wellbore. Not all formations require such supplementary well completion techniques to permit extraction of hydrocarbons. Some rocks naturally contain abundant fractures and connected pore space that, although often only a millimeter or less across, allow fluids to move freely through them. Other rock formations, such as many shale gas reservoirs, are not permeable (i.e., the pores are not connected) and have few natural fractures and visible pore space. Gas or oil trapped within such impermeable rock can only be extracted by fracturing the rocks.

Hydraulic fracturing is performed soon after a well has been drilled and the metal **well casing** has been cemented into place by filling the annular space around the casing with cement. Selected segments of the wellbore are isolated, and specialized equipment is used to perforate holes through the production casing and cement of each segment. Water containing sand and chemical agents is then pumped at very high pressures, typically thousands of pounds per square inch, through the perforations into the surrounding rock. The intense pressure exerted by the water cracks the rock, creating minute fractures that propagate sometimes hundreds of feet away from the wellbore (fig. 5). Fracturing jobs are normally engineered to restrict the fractures to the target formation. The sand in the fracturing fluid, usually silica sand, is added as a "proppant"; that is, the fractures are propped open by the sand grains after the pressure is released. Although the fractures are held open only the width of a sand grain, it is enough to allow hydrocarbons trapped in the rocks to flow to the wellbore. Some wells are hydrofractured in more than one producing horizon, depending on where oil and gas occur in the subsurface.

Prior to the last decade, hydraulic fracturing was used primarily in vertical wellbores and in "conventional" rocks such as limestone and sandstone to stimulate oil and gas production (fig. 5). In recent years, operators have begun drilling more horizontal wells because they maximize the contact area within the targeted formation (fig. 6). Horizontal drilling has become especially useful in unconventional gas plays, such as tight gas sandstones, gas shales, and coalbed methane. In such operations, the horizontal part of a well can extend for 1,000 to 5,000 feet or more through a single rock formation. After the well casing and cement are installed in the well, perforations are made at several locations along that horizontal reach. Hydraulic fracture stimulation is then performed at those locations in stages, beginning at the far end and moving closer to the uphole end with each stage of the stimulation (fig. 6). This controlled procedure allows the operator to adjust for site-specific changes along the wellbore. For example, variations may occur in formation thickness, the integrity of the rock, the presence or absence of natural fractures, proximity to other wellbore fracture systems, and boreholes not centered in the formation at some points. Formation-specific data collected along the wellbore can be used to optimize the fracture patterns created.

Strong economic incentives compel operators to avoid propagating fractures beyond the target formation and into adjacent strata (Ground Water Protection Council and ALL Consulting, 2009). Besides constituting a waste of time, materials, and money, fracturing outside the targeted formation could result in loss of the well or in excess water encroachment from surrounding strata, which increases production costs. Before a fracturing operation commences, sophisticated computer models are used to design the process based on known characteristics of the rocks and fractures in the formation, and to "evaluate the height, length, and orientation of potential fracture development" (Ground Water Protection Council and ALL Consulting, 2009, p. 57). Tests are run on the well casings, cement, and fracturing equipment before and during the entire operation to assure that the well and equipment are working properly and safely. Technologies such as microseismic fracture mapping and fracture tilt measurements are used to evaluate the success and orientation of the fractures created.

Fracturing Fluids

Fluids used for hydraulic fracturing consist primarily of water and a proppant (usually sand), with various additives that serve different purposes (table 1). Water and sand make up 98% or more of the fluid, while the additives constitute 2% or less (FracFocus.org, 2011). The additives used vary according to site-specific characteristics of the well, the target formation(s), the water source, and individual company practices. Some companies keep the compositions of their frack fluids confidential for proprietary reasons, or simply list all the ingredients and keep their relative percentages confidential, whereas other companies disclose the exact composition of their frack fluids. Companies can voluntarily disclose the chemical additives they use for hydraulic fracturing on the web-based registry, www.hydraulicfracturingdisclosure.org/fracfocusfind/. Although in most cases only a limited number of additives are used in any one well treatment, the 2011 Environmental Protection Agency (EPA) Hydraulic Fracturing Study Plan (EPA, 2011) lists nearly 1,000 chemicals that have been identified in various frack fluids and flowback/produced waters. A separate table in that document lists 30 naturally occurring substances that may be leached from the rocks by fracking activities, including radium, thorium, uranium, arsenic, hydrogen sulfide, and lead.

In a typical fluid mixture, friction-reducing additives (called slickwater), often consisting of petroleum distillates or soap-like agents called surfactants, are used to facilitate pumping of the fluids and proppant at a higher rate and at lower pressures than if water alone were used (Ground Water Protection Council and ALL Consulting, 2009). Thickening agents, such as guar gum (also used as a thickener in food, toothpaste, and cosmetics), help suspend the proppant. Biocides eliminate bacteria that can cause biofouling of

Figure 4—Major shale gas plays in the contiguous United States (from EPA, 2011, p. 10).

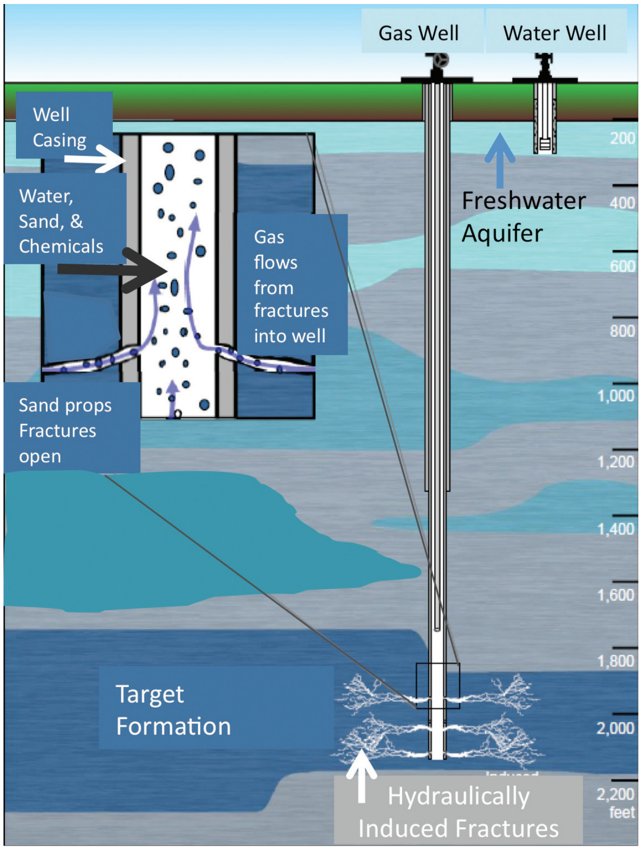

Figure 5—Hydraulic fracturing in a vertical well (modified from EPA, 2011, p. 13).

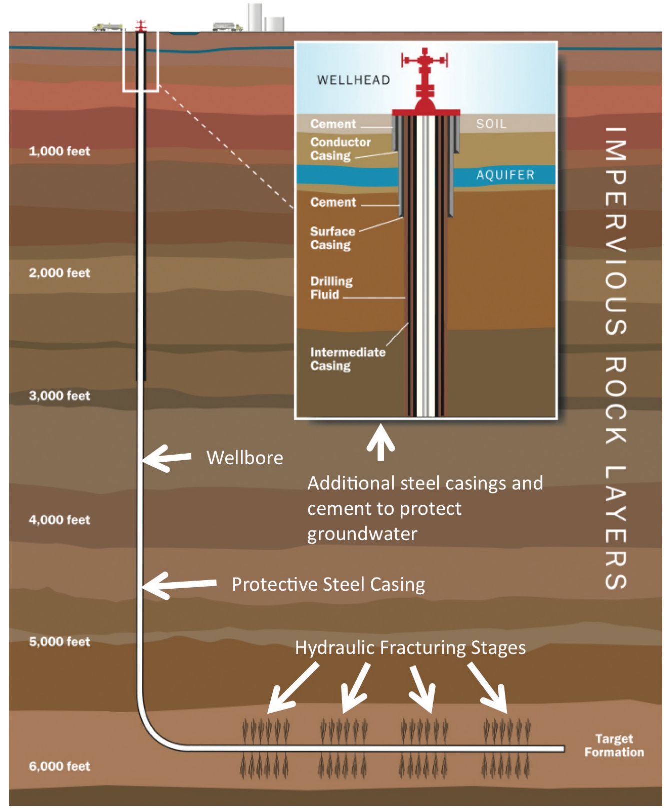

Figure 6—Illustration of a horizontal well drilled into a shale layer that has been hydraulically fractured approximately 6,000 feet below the surface. Steel casings lining the well and cemented in place are designed to prevent fracturing fluids and produced hydrocarbons from entering surrounding formations. Freshwater aquifers used for irrigation or drinking water are usually separated from the fractured shale by hundreds or thousands of feet of rock. (Modified from a figure in KCC, 2011.)

the fractures, corrosion of the pipes, or creation of unwanted by-products such as poisonous H_2S gas. Other stabilizing agents help prevent metal corrosion, and acids clear pore space clogged near the borehole by drilling mud.

Water Requirements and Management

According to the Ground Water Protection Council and ALL Consulting (2009, p. ES-4), "the drilling and hydraulic fracturing of a horizontal shale-gas well may typically require 2 to 4 million gallons of water." Some may require more. This is a one-time use, and the amounts are relatively small in comparison to, say, the amount of water used for irrigation. An average agricultural irrigation well in western Kansas, irrigating approximately 125 acres, pumps nearly 45 million gallons of water per year (calculated from 1998 water usage figures given in Rogers and Wilson, 2000). Hydraulic fracturing requirements vary from well to well, and as technologies and methods improve over time, the amount of water needed appears to be decreasing. The water used for hydraulic fracturing typically comes from local sources, such as rivers and lakes, ground water, municipal supplies, recycled flowback water from other frack jobs, and re-used water produced from the oil and gas formation. In areas where water supplies are limited, obtaining water can present a challenge. In Kansas, the Division of Water Resources, which governs how water is allocated and used in the state, issues permits to operators who pump water for industrial purposes such as fracking.

When a fracking treatment is completed and the pressure is relieved, the fracturing fluid, mixed with natural formation water, begins to flow back up the casing to the surface, where it is emptied into tanks or pits for later disposal. This water, which can vary from fresh to saline, contains compounds from the fracturing fluid, formation waters, and dissolved components from the rocks. A large portion of the fracturing fluid is recovered within a few hours to a couple of weeks, but much of the frack material stays in the ground until it is pumped to the surface with the produced hydrocarbons, and some may stay in the deep subsurface permanently. The Ground Water Protection Council and ALL Consulting (2009) state that "the volume of produced water may account for less than 30% to more than 70% of the original fracture fluid volume," and "in some cases, flowback of fracturing fluid in produced water can continue for several months after [oil and/or] gas production has begun." This water must be managed or disposed of properly. In Kansas, the Kansas Corporation Commission (KCC) regulates management of the storage pits and tanks, and the ultimate disposal of fracking fluids and produced water. Fracturing fluids can sometimes be re-used for the same purpose in another well, but oftentimes they are injected into deep disposal wells, which also are regulated by the KCC.

Protecting the Ground Water

In the majority of cases in Kansas, formations targeted for oil and gas production lie thousands of feet beneath the surface of the earth, whereas ground-water **aquifers** used for drinking water and irrigation lie within a few hundred feet of the surface (fig. 6). The drinking-water aquifer is therefore separated from the oil or gas reservoir by thousands of feet of impermeable rock and is thus protected from contamination by oil or gas. When hydraulic fractur-

Table 1—Example of volumetric composition of typical hydraulic fracturing fluid (from EPA, 2011, p. 29).

