Kansas Field Conference
June 3–5, 2014

Central Kansas and the Arkansas River Valley

Surface Water, Wetlands, and Petroleum Industries

Field Guide

Compiled by Shane A. Lyle and Catherine S. Evans

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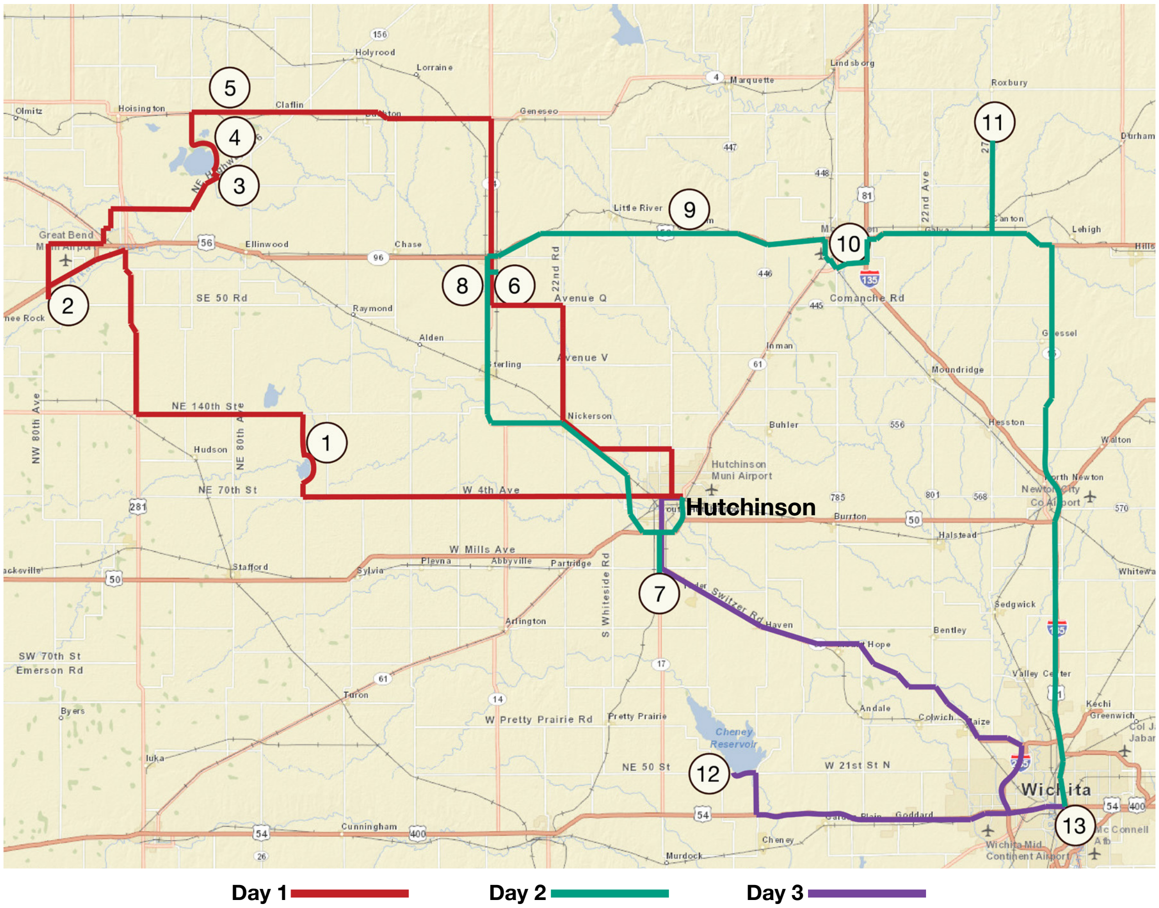
Hutchinson
Wichita
Day 1
Day 2
Day 3

2014 Kansas Field Conference

Central Kansas and the Arkansas River Valley: Surface Water, Wetlands, and Petroleum Industries

Contents

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Shari Feist Albrecht, Chair, Kansas Corporation Commission

David Barfield, Chief Engineer, Division of Water Resources, Kansas Department of Agriculture

Patricia S. Bergman, Assistant Director for Corporate Partnerships, KU Office of Research

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Central Kansas and the Arkansas River Valley

Surface Water, Wetlands, and Petroleum Industries

June 3–5, 2014

This marks the 20th anniversary of the annual Kansas Field Conference. Over the years, the Kansas Geological Survey (KGS) and its co-sponsors have provided the opportunity for decision-makers who influence policy on Kansas natural resources to explore every corner of the state and many stops in between. In 2014, the Field Conference heads to the heart of Kansas, at one point coming within a mile or two of the state's geographic center near Cheyenne Bottoms. The KGS and this year's other sponsors—the Kansas Water Office, Kansas Department of Transportation, and Kansas Department of Wildlife, Parks and Tourism—along with experts from various private companies, agencies, and organizations will provide background on topics that affect the economy, environment, and future of Kansas communities. Issues to be addressed include water rights and use, water diversion and wetland management, air quality, crop selection, underground cavern stabilization, petrochemical manufacturing, petroleum transport and refining, natural gas storage, and rail transportation. Participants will get the chance to visit many locations not readily accessible to the public and will be able to ask questions and share their ideas at every stop on the way.

Day one starts in Hutchinson and includes stops at Quivira National Wildlife Refuge, the Dundee Diversion Dam southwest of Great Bend built to funnel water to Cheyenne Bottoms, the Kansas Education Wetland Center at Cheyenne Bottoms, an ethanol plant near Lyons, and the Kansas Cosmosphere and Space Center. Day two starts at an underground cavern stabilization facility in Hutchinson then heads to a petrochemical manufacturing company in Sterling, a liquid natural gas storage facility in Conway, an oil refinery in McPherson, and Maxwell State Game Refuge north of Canton before stopping in Wichita for the night. Day three starts at Cheney Reservoir with a demonstration of an unmanned aerial vehicle that could be used to monitor harmful algal blooms and finishes with a ride on a short line railroad from Wichita to Hutchinson.

A detailed itinerary for every day—Tuesday, June 3, through early afternoon on Thursday, June 5—can be found in this guidebook at the front of each daily section, labeled Day 1, Day 2, and Day 3.

About the Kansas Field Conference

The 2014 Field Conference is designed to give a diverse group of policymakers with a range of legislative, government, education, and private-business expertise the opportunity to learn about and discuss natural-resource issues. Local and regional experts will be on hand at many of the stops to discuss topics related to specific locations. The objective of the Field Conference is to let participants observe what effects government and business decisions can have on natural resources and communities and to talk with local, state, and federal officials, environmental groups, business people, and citizens' organizations. The co-sponsors aim to provide a broad, informed perspective that will be useful in formulating policies. In addition, this Field Guide provides background on this year's sites and issues and can serve as a handy reference long after the Field Conference is over.

At each stop and on the bus, 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, water, and other resources, 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.

As often as possible, we attempt to provide a forum for all sides of contentious issues. The opinions presented during the Field Conference are not necessarily those of the KGS or Field Conference co-sponsors. Nonetheless, we believe it is important for participants to hear various viewpoints on complex issues.

About the Kansas Field Conference

The Field Conference began in 1995 with the support of Lee Gerhard, then the KGS'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 co-sponsors appreciate your attendance at this year's Field Conference. Participant input over the past 20 years has helped make the Field Conference a model that has been adopted by other state geological surveys, and we look forward to receiving any insights you may have about ways to improve it and locations to visit in the future.

Sponsors

Kansas Geological Survey

The KGS is a research and service division of the University of Kansas. Its mission is to study and report on the state's geologic resources and hazards. 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 surface and subsurface geology. By statutory charge, the KGS role is strictly one of research and reporting. The KGS has no regulatory functions.

The following KGS staff are participating in the 2014 Field Conference:

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

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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. Mike King is Secretary of Transportation and Bob Henthorne is KDOT's Chief Geologist.

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Kansas Department of Wildlife, Parks and Tourism

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

Robin Jennison is Secretary of Wildlife, Parks and Tourism and Steve Adams is the Natural Resource Advisor. A seven-member Wildlife and Parks Commission advises KDWPT.

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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 Upper and Lower Arkansas River basins. Tracy Streeter is the Director of the KWO and Earl Lewis is the Assistant 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 companies, organizations, and agencies that have contributed to the Field Conference, in 2014 and in previous years. In particular, Secretary Mike King of the Kansas Department of Transportation, David Barfield, Chief Engineer at the Division of Water Resources, Kansas Department of Agriculture, and Mike Oldham, Refuge Manager, Quivira National Wildlife Refuge, 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, Robin Jennison and Steve Adams of the Kansas Department of Wildlife, Parks and Tourism, Lane Letourneau of the Division of Water Resources, Earl Lewis and Susan Metzger of the Kansas Water Office, and Bob Henthorne of the Kansas Department of Transportation provided advice about topics and locations. Julie Tollefson, KGS editor, edited and laid out the field guide; and Julie Bogle, KGS assistant to administration, compiled the biographical information. The City of Wichita, K&O Railroad, and the National Cooperative Refinery graciously donated funds to cover expenses for meals.