Component/ Additive Type	Example Compound(s)	Purpose	Percent Composition (by volume)	Volume of Chemical (gallons)
Water		Deliver proppant	90	2,700,000
Proppant	Silica, quartz sand	Keep fractures open to allow gas flow out	9.51	285,300
Acid	Hydrochloric acid	Dissolve minerals, initiate cracks in the rock	0.123	3,690
Friction reducer	Polyacrylamide, mineral oil	Minimize friction between fluid and the pipe	0.088	2,640
Surfactant	Isopropanol	Increase the viscosity of the fluid	0.085	2,550
Potassium chloride		Create a brine carrier fluid	0.06	1,800
Gelling agent	Guar gum, hydroxyethyl cellulose	Thicken the fluid to suspend the proppant	0.056	1,680
Scale inhibitor	Ethylene glycol	Prevent scale deposits in the pipe	0.043	1,290
pH adjusting agent	Sodium or potassium carbonate	Maintain the effectiveness of other components	0.011	330
Breaker	Ammonium persulfate	Allow delayed breakdown of the gel	0.01	300
Crosslinker	Borate salts	Maintain fluid viscosity as temperature increases	0.007	210
Iron control	Citric acid	Prevent precipitation of metal oxides	0.004	120
Corrosion inhibitor	N, n-dimethyl formamide	Prevent pipe corrosion	0.002	60
Biocide	Glutaraldehyde	Eliminate bacteria	0.001	30

ing is applied to a formation, care is taken to confine fracturing to the targeted formation. With the additional safeguard of thousands of feet of overlying rock in most drilling situations, it is highly unlikely that fractures will propagate far enough through the rock to reach overlying aquifers.

The metal well casing installed in the borehole and the cement that seals the annular space around the casing (fig. 6) confine the fracking fluids and any produced hydrocarbons and other formation fluids within the casing and prevent them from entering surrounding formations. KCC regulations require that additional casings be installed through freshwater aquifers to add extra protection against ground-water contamination.

In some areas of Kansas, hydrocarbon reservoirs, especially gas reservoirs, lie closer to the surface and thus extra vigilance is required to reduce the risk of ground-water contamination. Additionally, with the advent of horizontal drilling, the risk of encountering natural faults or fractures that extend into overlying layers increases with the increasing horizontal lengths of the boreholes. Special precautions must be taken not only to assure good casing and cement installations, but also to employ good engineering and rock characterization to avoid natural faults that may be conductive to overlying aquifers, and to confine hydraulic fracturing to the target formation.

In some areas where drilling occurred very early in the history of the oil and gas industry in Kansas, undocumented unplugged wells may still be present. These wells were drilled before serious oversight commenced, or before anyone truly understood many of the relevant stratigraphic and structural geologic principles. The KCC is plugging abandoned wells as it becomes aware of them and as the budget allows.

Is it Safe?

Many of the additives in fracking fluids are generally safe (water, sand, certain acids, etc.), but some additives and formation flowback chemical solutions (benzene, toluene, radium, saline waters, etc.) are less safe and need to be managed properly. Oil and gas statutes developed by the Kansas Legislature and regulations developed by the KCC serve to govern hydraulic fracturing in oil and gas wells and the subsequent management of fluids and chemicals. The KCC, as the regulatory agency, approves, oversees, and inspects such operations, and no ground-water contamination has been reported to them as a consequence of fracking operations in Kansas. Additionally, since the method was pioneered in Grant County in 1947, technologies and treatments have evolved and become more precise, controlled, and safe.

Other states have experienced concerns with fracking or with disposal of the resulting fluids. Questions have been raised about possible contamination of local water wells by natural gas or by fracking fluids in Pennsylvania, Colorado, Wyoming, and Texas, among others (Biello, 2010; Earthjustice, 2011; Lustgarten and ProPublica, 2011). A well blowout in Pennsylvania resulted in fracking fluids spilling onto the ground and flowing across fields and into streams (WNEP, 2011). Also in Pennsylvania, where few deep injection wells are available for disposal, fracking fluids have been taken to local wastewater-treatment plants, which are ill-prepared to deal with the huge volumes of additional wastewater and the types of contaminants found in them (The New York Times, 2011). As a result, high levels of undesirable contaminants, such as radium, benzene, toluene, trihalomethanes, and highly saline water have been released into major streams that supply drinking water for millions of people. In addition, methane, known to be a powerful greenhouse gas, is sometimes released into ground water or into the atmosphere due to improperly cased wells or leaking pipes (Food & Water Watch, 2011). Other airborne pollutants found at higher than allowable limits near fracking sites in Texas and Wyoming include methanol, formaldehyde, carbon disulfide, benzene, and other neurotoxins and carcinogens, as well as volatile organic compounds that can react with sunlight to create smog (Biello, 2010; Food & Water Watch, 2011). Concerns about induced seismicity, or earthquake activity related to injection of fluids into the subsurface, have been raised in some areas, but there is no evidence that hydraulic fracturing itself triggers earthquakes. Instead, small earthquakes may have been triggered by deep disposal of fluids from oil and gas operations (Zoback, 2012).

Some of these incidents may have resulted from fracking in unfamiliar formations or geologic situations, or perhaps due to unsuspected faults, unplugged abandoned wells, or other unexpected fluid migration routes. Inadequate means of dealing with the volumes of fluid generated can be a problem, as in Pennsylvania. In some cases, the problems may not be directly related to hydraulic fracturing itself, but rather to operating issues such as casing problems, or broken pit liners or mud tanks (Durham, 2011). Clearly, experience, good engineering, and good regulatory oversight are important for the successful management of hydraulic fracturing treatments.

For the most part, Kansas has not encountered the problems some other states have, and no documented cases of ground-water contamination by hydraulic fracturing have been reported in the state. Hydraulic fracturing has been employed for over 60 years in Kansas, in most cases hundreds or thousands of feet beneath any usable aquifers, thus posing little threat to them. Casing, cementing, and plugging regulations secure the safety and integrity of the wells when carried out properly. Deep disposal wells are available throughout much of the state, and they have been regulated and overseen by the KCC and Kansas Department of Health and Environment for many years; consequently, in Kansas, fracking fluids are not disposed of in wastewater-treatment plants. In short, Kansas' favorable geologic setting, its regulatory process, and its successful history of hydraulic fracturing and fluid management make it one of the safer regions of the country to employ the practice.

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Glossary

Aquifer: a geologic formation or body of rock that is porous and permeable enough to transmit ground water at a rate sufficient to yield significant quantities of water to wells or springs.

Coalbed methane: natural gas (primarily methane) produced from coal beds; the methane is adsorbed into the solid matrix of the coal, and the coal must be fractured and dewatered to release the gas.

Drilling mud: a mixture of mud-like substances used to lubricate the drill bit and drill stem when drilling an oil or gas well.

Fracture stages: each of the individual hydraulic fracturing operations carried out at different levels or locations within a single oil or gas well.

Shale gas: natural gas produced from shale, usually trapped in tiny unconnected pore spaces in impermeable shale that requires fracturing of the rock to release the gas.

Tight gas sandstone: sandstone that contains natural gas trapped in small unconnected pore spaces; needs fracturing to release the gas.

Well casing: "Heavy metal pipe, lowered into a bore hole during or after drilling and cemented into place. It prevents the sides of the hole from caving, prevents loss of drilling mud or other fluids into porous formations, and prevents unwanted fluids from entering the hole" (Bates and Jackson, 1980, p. 97). The types of casing permitted in Kansas are discussed in KCC regulations online (KCC, 2011).

KU
KANSAS GEOLOGICAL SURVEY
The University of Kansas

The mission of the Kansas Geological Survey, operated by the University of Kansas in connection with its research and service program, is to conduct geological studies and research and to collect, correlate, preserve, and disseminate information leading to a better understanding of the geology of Kansas, with special emphasis on natural resources of economic value, water quality and quantity, and geologic hazards.

The Geology Extension program furthers the mission of the KGS by developing materials, projects, and services that communicate information about the geology of Kansas, the state's earth resources, and the products of the Kansas Geological Survey to the people of the state.

Public Information Circular 32
December 2011
Revised May 2012

Kansas Geological Survey
Geology Extension
The University of Kansas
1930 Constant Avenue
Lawrence, Kansas
66047–3724
(785) 864–3965
http://www.kgs.ku.edu

Wednesday, June 5, 2013

6:00 a.m.	Breakfast at Cobblestone Inn and Suites, Anthony Catered by Fence Post Supper Club (breakfast served as early as 6 a.m. but starting time is informal)
8:00 a.m.	**Bus leaves Cobblestone Inn and Suites, Anthony, for Medicine Lodge**
8:45 a.m.	Restroom Break, USD 245 Central Office, Medicine Lodge
9:00 a.m.	Bus to Site 6
	SITE 6 – Mississippian Limestones Oil Production and Development Woolsey Operating Company, Barber County
	Economic Assessment of Horizontal Wells in the Mississippian Play *K. David Newell*, Associate Scientist, Petroleum Geology, Kansas Geological Survey
	Vertical Well Development in the Mississippian Limestones *David Clothier*, Vice President of Exploration, McCoy Petroleum
	Horizontal Well Development in the Mississippian Limestones *I. Wayne Woolsey*, President, Woolsey Operating Company
	Legislative Update: Fracking Fluid Disclosure and Cutting Disposal Regulations *Jeff Klock,* District 2 Supervisor, Conservation Division, Kansas Corporation Commission
12:30 p.m.	Lunch – Community Bible Fellowship Church, Medicine Lodge Six L Catering
1:30 p.m.	Bus to Site 7
1:45 p.m.	**SITE 7** – Red Hills Initiative, Barber County *Rob Manes*, State Director, The Nature Conservancy
2:15 p.m.	Bus to Site 8

2:30 p.m.	**SITE 8** – Alexander Ranch
	Rangeland Management *Ted Alexander*, Owner, Alexander Ranch
	Unmanned Aerial Drone Assessment of Red Cedar Encroachment *Larry Biles,* State Forester, Kansas Forest Service *David Burchfield,* GIS Specialist, Kansas Forest Service *Deon van der Merwe*, Associate Professor, Head of Toxicology, Kansas State Veterinary Diagnostic Laboratory
3:15 p.m.	Bus to Site 9
3:30 p.m.	**SITE 9** – Buster's Saloon, Sun City
	Commercial Hunting and Guide Service *Rick Lambert,* Buster's Outfitters
4:30 p.m.	Bus to Holiday Inn Express, Pratt
5:00 p.m.	Arrive at Holiday Inn Express, Pratt
6:00 p.m.	Bus to supper
6:15 p.m.	Supper – Kansas Department of Wildlife, Parks and Tourism Regional Office, Pratt
8:00 p.m.	Return to Holiday Inn Express, Pratt

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Public Information Circular 33 March 2013

The Mississippian Limestone Play in Kansas: Oil and Gas in a Complex Geologic Setting

Catherine S. Evans and **K. David Newell**, Kansas Geological Survey

At the onset of the 21st Century, innovations in drilling technology led to significant increases in production in several U.S. oil and gas **plays** previously considered nearly tapped out or not highly productive. In the Bakken shale play in North Dakota, use of techniques combining **horizontal drilling** and **hydraulic fracturing**, popularly called "fracking," resulted in a dramatic increase in drilling and production. As the Bakken was proving profitable, exploration companies began targeting oil and associated natural gas in the Mississippian limestone play of Oklahoma. Following successes there, companies bought mineral rights in areas of southern and western Kansas, where Mississippian rocks and associated petroleum production extended into Kansas (fig. 1).

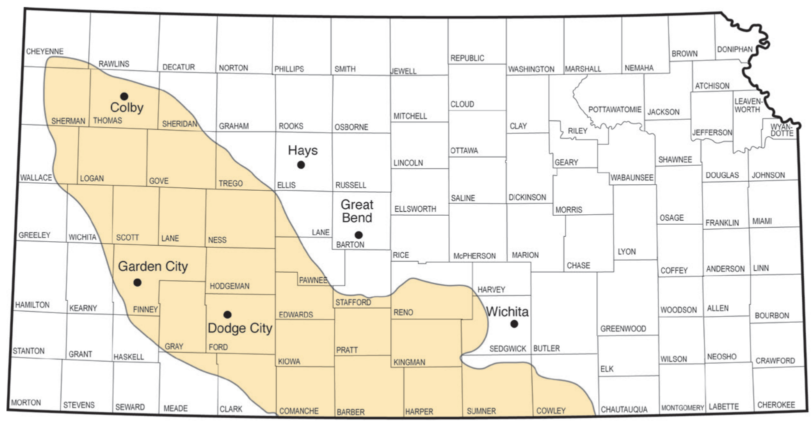

Figure 1—Boundary of the Mississippian limestone play in Kansas.

Since 1970, 12% of the state's total oil production came from Mississippian zones. In 2012, 15% of production was Mississippian.

The upper boundary of the Mississippian play—a complex group of oil and gas reservoirs within a shared geologic and geographic setting—had already been delineated in Kansas using data collected from thousands of vertical wells over several decades. Colloquially known as the "Mississippi lime," the play attracted national oil and gas companies to areas previously dominated by smaller independent companies. Although not on nearly the same scale as in North Dakota, horizontal drilling in southern Kansas accelerated.

The Bakken and Other Plays: How the Mississippian Limestone Play Compares

The innovation of horizontal drilling and multistage hydraulic fracturing has been particularly important in the production of natural gas locked in deeply buried shales, such as the Woodford Shale in Oklahoma, the Barnett Shale in Texas, and the Fayetteville Shale in Arkansas. The Bakken shale, which extends from North Dakota and Montana into Canada, was one of the first plays in which advanced drilling techniques were successfully used to recover oil. Once the profitability of the new Bakken oil wells was proven in 2007, the number of rigs in North Dakota rose rapidly (fig. 2) and the economy boomed. Due in large part to the potential seen in the Mississippian limestone play, the

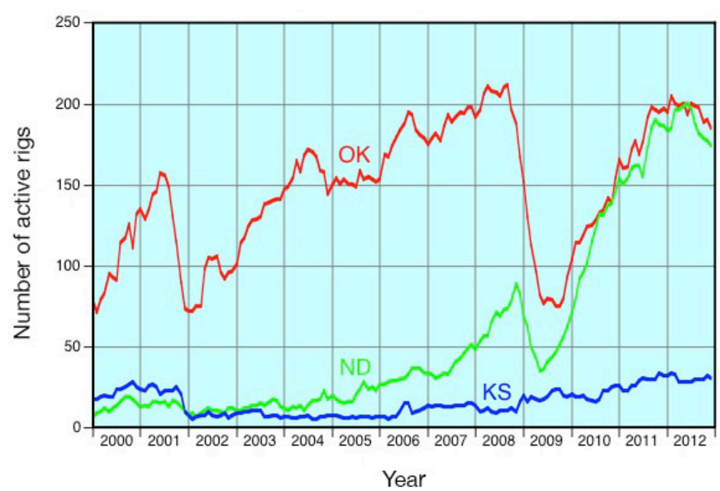

Figure 2—Drilling rigs operating in North Dakota, Oklahoma, and Kansas between 2000 and 2012 (source: Baker Hughes).

Note: Terms in **bold face** type are defined in the glossary on page 6.

Table 1—Comparison between the Bakken shale play in North Dakota and the Mississippian limestone play in Kansas.

Play Attributes	Bakken Shale Play	Mississippian Limestone Play
Estimated recoverable oil	2 to 24 billion bbls[a]	Unknown
Average depth to oil	~9,000 ft (2,743 m)	~4,500 ft (1,372 m)
Rock type	Organic-rich shale	Variety of low-permeable limestone
Average thickness	~40 ft (12 m)	~50 ft (15 m)
Average recoverable oil/well	~350,000–850,000 bbls[a]	~50,000–350,000 bbls[a] (?)
Average cost per well	$7,000,000	$3,000,000
Gravity of oil[b]	42 °API with natural gas	30 °API with (or solely) natural gas
No. of horizontal wells	~2,000 as of mid-2012	113 (as of October 2012)
Acres per well	160, 640, or 1,280	160 (as of January 2013)
Max. production rate recorded as of Jan. 2013	~7,000 bbls[a]/day	~850 bbls[a]/day
Statewide production in 2012	360,000 bbls[a]/day	115,000 bbls[a]/day

[a]barrels of oil

[b]API gravity is an arbitrary measurement of relative density. Less dense, or lighter, petroleum products are easier to refine and, therefore, have a higher value. Heavy oils, with lower API gravities, are less valuable. A value of 30 °API or higher is considered light.

horizontal rig count revived in Oklahoma after earlier declines. Interest in Kansas grew also, but the increase in rigs in the state through 2012 was modest in comparison to the two other states.

Although horizontal drilling and hydraulic fracturing techniques being used in the Mississippian play in Kansas are similar to those used in the Bakken shale and other plays in the United States, development and future production in Kansas cannot be predicted based on results in areas with different geologic settings and properties. How production in Kansas will stack up to that in North Dakota has yet to be determined. Table 1 shows a comparison between the geology, development, and production of the Mississippian limestone play in Kansas and the Bakken shale play in North Dakota as of early 2013.

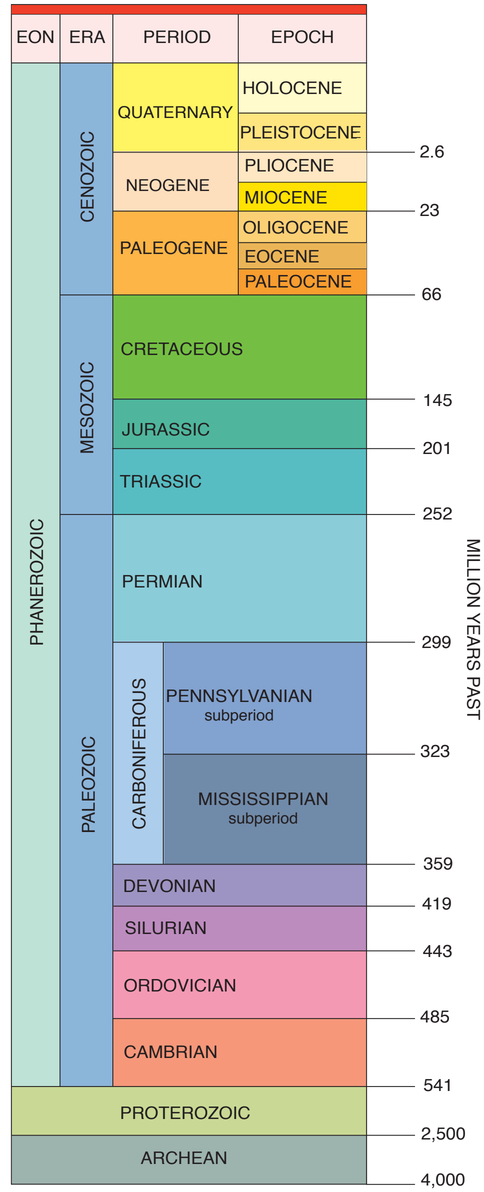

Figure 3—Geologic timetable for Kansas (modified from International Commission on Stratigraphy, 2012). The Mississippian Subperiod of the Carboniferous Period lasted from about 359 million to 323 million years ago.

Mississippian Rocks and the Mississippian Limestone Play in Kansas

Rocks deposited during the Mississippian Subperiod, spanning about 359 million to 323 million years ago (fig. 3), are found in the subsurface throughout most of Kansas. Exposed at the surface only in the extreme southeastern corner of the state, Mississippian rocks get progressively deeper from east to west. Mississippian rocks are oil-bearing in several parts of central and western Kansas, where they have been buried several thousand feet deep. Due to erosion, Mississippian rocks are absent along the crest of two now-buried structural highs—the **Central Kansas uplift** and the **Nemaha uplift**—although oil and gas production from the Mississippian is prevalent along the flanks of the uplifts (fig. 4). Mississippian rocks are also thin to absent on local **anticlines** but are relatively thick in **synclines** and **basins**.

Shallow seas covered nearly the entire state in early Mississippian time but inundated only the southern portion toward the end of the period when rocks in the Mississippian limestone play were deposited (fig. 5). During that time, Kansas was below the equator, at approximately 20° latitude within the tropical to subtropical latitudinal belt (Franseen, 2006). (Over hundreds of millions of subsequent years, the North American plate slowly migrated to its current location.)

Marine lime mud and shelly debris from seas that repeatedly advanced and regressed resulted in the Mississippian limestone and **chert** layers found in the subsurface of south-central Kansas (Watney et al., 2002). In what is now a porous and fractured target zone of the Mississippian play, the limestone, but not the more durable chert, dissolved through weathering during periods

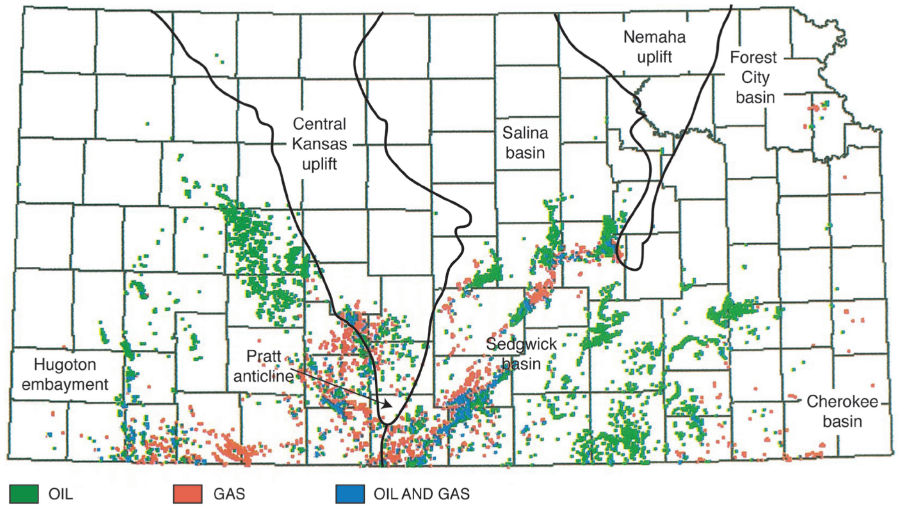

Figure 4—Mississippian oil and gas production and the major subsurface structural elements in Kansas (modified from Newell et al., 1987).

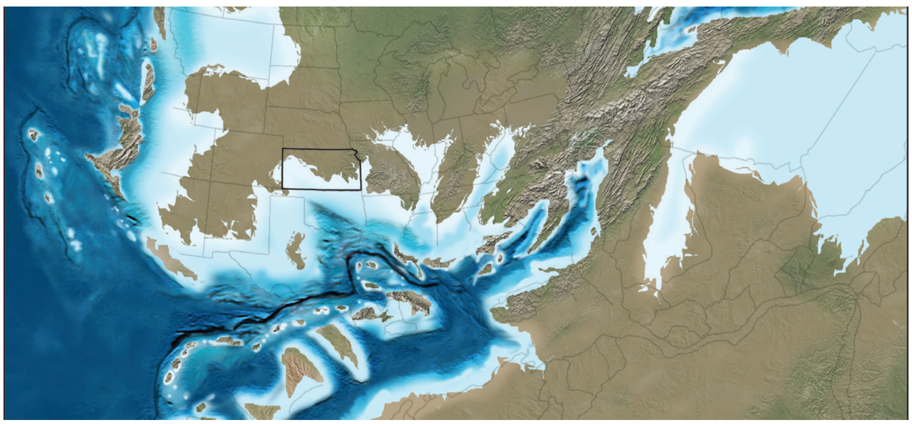

Figure 5—The southern portion of Kansas was inundated with shallow seas during the Late Mississippian Subperiod, when rocks from the Mississippian limestone play were deposited (modified from Blakey, 2010).

Figure 6—Core from a well in the Wellington field in Sumner County. The core, which starts 2 ft (0.6 m) below the top of the Mississippian at 3,660.85 ft (1,116 m), is dominated by a cherty conglomerate, informally called "chat," that extends down to 3,670.5 ft (1,119 m).

of exposure when sea levels dropped. This residual chert reservoir is informally called "**chat**" (fig. 6).

Mississippian rocks in Kansas can be divided into two general **lithologic** sequences. The older sequence is a group of shallow-marine limestones, cherts, and cherty limestones that are Kinderhookian, Osagean, and Meramecian in age (fig. 7). Many of the groups of rocks targeted in the Mississippian limestone play are part of that sequence. The Cowley formation—a cherty, fine-grained limestone that commonly has interbedded shale—is also part of the older sequence in south-central Kansas. Despite its economic potential, the Cowley's stratigraphic relationship to the shallow-water limestones is ambiguous and under debate (Mazzullo et al., 2009). Whereas the Cowley may be equivalent in age to other rocks in the Mississippian limestone play, it could represent a deeper-water deposit.

The younger Mississippian lithologic sequence consists of marine and nonmarine shales and sandstones with minor limestones that are Chesterian in age (Newell et al., 1987). Widespread in Oklahoma, Chesterian rocks extend into only a handful of southwestern Kansas counties (Stanton, Grant, Haskell, Morton, Seward, and Meade).

Hundreds of fields throughout the southern half of Kansas include Mississippian production zones (fig. 4). Oil, without significant gas, has been produced from the Mississippian on the flank of the **Hugoton embayment** southwest of the Central Kansas uplift. Mississippian production dominates on the flanks of the Nemaha uplift and western side of the Cherokee basin. Gas, and associated oil and gas production, occur on the Pratt anticline, in the Sedgwick basin, and in the Hugoton basin near the Kansas-Oklahoma state line. Scattered gas production occurs farther east (Newell et al., 1987).

Although much of the oil in Kansas has been produced from zones older and younger than the Mississippian along the crests of the Central Kansas and Nemaha uplifts, Mississippian production is still substantial in the state. Since 1970, 12% of the state's total oil production came from Mississippian zones (fig. 8). In 2012, 15% of the production was Mississippian.

Exploration and Production

In 2010, renewed interest in the Mississippian play in southern Kansas emerged even as production from vertical wells there continued to decline. The norm in hydrocarbon exploration and development for decades,

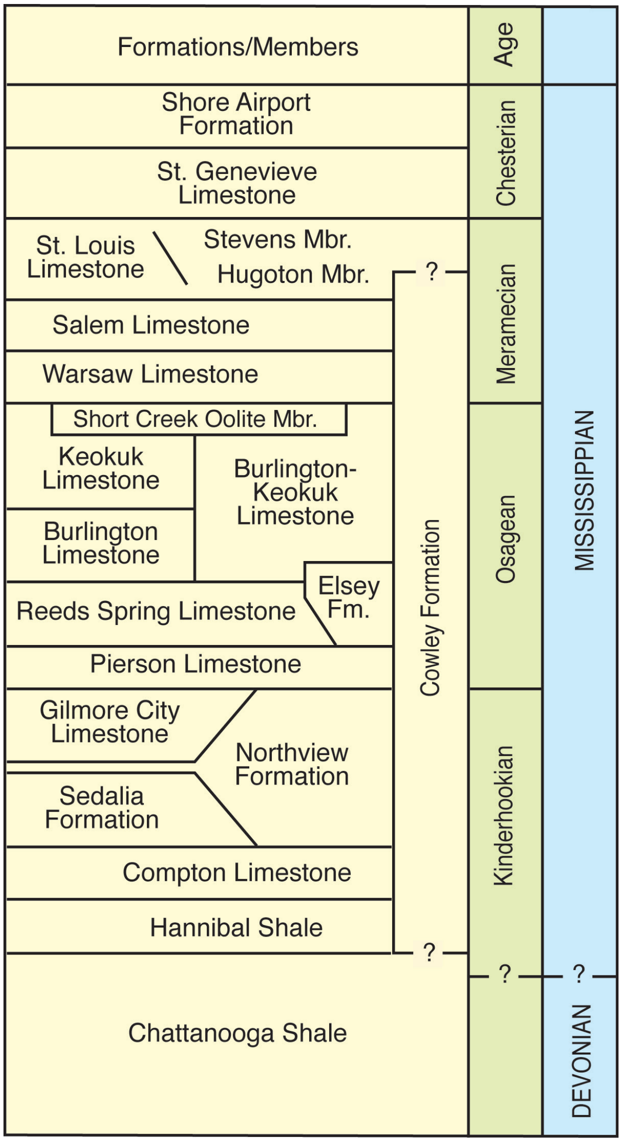

Figure 7—Mississippian nomenclature in Kansas as proposed by Maples (1994). The Mississippian limestone play includes rocks that range in age from Chesterian to Kinderhookian but are predominantly Osagean. The Cowley formation, whose stratigraphic relationship to other rocks in the play is still under debate, may be found in place of all or part of the interval of rocks from the lower St. Louis Limestone to the Chattanooga Shale (Maples, 1994).

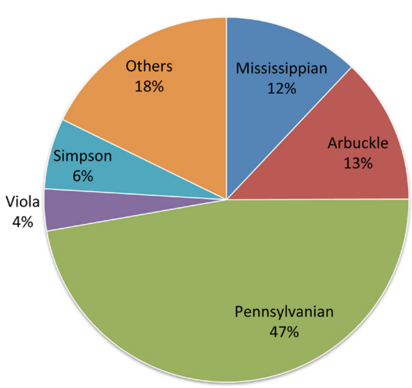

Figure 8—Oil production by geologic unit in Kansas since 1970 (based on production numbers from the Kansas Department of Revenue).

vertical wells are sunk directly downward into oil- or gas-bearing reservoir rocks ("pay zones"). Because a vertical hole has limited contact with any given zone, more oil or gas is usually left in a reservoir than is produced over the typical multiyear lifespan of the well. In contrast, horizontal wells now drilled in southern Kansas more precisely target potential pay zones. The wellbore of a horizontal well turns gradually from vertical to horizontal over a few hundred feet before continuing through a target zone. Boreholes can be drilled horizontally for 10,000 feet (3,048 m) or more, though to date most Kansas wells extend horizontally only 2,000 to 3,000 feet (610 to 914 m).

Multistage hydraulic fracturing, used in combination with horizontal drilling, is applied along the horizontal segment of wellbore to crack the rocks and provide access to oil trapped in unconnected pores. Poor drainage in hydrocarbon production of the Mississippian limestone reservoirs has hampered its oil-field development for decades. Rocks in the play often have excellent **porosity** due to numerous and large pores but are plagued by poor **permeability**, where pores are isolated from each other or poorly connected. Low permeability results in poor hydrocarbon recovery with traditional methods. Horizontal drilling and hydraulic fracturing together provide better access to isolated hydrocarbon-bearing pores and, as a result, better hydrocarbon recovery.

Three-dimensional seismic imaging also has become an integral part of the exploration process. Before drilling, exploration companies often send seismic (sound) waves into the ground and measure the rebounding energy with a widespread grid of electronic receptors called geophones. The sound waves reflect off different rocks and layers in different ways to create a 3-D image of the subsurface. Seismic reflection helps identify potential oil and gas sources before drilling begins.

Most of the production in the Mississippian limestone play in Kansas has occurred at or near the top of the Mississippian rocks still present, particularly from the chat. Thickest on the flanks of the Central Kansas uplift and Pratt anticline, the cherty beds can be quite variable in reservoir characteristics. The porosity and permeability of the beds have been hard to predict, and overlying conglomerates at the base of the overlying Pennsylvanian rocks, which may also serve as reservoir rocks, are difficult to distinguish from the chat (Newell et al., 1987).

The Mississippian play encompasses several units that were not well differentiated in the past, and questions still remain about the geologic structure of the reservoirs involved as well as the subtle but important depositional relationships of some of the Mississippian beds. Subtle **stratigraphic traps**, attributable to the varying reservoir quality of the chat and overlying basal Pennsylvanian conglomerates, are targets for horizontal-drilling exploration in the area centered on Harper, Barber, and Comanche counties (Newell et al., 1987). Mississippian limestone reservoirs have also been targeted for exploration farther north and west in Gove, Ness, Lane, and Reno counties.

Economics of Drilling

Oil companies have to reckon with an economic tradeoff when they choose to drill a horizontal well in the Mississippian limestone play. A horizontal well is expensive, costing up to 10 times more than a vertical well. A company choosing to drill a horizontal development well is thus betting that one horizontal well will be less expensive to drill than several vertical wells and that it will have better rates of production and hydrocarbon recovery over its lifetime.

Historically, smaller, mainly local, independent companies have drilled most of the oil and gas wells in Kansas because profit margins and production rates and volumes rarely attracted national or international companies. About 2010, however, larger regional and international companies started leasing substantial acreage in Kansas with the idea that oil-bearing Mississippian strata could be best developed with the more expensive horizontal wells and multistage hydraulic fracturing. The main companies were Oklahoma-based SandRidge Energy and Chesapeake Energy as well as Shell Oil Gulf of Mexico. Shell GOM is a subsidiary of Shell Oil, which has had limited activity in Kansas after 1950 and last drilled in the state in 1984 (Hall, 2012). Following successes in the Mississippian play in Oklahoma, activity spread into southern Kansas, and several companies bought or leased mineral rights from southern to northwestern Kansas.

The economic impact that drilling in the Mississippian play could have on the state is unclear. The Mississippian limestone is shallower and easier to fracture than the Bakken shale in North Dakota and Montana or the Eagle Ford Shale in Texas, but the Mississippian produces much more saltwater, which must be disposed of (Hall, 2012). Most companies are still experimenting with optimizing production rates and hydrocarbon recoveries and, concomitantly, minimizing costs. In addition to the multiple uncertainties and risks inherent in the industry, fluctuations in the price of oil and gas have a major influence on decisions to explore and drill in the state.

Beyond the impact on the oil and gas industry, booms related to rapid, large-scale development can significantly affect surrounding communities. Largely due to job opportunities related to soaring production in the Bakken, North Dakota's unemployment rate of 3.2% in December 2012 was the lowest in the country (Bureau of Labor Statistics, 2012). On a less positive note, the oil-boom town of Williston experienced infrastructure problems, housing shortages, an increased cost of living for long-term residents, and strains on public-safety, education, and social services.

Concerns about potential problems brought on by increased activity in the area centered on Barber, Harper, and Comanche counties in south-central Kansas have prompted state and local governmental units to institute collaborative planning with industry representatives (Hall, 2012). Topics of discussion include housing shortages, infrastructure deficiencies—especially inadequate roads and sources of electrical power—and surface water and groundwater availability. The source of freshwater needed for hydraulic fracturing and drilling is of particular concern in this region with limited water resources, as is the safe disposal or treatment of fracturing fluids, drill cuttings, and saltwater removed during drilling.

Regulations and Safety Standards

The Kansas Corporation Commission (KCC) is the main state governmental agency in charge of regulating exploration and production of oil and gas in Kansas, with primary responsibilities falling to the agency's Oil and Gas Conservation Division (KCC, 2013). Established by Kansas statute, a 12-member Oil and Gas Advisory Committee representing industry, landowners, and other interested parties reviews and makes recommendations on the Oil and Gas Conservation Division's rules and regulations. The KCC's rules and procedures related to exploration and drilling encompass intent-to-drill and production reports; casing and cementing standards; preservation of well samples, cores, and logs; environmental issues; abandonment of wells and plugging procedures; storage requirements; and safety plans and inspections. Federal regulators include the Environmental Protection Agency (EPA) and the Department of Labor's Occupational Safety and Health Administration (OSHA) (Hall, 2012).

The Kansas Department of Health and Environment (KDHE) Bureau of Air issues permits for air emissions related to horizontal drilling, and the KCC Underground Injection Control Program oversees the permitting of injection wells. Spills during oil and gas activities must be reported to the KDHE, KCC, Kansas Division of Emergency Management, and/or other state and federal agencies, depending upon the material and volume spilled (KDHE, 2013). Direct diversion of surface water or groundwater for oil and gas production and hydraulic fracturing requires a permit from the Kansas Department of Agriculture's Division of Water Resources (DWR, 2013).

To address issues related specifically to activity in the Mississippian limestone play, the state formed the Inter-Agency Working Group (IAWG) with representatives from the KCC; Kansas Geological Survey; Kansas Departments of Agriculture, Transportation, Revenue, Health and Environment, and Wildlife, Parks and Tourism; Kansas Water Office; Kansas Attorney General's Office; and the Kansas Housing Resources Corporation (Kansas Department of Commerce, 2013). An Industry Advisory Group and a Community Advisory Group also were organized.

Related KGS Public Information Circulars

- Hydraulic Fracturing of Oil and Gas Wells in Kansas
- Hugoton Natural Gas Area of Kansas
- Geologic Sequestration of Carbon Dioxide in Kansas
- Guidelines for Voluntary Baseline Groundwater Quality Sampling in the Vicinity of Hydraulic Fracturing Operations
- The High Plains Aquifer
- Geothermal Energy and Heat Pump Potential in Kansas
- The Data Resources Library at the Kansas Geological Survey

Available from the KGS and online at http://www.kgs.ku.edu/Publications/pubCirculars.html.

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KU
KANSAS GEOLOGICAL SURVEY
The University of Kansas

The mission of the Kansas Geological Survey, operated by the University of Kansas in connection with its research and service program, is to conduct geological studies and research and to collect, correlate, preserve, and disseminate information leading to a better understanding of the geology of Kansas, with special emphasis on natural resources of economic value, water quality and quantity, and geologic hazards.

The Geology Extension program furthers the mission of the KGS by developing materials, projects, and services that communicate information about the geology of Kansas, the state's earth resources, and the products of the Kansas Geological Survey to the people of the state.

Public Information Circular 33
March 2013

Kansas Geological Survey
Geology Extension
The University of Kansas
1930 Constant Avenue
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66047–3724
785-864–3965
http://www.kgs.ku.edu/

Hall, A. P., 2012, The Kansas oil and gas industry—An enduring model of high-tech entrepreneurship: University of Kansas School of Business, The Center for Applied Economics, Technical Report 12-1116, 95 p., http://www.business.ku.edu/publications-0.

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Glossary

Anticline—A fold of rock layers, raised generally upward, in which the older layers are in the core of the fold. Anticlines can be as small as a hill or as large as a mountain range. Petroleum can concentrate at the crest of an anticline in what is called a structural trap.

Basin—A low-lying area in which thick sequences of sediments have accumulated. Five basins, divided by uplifts, are found in the subsurface of Kansas (fig. 4).

Central Kansas uplift—A broad and complex structural high that trends northwest to southeast across north-central Kansas (fig. 4) and is now found only in the subsurface. Raised about 320 million years ago at the end of the Mississippian and beginning of the Pennsylvanian, the Central Kansas uplift is the largest structural feature in Kansas.

Chat—An informal name for the residual cherty, porous, weathered limestone zone in the Mississippian play.

Chert—Commonly called flint, chert is a fine-grained, microcrystalline sedimentary rock made up of silicon dioxide (SiO_2)—the same chemical formula as the mineral quartz. Usually found as rounded nodules in limestone and dolomite or, less often, an extensive layered deposit, chert is harder and more resistant to erosion than limestone.

Horizontal drilling—Drilling that starts out vertical then gradually turns in a horizontal direction to extend a greater distance into a known oil-producing zone.

Hugoton embayment—The northwestern shelf area of the Anadarko basin (fig. 4). The Hugoton gas field of western Kansas is the largest conventional gas field in North America.

Hydraulic fracturing—Injection of fluids and sand into a well to fracture oil-bearing rock layers. Colloquially called "fracking," especially when used in conjunction with horizontal drilling, hydraulic fracturing increases permeability in rocks to free trapped oil.

Lithologic—Relating to lithology, which is the description of a rock based on such physical characteristics as color, mineral composition, texture, and grain size.

Nemaha uplift—A complexly folded and faulted northeast-trending structural high in east-central Kansas (fig. 4) that formed about 320 million years ago at the end of the Mississippian and beginning of the Pennsylvanian and extends into Nebraska and Oklahoma.

Permeability—The capacity of rock, soil, or sediment to transmit fluid through connected pores.

Play—A set of oil and/or gas accumulations and reservoirs that share a geologic setting within a defined geographic area.

Porosity—The ratio of the combined volume of pores in a rock to the rock's total volume, usually expressed as a percentage. Porous rocks are permeable only when the pores are interconnected.

Stratigraphic trap—A trap for oil or gas created by changes in rock lithology rather than from a structural deformation, such as when an impermeable cap of shale traps oil that has moved up through an underlying layer of permeable sandstone.

Syncline—A generally downward fold of rock layers, in which the younger rocks are in the core of the fold.

Preliminary Economic Assessment of Horizontal Wells Drilled in the Mississippian Limestone Play in Kansas

More than 665 horizontal wells have been drilled in Kansas since the 1940s. However, a new era in Kansas horizontal drilling began in 2010 when innovative techniques that combined it with staged hydraulic fracturing were first used in the state, mainly in the producing zone of Mississippian chert and limestone dubbed the Mississippian limestone play (MLP) in southern Kansas. Modern horizontal drilling activity in the MLP, also known as the Mississippian chat play or Mississippi lime, started in Oklahoma then extended across the state line into an area centered on Barber, Harper, and Comanche counties. Wichita-based Woolsey Petroleum reported the first oil and gas production from an MLP horizontal well—in Barber County—to the Kansas Corporation Commission (KCC) in September 2010. SandRidge Energy of Oklahoma City soon after reported production from a nearby Barber County well in early 2011.

By the end of 2011, 16 horizontal wells in the MLP had reported production. By the end of 2012, for which the most recent data are available, 162 modern horizontal wells in southern and western Kansas had reported production. Of those, 157 targeted the MLP and five targeted other formations. Production from all 162 wells now constitutes almost 6% of monthly Kansas oil and gas production. The remaining 94% of Kansas oil and gas production comes from 49,275 oil wells and 24,625 gas wells.

More of the recently drilled horizontal wells will likely produce oil and gas in the near future. Production for some of them may have already started but not yet been reported. Production for others may be on hold pending further testing, the arrival of surface equipment, upgrades to local electrical power needed for pumping, or drilling of disposal wells.

Companies continue to file intents-to-drill with the KCC. Filings for wells in Barber and adjacent counties peaked in June 2012 then gradually declined. Filings for horizontal wells farther north and west jumped abruptly in April

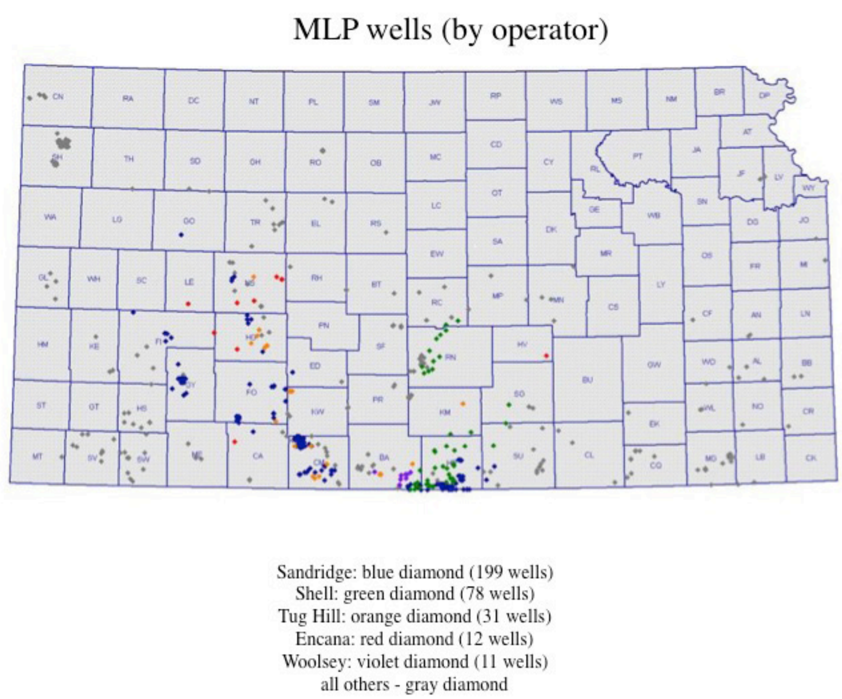

Figure 1—Mississippian limestone play wells in Kansas, by operator, as of February 1, 2013.

2012 and have since remained fairly steady. As of April 15, 2013, 585 intents-to-drill for MLP horizontal wells have been approved by the KCC. The majority (about 140) of those were filed by SandRidge Energy. Other companies with significant activity include Shell Gulf of Mexico (about 70), Tug Hill Operating (31), Encana Corporation (12), and Woolsey Petroleum (11) (fig. 1). Twenty-one additional companies filed the other intents. Typically, an intent-to-drill filing results in a drilled well 90% of the time.

Production

Most wells reach peak production in the first three to four months. In September 2012, 59 of the 103 horizontal wells reporting production in Kansas then had been producing at least four months. Ten of the 59 wells registered peak production in their first reported month, 22 in the second month, 12 in the third month, three in the fourth reported month, and 13 in the fifth month or later.

For combined oil and gas production, where gas is converted to barrels of oil equivalent (boe), the production decline for the first month after the peak month for a Kansas horizontal well, on average, is a dramatic 24%. The second through tenth month after peak production have average declines, respectively, of 21%, 17%, 4%, 7%, 14%, 17%, 11%, 12%, and 13%. Average decline rates beyond 10 months are difficult to determine because too few wells have such long production histories. If, however, a modest 7.5% decline is assumed for months 11 and 12, analysis indicates that a horizontal well will produce only 19% of its peak production a year after production peaks.

In comparison, natural gas production for the long-producing Hugoton Field in western Kansas declined from 2010 to 2011 at a rate of only 6.3% per well per year. In the MLP, the drop in natural gas production is not as severe as that for oil, which may be because the gas-oil ratio in many wells increases with their production duration. Also, peak natural gas production follows peak oil production by one or more months.

Production declines in the Mississippian horizontal wells in southern Kansas appear to be similar to those in the Mississippian vertical wells (fig. 2). To compare the two, production declines in vertical wells were summarized for the Little Sandy Creek Field, a Mississippian

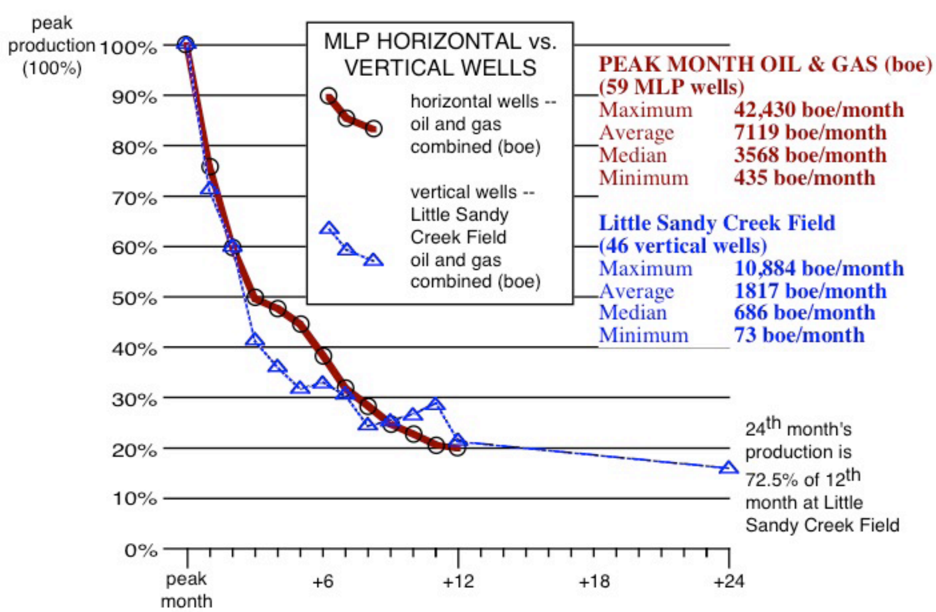

Figure 2—Comparison of production declines for horizontal wells in the Mississippian limestone play and Mississippian vertical wells in the Little Sandy Creek Field on the Barber-Harper county line. Oil and gas production has been combined using barrels of oil equivalence (boe) as a common measure.

oil and gas field that straddles the Barber-Harper county line. This field was discovered in 1973 and has produced 2,003,576 bbls of oil and 1,714,452 mcf of natural gas from 67 vertical producing wells. On average, oil and gas wells in this field declined 29% in the first month after peak production. A year after their peak production, wells produced only 21% of that peak. The Mississippian play horizontal wells experienced similar peaks and declines. Thus, production declines for Mississippian horizontal wells can be predicted if they continue to decline in a manner similar to Mississippian vertical wells. Production data from the Little Sandy Creek Field indicated that wells two years after their peak month were, on average, producing only about 17% of the volume of their peak month.

Production from all wells is reported by the operator to the Kansas Corporation Commission (KCC) and subsequently posted on the website of the Kansas Geological Survey (www.kgs.ku.edu), within about three months, depending on proprietary delays.

Economic Viability of MLP Horizontal Wells in Kansas

Whether or not a horizontal well is economically viable depends on a number of factors. Every well is different in its geology, engineering, and attendant costs, and the economic viability of every energy company is different. What is considered satisfactory production varies from one company to the next. At the current point in the Mississippian play exploration process, optimal production is hard to determine. Production techniques and economical solutions in drilling and well treatment are still being developed. Nevertheless, a general estimate as to how many wells in the play will be economically viable can be calculated based on probable outcomes.

According to several industry representatives, drilling a horizontal well in the MLP costs about $3 million (not including operational costs such as maintenance, royalties, electricity, disposal fees, fines, depreciation, taxes, and salaries). For an

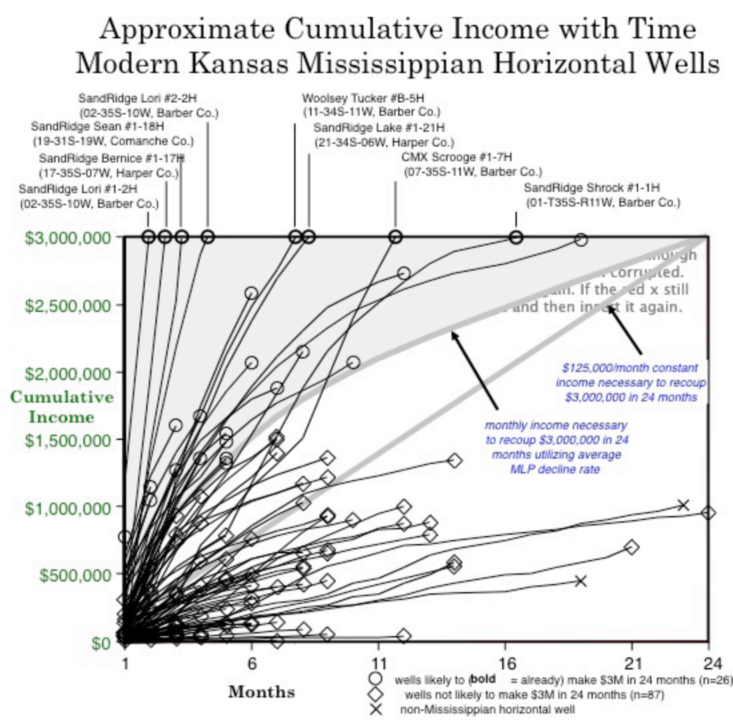

Figure 3—Approximate cumulative income for MLP wells over time, as of October 2012. Twenty-six of the 113 MLP wells drilled by that time were projected to recoup an estimated $3 million in drilling costs in less than 24 months. Eight wells had already reached that goal.

optimal return, the cost of drilling should be recovered in two years by income from production. Dividing $3 million by 24 months shows that an average monthly income of $125,000, or $4,110/day, is required to achieve that target. Because production from the wells declines drastically after the peak month, the income in the peak month must be about $399,500, or $13,032/day, to compensate for lower rates in succeeding months. (Based on the average rate of decline, a well producing an income of $399,500 per month in the peak month will be producing an income of only $63,475, or $2,120/day, in the 24th month).

Because all horizontal drilling in the Mississippian limestone play has occurred over the last three years, only a few wells have had two years of reported production. However, the likelihood of a well paying for itself within two years can be determined by multiplying the wells' monthly production volumes by current prices available from the Energy Information Agency's Kansas oil and gas pricing data. The cross plot in fig. 3 shows the approximate cumulative income for each MLP horizontal well over 24 months or the life of the well, if shorter than 24 months. As the graph shows, eight wells achieved an income of $3 million in less than two years and several others were likely to pay for themselves within two years. Twenty-six, or 23%, of the modern Mississippian horizontal wells producing by October 2012 will likely gross $3 million in two years. The remaining 77% will take longer than two years, and some may never recover their drilling costs.

Source

Based on the report "An overview and preliminary economic assessment of horizontal wells drilled in the Mississippian limestone play in Kansas, 2010-2012" by K. David Newell, W. Lynn Watney, and Paul Gerlach, unpublished.

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Red Hills Geology and The Nature Conservancy's Red Hills Initiative

The shales, siltstones, and sandstones that give the Red Hills their bright color were deposited in the remnants of an inland saline sea about 260 million years ago. Like the Flint Hills farther east, the Red Hills were formed during the Permian Period. Unlike the rolling landscape of the Flint Hills, which are composed of mainly thick and cherty limestone, the Red Hills' butte-and mesa topography (fig. 1) was influenced by layers of gypsum more resistant to erosion than the underlying iron-oxide-stained shales and siltstones (Buchanan and McCauley, 2010). Covering much of Clark, Barber, and Comanche counties, the Red Hills, sometimes called the Gyp Hills, also spill over into adjacent counties in Kansas and Oklahoma.

Although gypsum in the Red Hills is more resistant to weathering than the other rocks and sediments, it is an evaporite left behind as the seas dried up and, thus, soluble in water. As a result, numerous caves have formed in the region. Of the 528 caves catalogued in the state by the Kansas Speleological Society, 128 are in Comanche County and 117 are in Barber County (Buchanan and McCauley, 2010). The gypsum caves are typically 100 to 300 feet long (Young and Beard, 1993). Small natural bridges also are found throughout the Red Hills. One of the largest—35 feet wide and 55 feet deep—stood 12 feet above the stream that helped create it south of Sun City before collapsing in 1962 (Buchanan and McCauley; fig. 2).

Dissolution of gypsum does not occur just near the surface where the rock is exposed to streams and weathering. Layers of gypsum, as well as salt, dissolved hundreds of feet underground, causing the ground to sink. In Clark County, U.S. Highway 283 runs 1.5

Figure 1—U.S. Highway 160 running through the Red Hills in Barber County.

Figure 2—Natural bridge south of Sun City in Barber County. Upper: In 1952 (photo by H. A. [Steve] Stephens, courtesy of Stan Roth). Lower: In 1962 after its collapse due to erosion by an intermittent stream (photo by Stan Roth).

miles across the floor of Big Basin, a massive depression likely formed by subsurface dissolution. Just to the east, another depression called Little Basin is about a half mile in diameter. Within Little Basin is a smaller sink, a deep, spring-fed pool known as St. Jacob's Well.

Besides having a significant impact on the region's topography, gypsum is a contributing resource to the region's economy. First mined southwest of Medicine Lodge in 1888, it is still being extracted from an open-pit quarry and an underground mine operated by the National Gypsum Company north of Sun City. Gypsum from those locations is used in cement, sheet rock, and plaster of Paris (Buchanan and McCauley, 2010).

In the subsurface, a geologic feature that runs along the western edge of Barber County called the Pratt Anticline likely contributes to minor earthquake activity. Movement along the anticline is the probable source of an earthquake on January 6, 1956, that was likely centered in Barber County and felt as far away as Dodge City and Great Bend. The strongest impact was recorded in the Pratt County communities of Coats, just across the county line, and Pratt, where a bed reportedly bounced across the floor at a hotel. Since 1977, the Kansas Geological Survey has recorded six microearthquakes in the area that were too small to be felt (Buchanan and McCauley, 2010).

The Nature Conservancy's Red Hills Initiative

The Red Hills Initiative, a community-based conservation program of The Nature Conservancy Kansas Chapter, focuses on providing critical habitat for many rare or at-risk species, including the lesser prairie chicken. The region has the highest concentration of bat caves in Kansas and is also home to the southern prairie skink, the Texas blind snake, the red-spotted toad, raccoons, deer, turkeys, quail, bobcats, porcupine, armadillo, and other species.

Native species have been able to persist under the western rangeland and ranching land-use practices in the region. However, The Nature Conservancy has become increasingly concerned that encroaching invasive-plant species and the expansion of energy development, mining, rural subdivisions, and other land-use practices could threaten the region's landscape and biological diversity. The Kansas Chapter's goal is to partner with private landowners, other conservation organizations, and agencies to conserve ecological diversity over a large area and ensure the recovery and wellbeing of key species populations. Conservation easements, prescribed fire, tree removal, and stream recovery are among the strategies the Conservancy advocates to benefit both grazing operations and grassland wildlife conservation (The Kansas Nature Conservancy, 2013).

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The Alexander Ranch

The Alexander Ranch, owned and operated by Ted Alexander since 1984, covers 7,000 acres in the heart of the Red Hills near Sun City (fig. 1). The ranch stocks between 500 and 700 cow-calf pairs or 2,500 yearlings in a custom, rotational grazing operation. Cattle are also custom grazed during the winter months when it's beneficial to the management of stockpiled forage. The ranch is divided into three grazing cells, each consisting of multiple, smaller paddocks. The paddock system improves the pastures and allows the ranch to operate with the environment in mind.

Initially, more than 3,000 acres of the ranch had 80% canopy cover due to eastern red cedar encroachment. Alexander used prescribed burning, supplemented with mechanical eradication methods, to restore the rangeland. Routine burning has reduced the cedar canopy to less than 15% and largely restricted the trees' encroachment to canyons and draws. Of the different eradication methods used, prescribed burning was the most effective at cedar and brush control. Rangeland restoration improved livestock water sources and forage productivity and increased native plants and wildlife diversity.

The ranch has an extensive livestock-water system that uses solar energy because electric power lines do not cross the ranch. The solar-powered pumps and pipes transfer water from a valley pond to storage tanks on nearby hills. Gravity flow supplies water as needed to stock tanks around the ranch. Solar energy also powers energizers for electric fences that set the grazing cell boundaries needed for the rotational grazing operation.

The Alexander Ranch is home to many wildlife and aquatic species that are candidates for protection under the Endangered Species Act. The lesser prairie chicken, Arkansas darter, and the red-spotted toad are some of the at-risk native species found on the ranch. In cooperation with the U.S. Fish and Wildlife Service and the Kansas Department of Wildlife, Parks and Tourism, the ranch has

Figure 1—Alexander Ranch near Sun City in Barber County (KDWPT, 2010).

Figure 2—Red Hills canyons and draws with cedar trees in Comanche County (photo by Grace Muilenburg).

worked on management plans to protect and enhance wildlife. Biologists have documented more than 150 species of plants and nearly 50 species of reptiles and amphibians on the ranch.

Alexander has received multiple stewardship and ranching excellence awards from the National Cattleman's Beef Association, Natural Resources Conservation Service, Kansas Department of Wildlife, Parks and Tourism, U. S. Environmental Protection Agency, Kansas Wildlife Federation, Society of Range Management, Kansas Association of Conservation Districts, and the Association of Fish and Wildlife Agencies. At the same time, the ranch's stocking rate has increased to more than double the initial 1984 rate while maintaining animal performance and increasing the pounds of beef produced per acre. Net return to management has more than doubled over the last several years, making the ranch more profitable and sustainable in the face of regional drought.

Eastern Red Cedar Encroachment

By some estimates, eastern red cedar overtakes nearly 300,000 acres of pasture per year in Oklahoma. Its presence has a negative impact on cattle ranching, water quality, wildlife, and rangeland management. Cedar encroachment is a direct result of fire suppression. Before European settlement in America, the eastern red cedar was rare, except in areas where fire could not reach, such as canyons, rock outcrops, and bluffs (fig. 2).

Oklahoma State University estimated that if cedar encroachment was not addressed, the state of Oklahoma would incur $447 million in economic losses and damages: $107 million from catastrophic wildfires, $205 million in cattle forage, $107 million in lease hunting, $17 million in recreation, and $11 million in lost water yield.

Eastern Red Cedar Management

No single cedar-management practice is ideal for every parcel of land, but prescribed burning is the most environmentally appropriate and cost-effective practice to maintain a prairie ecosystem. For an ecosystem that requires restoration, prescribed burns typically must be supplemented with mechanical treatment methods. However, the high-intensity fire necessary for restoration has greater risk and costs than the low-intensity fire used for prairie maintenance.

In addition to mechanical methods and prescribed burning, red cedar management may be supplemented by private industry interest in commercially harvesting the trees for refining and biofuels. In general, cedars are refined through a pyrolytic process that heats shredded wood in the absence of oxygen to recover cedar oil. The oil has different industrial and biomedical applications and retails for $50 to $250 per gallon on the open market.

Kansas Forest Service—Eastern Red Cedar Assessment

The Kansas Forest Service (KFS) is assessing the encroachment of eastern red cedars in Kansas through analysis of Landsat and drone aircraft imagery. The analysis will also aid the potential development of a new commercial market for red cedars.

In addition to Landsat data, two drone aircraft, more accurately called small unmanned aerial systems (sUAS), are used by the KFS to collect aerial imagery. The first is a six-bladed hexacopter (fig. 3), and the other is a flying wing-type Zephyr II (fig. 4). The hexacopter is used to assess small areas in high detail, and the Zephyr II is used for flying over large areas in a small amount of time (e.g., 18 minutes per section).

Computer imagery analysis of Landsat data differentiates red cedar cover from other cover types (e.g., deciduous trees, grassland, water bodies, etc.). Large stands of cedar greater than 10 acres are identified for additional drone analysis.

Drone aircraft collect imagery at a spatial resolution, or the detail discernible in an image, of about one centimeter or less. This resolution is small enough to accurately measure the canopy axis of the trees, which correlates to total aboveground biomass (i.e., the weight of

Figure 3—Small unmanned aerial systems (sUAS) hexacopter. Photo courtesy David Burchfield, KFS.

the tree above the ground). Weight data can be used to assess the feasibility of producing commercially refined aromatic oil and biofuel products.

Figure 4—Small unmanned aerial systems (sUAS) Zephyr II flying wing. Photo courtesy David Burchfield, KFS.

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Thursday, June 6, 2013

6:00 a.m.	Breakfast at Holiday Inn Express, Pratt Rick's Restaurant (breakfast served as early as 6 a.m. but starting time is informal)
8:00 a.m.	**Bus leaves Holiday Inn Express for Site 10** Bus Session – Legislative Update: Local Enhanced Management Areas (LEMAs) *David Barfield,* Chief Engineer, Kansas Department of Agriculture, Division of Water Resources Bus Session – Hydraulic-Fracturing Aggregate Supplies and Transportation *Robert Henthorne,* Chief Geologist, Kansas Department of Transportation *Wade Wiebe,* Director of Partner Relations, Kansas Department of Transportation
9:15 a.m.	**SITE 10 –** Ninnescah Sailing Association, Cheney Reservoir
9:15 a.m.	Restroom Break
9:45 a.m.	Drought Effects on Lake Recreation and Local Economy *Robin Jennison,* Secretary, Kansas Department of Wildlife, Parks and Tourism
10:00 a.m.	Municipal Drought Management and Regional Water Supply *Joseph T. Pajor,* Deputy Director of Public Works & Utilities, City of Wichita
10:30 a.m.	Bus to Hampton Inn & Suites, Mulvane
11:30 a.m.	End Field Conference at Hampton Inn & Suites, Mulvane

Cheney Reservoir

Designed for flood control and as a supplemental water supply for the City of Wichita, Cheney Reservoir in south-central Kansas was built in the early 1960s by the U.S. Bureau of Reclamation and now supplies 70% of Wichita's water (Citizens Management Committee, 2011). Recreation and wildlife habitat—secondary benefits—provide public access to such activities as camping, swimming, boating, fishing, and bird watching. In particular, the lake has become a popular spot for sailing and windsurfing and has been the site of national sailing regattas (KDWPT, 2013). The Kansas Department of Wildlife, Parks and Tourism administers the recreation areas.

Cheney Dam is on the North Fork Ninnescah River (fig. 1) at the intersection of Kingman, Sedgwick, and Reno counties. The reservoir's drainage basin covers about 850 miles, including parts of Reno, Stafford, Pratt, Sedgwick, and Kingman counties (KDWPT, 2013). Land use in the watershed is about 58% cropland, 25% grassland, 17% conservation reserve program (CRP), and less than 1% urban (Citizens Management Committee, 2011). The North Fork Ninnescah River, which contributes about 70 percent of the inflow to the reservoir, lies in the lower part of the Permian "red beds" and cuts through a broad shallow valley of sand and clay beds of the Ogallala formation, which form the uplands (USBR, 2013a).

The City of Wichita's pumping plant at the dam, which conveys municipal water through a 5-foot-diameter pipeline to the city's water treatment plant, includes a vertical intake structure with four 6-foot-square motor-operated slide gates for selective withdrawal of water (fig. 2; USBR, 2013b). More than 350,000 people in Wichita and surrounding communities depend on Cheney Reservoir water, which is also marketed to Valley Center, Andover, Derby, Rose Hill, Eastborough, Bentley, Benton, Bel Aire, Park City, Kechi,

Figure 1—North Fork Ninnescah River (photo by William C. Johnson).

Figure 2—Water intake Cheney Reservoir (photo courtesy KDHE).

and several rural water districts. Wells in the Cheney Lake Watershed are the source of water for a number of towns and public facilities upstream from the reservoir, including Haviland, Stafford, Arlington, Cheney, Garden Plain, Camp Kanza, and Cheney State Park Marina (Citizens Management Committee, 2011).

In the early 1990s, taste and odor problems related to algae blooms led to the formation of the Cheney Reservoir Task Force, which was directed to identify and alleviate potential sources of pollution in the watershed and reservoir. The task force comprised local landowners and representatives of the Reno and Sedgwick county conservation districts, Reno County Health Department, Wichita Water and Sewer Department, Kansas Department of Health and Environment, Kansas Department of Wildlife and Parks, Kansas Water Office, and other local, state, and federal agencies (Citizen's Management Committee, 2011; Stone, 2013). The task force's master plan to alleviate degradation of the reservoir has been implemented since 1994 under the leadership of the Citizen's Management Committee (CMC), a subcommittee of the Reno County Conservation District. Reducing sedimentation and phosphorus is a top priority for the CMC (Citizen's Management Committee, 2011).

In 1996, the U.S. Geological Survey (USGS) began cooperative studies of the Cheney Reservoir watershed with the city of Wichita to investigate sedimentation, watershed sources of phosphorus, cyanobacterial blooms, and other problems and pollutants. The USGS has continuously collected water-quality data at a monitoring site on the river above the reservoir since 1998 (USGS, 2013).

Recent aridity has only added to water quantity and quality problems at Cheney Reservoir. Although easing of drought conditions in early 2013 allowed some rivers and streams to return to near-normal stream flows, water levels at Cheney were still about 40% below normal (NOAA, 2013).

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A Millennium of Drought and Climate Trends in Kansas

The Dust Bowl of the 1930s (fig. 1) and the 1950s drought are the two worst drought episodes recorded in Kansas since the widespread documentation of instrumental precipitation and temperature data began just over 100 years ago. Yet several droughts in the past 1,000 years—identified from tree rings, sediments, archaeological records, and other proxies—exceeded them both in intensity and duration. If a period of aridity equal to any of the several decades-long droughts that occurred between 1100 and 1500 AD were to occur again, subsequent losses in surface-water and groundwater resources would threaten municipal, industrial, and agricultural water supplies and cause widespread crop failure.

The imperative to better forecast and plan for dry conditions surpassing the duration of the Dust Bowl and 1950s drought combined requires an understanding of the climate variability over many centuries. To assess these drought conditions, climatologists and other scientists use a variety of proxies to reconstruct paleoclimates—past climates dating back thousands of years—across North America.

Figure 1—Drifts of wind-blown soil on farm near Liberal, Kansas, March 1936 (photo by Arthur Rothstein: Library of Congress).

Measuring Drought

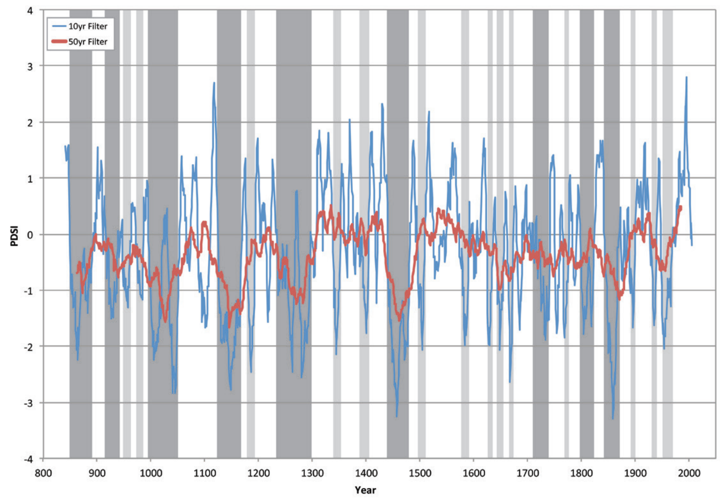
Several indices have been developed to measure drought. The Palmer Drought Severity Index (PDSI), one of the most widely used indices in North America, was introduced in 1965 and is used to measure the severity of a drought occurrence for a specified period. PDSI values can be calculated from weather data collected using thermometers, rain gages, and other instruments—available for most of North America since about 1895—or from paleoclimatic data reconstructed from tree-ring and other proxy evidence.

PDSI values, representing relative wetness and dryness, typically range from -4 (extremely dry) to 4 (extremely wet), although the range is unlimited. Although a PDSI value of -4 or less (even more extreme) is daunting, a persistent drought that averages moderate (-2) to severe (-3) PDSI values over many years may actually cause more damage than a more severe but shorter episode.

Measuring annual growth rings in living trees and preserved wood is one of the most common ways to determine past PDSI values and reconstruct climatic patterns over extensive areas. Although trees are sparse in the Great Plains, investigators have been able to determine paleoclimatic patterns there using predictive models that rely partially on tree-ring chronologies from surrounding regions. Reconstructed PDSI values based on tree-ring chronologies are available for as far back as 837 AD in western Kansas and the whole state by 1000 AD.

A diverse variety of other proxies—derived from sand dunes, lake sediment, coral reefs, ice sheets, rock formations, microfossils, cave deposits, archaeological discoveries, and historical records—helps verify droughts identified in tree-ring studies. For example, evidence from once-active sand dunes in Kansas testifies to the periodic droughts that occurred in the state over several centuries (Arbogast, 1996), while far-off ice cores in

Greenland and coral reefs in the South Pacific hold clues to worldwide paleoclimatic patterns (NOAA, 2010) that may have contributed to periods of aridity in the Great Plains.



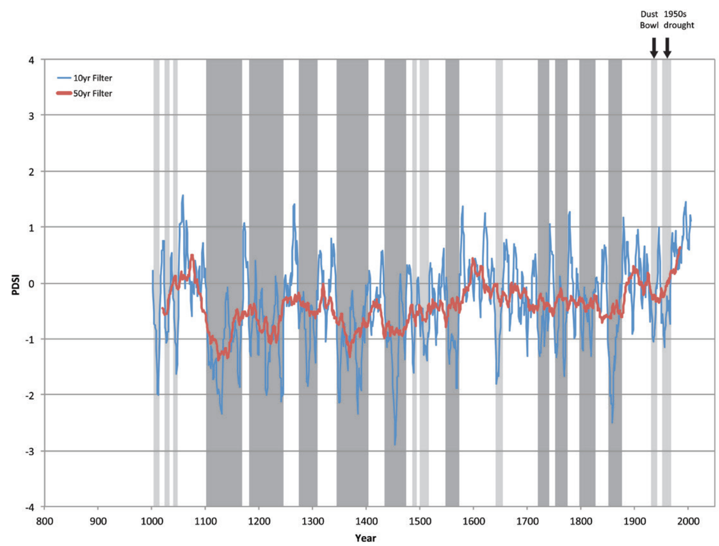


Figure 2—Smoothed PDSI reconstructions showing drought durations for southwestern Kansas (top) and southeastern Kansas (bottom). Light gray bars indicate episodes of similar duration to the 1930s and 1950s droughts and dark gray bars represent episodes of greater duration. Annual PDSI values have been smoothed to filter out anomalous high and low values over a 10-year range (blue) and a 50-year range (red) (Layzell, 2012). PDSI values are from Cook and Krusic, 2004. Reconstructions for all six Kansas regions online are at http://www.kgs.ku.edu/Hydro/Publications/2012/OFR12_18/index.html.

Drought Severity and Duration

A key characteristic distinguishing the 1930s and 1950s droughts from other modern drought periods is aridity that was not only severe but also long lasting. The negative effects of one extremely dry year can be overcome relatively quickly when it is preceded or followed by a wetter year, but several years of nearly uninterrupted drought can lead to serious long-lasting socioeconomic and environmental problems. Furthermore, there is no single method for calculating duration. In fig. 2, the durations of the 1930s and 1950s droughts in southwestern and southeastern Kansas were calculated by smoothing PDSI values—that is, filtering out the extreme high and low values by averaging over a 10- or 50-year period.

Droughts of unusually long duration are commonly referred to as "megadroughts." These extreme episodes, which last 20 or more years, do contain individual years of normal or even above-average precipitation. Megadroughts appear to be most prevalent in Kansas between 850 AD and 1500 AD (fig. 3). The longest one occurred in north-central Kansas from 1317 to 1427. As north-central Kansas was enduring that near-continuous 110-year drought, northwestern Kansas experienced two long-term droughts separated by a wetter period, while southwestern Kansas conditions did not reach megadrought proportions. These differences underscore how much circumstances can vary over a short distance. Many dune records from the central Great Plains show significant sand dune activation—a sign of increased aridity and reduced vegetation—during these periods. Sand-dune mobilizations have been documented from the 9th to the early 20th centuries in Kansas.

Evidence that megadroughts destabilized North American civilizations between 850 and 1500 AD is found in the archaeological record. Although drought probably affected populations in the Great Plains during that time, clues there are sparse. Archaeological evidence of agricultural societies in adjacent regions, however, provides signs of widespread drought conditions that most likely also afflicted the plains people. Several major droughts between the 11th and 15th centuries probably contributed to the abandonment of well-established Native American settlements, including ones occupied by the Freemont and Anasazi cultures in the Four Corners region of the U.S. Southwest and the Mississippian agricultural societies around Cahokia (fig. 3; Layzell, 2012).

Widespread drought during the Stephen Long expedition of 1819–1820 likely influenced the explorers' perception of the western Great Plains as the "Great American Desert." Trader and explorer Jacob Fowler noted that on his way to Santa Fe in 1821, the sand hills along the Arkansas River in south-central Kansas were "distetute of vigetation as they are Bald" (Muhs and Holliday, 1995). Set-tan (Little Bear) of the Kiowa recorded in his 60-year calendar history that during the hot "sitting summer" of 1855, the prairie grasses dried out and the Kiowa had to stop frequently to rest their emaciated horses (Stahl et al., 2007). Early settlers in eastern Kansas Territory wrote of the "scorching, withering, blighting" winds that drove recent arrivals back east and drought conditions that lasted from at least 1854, with only short reprieves, into the early 1860s (Malin, 1946).

Drought Risks, Water Resources, and Future Prospects

As groundwater usage in western Kansas escalated, starting in the 1950s, the semi-arid region became even more susceptible to the affects of long-term drought. The High Plains aquifer system, which consists largely of the Ogallala aquifer, is the primary source of municipal, industrial, and irrigation water in

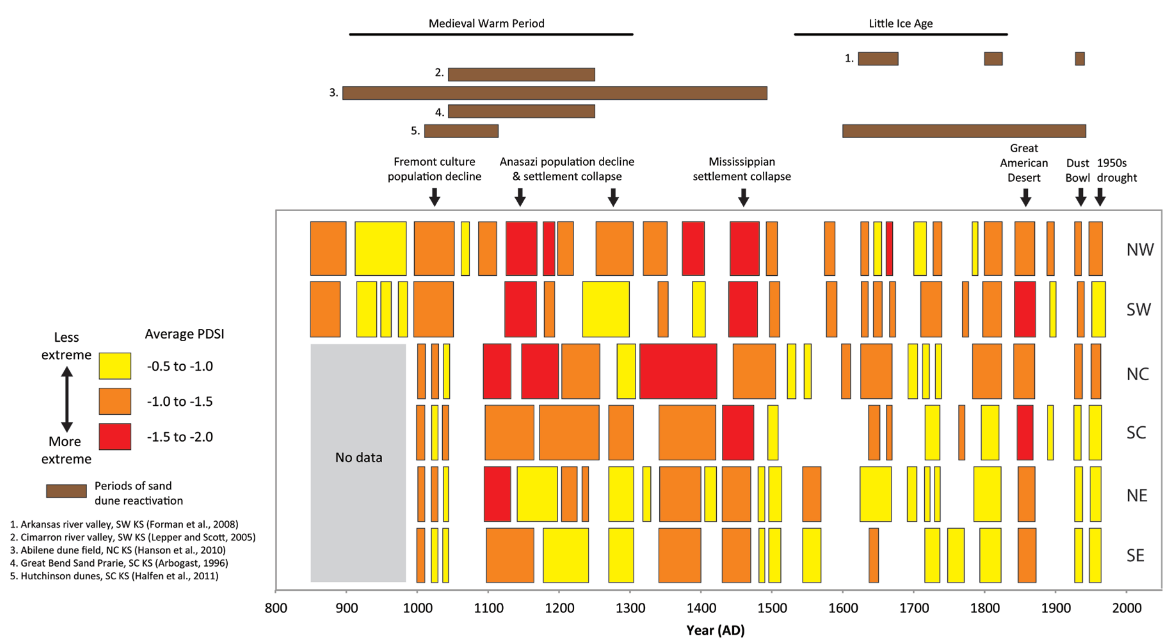


Figure 3—Synthesis of reconstructed PDSI data for the six regions of Kansas showing the severity and duration of droughts since about 850 AD. Events identified using geomorphic (sand dune), archaeological, and historical proxies are marked (Layzell, 2012).

western and central Kansas. In drought years, greater than normal amounts of groundwater are withdrawn from the aquifer to compensate for the lack of precipitation, particularly during the growing season. Since 1996, the overall average water level in the Kansas portion of the High Plains aquifer has dropped 14 feet. Southwestern Kansas on its own has experienced an average decline of 32.5 feet during that time. Under drought conditions in 2011 and 2012, water levels in southwestern Kansas declined 3.56 feet and 4.26 feet, respectively (Kansas Geological Survey, 2013).

The KGS continuously monitors three wells in the High Plains aquifer—in Thomas, Scott, and Haskell counties—and is correlating groundwater-level data from those wells with values from the PDSI and other drought climatic indices. Based on those correlations, researchers are able to predict how water levels would likely respond to increased pumping for irrigation and other uses under drought conditions similar to or greater than those in the 1930s and 1950s (Butler et al., 2013).

Eastern Kansas depends mainly on surface water from federal reservoirs, the source of municipal and industrial water for more than two-thirds of the state's population. Most of these lakes have already been diminished over time by sedimentation, and a sustained period of drought could lead to unprecedented water shortages (Kansas Water Office, 2011).

Water systems and management plans are commonly designed to handle the "drought of record," that is, the most severe hydrological event documented in the instrumental record. For the state of Kansas, the drought years from 1952 to 1957 remain the planning benchmark. Planning for a worst-case scenario of five years or even a decade, however, does not prepare the state for multi-decade megadroughts that modern-day agricultural and water systems may not be able to withstand. Continued investigations into centuries of past climatic and drought variability will provide a clearer understanding of how climate and global warming affect aridity and enable scientists and policymakers to better forecast droughts and plan for the sustainability of the state's groundwater and surface-water resources.

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