Tuesday, June 3, 2014

6:00 a.m.	Breakfast—Fairfield Inn & Suites Conference Room, Hutchinson Catering Service by Catering For You (starting time is informal)
7:15 a.m.	Conference Overview *Rex Buchanan,* Interim Director, Kansas Geological Survey
8:00 a.m.	**Bus leaves Fairfield Inn & Suites, Hutchinson for Site 1**
	Bus Session—Legislative Update: Regional Water Issues *David Barfield,* Chief Engineer, Division of Water Resources, Kansas Department of Agriculture
8:45 a.m.	**SITE 1**—Surface Water Rights and Wetlands Management, Quivira National Wildlife Refuge *Mike Oldham,* Quivira Refuge Manager, U.S. Fish & Wildlife Service *David Barfield,* Chief Engineer, Division of Water Resources, Kansas Department of Agriculture
9:45 a.m.	Restroom break—Quivira National Wildlife Refuge
10:00 a.m.	Bus to Site 2
	Bus Session—Legislative Update: Regional Water Issues *David Barfield,* Chief Engineer, Division of Water Resources, Kansas Department of Agriculture
11:00 a.m.	**SITE 2**—Surface Water Diversion and Wetlands Management, Dundee *Secretary Robin Jennison,* Kansas Department of Wildlife, Parks and Tourism *Karl Grover,* Area Wildlife Manager, Kansas Department of Wildlife, Parks and Tourism
11:30 a.m.	Bus to Lunch
12:00 p.m.	Lunch—Kansas Wetlands Education Center, Cheyenne Bottoms Catering Service by Playa Azul
1:00 p.m.	**SITE 3**—Update on Air Quality Planning and Standards, Kansas Education Wetlands Center *Tom Gross,* Air Monitoring and Planning Chief, Kansas Department of Health & Environment

1:30 p.m.	Bus to Site 4
	SITE 4—Wetlands Management, Cheyenne Bottoms *Secretary Robin Jennison,* Kansas Department of Wildlife, Parks and Tourism *Karl Grover,* Area Wildlife Manager, Kansas Department of Wildlife, Parks and Tourism
2:15 p.m.	**SITE 5**—The Value of the Central Flyway Wetlands in Kansas, Cheyenne Bottoms Overlook, Redwing *Rob Manes,* State Director, The Nature Conservancy
2:45 p.m.	Bus to Site 6
	Bus Session—Legislative Update: Kansas 50 Year Water Vision *Tracy Streeter,* Director, Kansas Water Office
	Bus Session—Water's Role in the Selection of Agricultural Crops *Gary Harshberger,* Chair, Kansas Water Authority
3:30 p.m.	Restroom Break, Lyons High School
3:45 p.m.	**SITE 6**—Sorghum Markets, Uses, and Water Requirements *Sarah Sexton-Bowser,* Regional Manager, United Sorghum Checkoff Program *Michael J. Chisam,* President/CEO, Kansas Ethanol, LLC
4:45 p.m.	Bus to Fairfield Inn & Suites, Hutchinson
5:30 p.m.	Arrive at Fairfield Inn & Suites, Hutchinson
6:30 p.m.	Bus to Supper—Kansas Cosmosphere & Space Center
6:35 p.m.	Social Gathering and Self-Guided Museum Tour—Kansas Cosmosphere & Space Center
7:00 p.m.	Supper—Kansas Cosmosphere & Space Center Catering Service by Knackstedt Katering & BBQ and Hutchinson Town Club
8:30 p.m.	Return to Fairfield Inn & Suites, Hutchinson

Quivira National Wildlife Refuge and Water Management

Quivira National Wildlife Refuge in south-central Kansas is part of the National Wildlife Refuge System administered by the U.S. Fish and Wildlife Service (USFWS). It was established in 1955 primarily to provide habitat for migratory birds along the Central Flyway migration route. Annually, thousands of Canada geese, ducks, sandhill cranes, shorebirds, and other migratory birds use the wetlands during their migrations, and the refuge provides critical habitat for the federally listed whooping crane and state-listed western snowy plover. Bald eagles winter and nest on the refuge, and interior least terns nest there. The refuge also provides valuable habitat for hundreds of species of other birds, mammals, reptiles, amphibians, fish, and plants and serves as an educational and recreational resource. The entire refuge is open to fishing and foot traffic and 40% is open to hunting (Quivira National Wildlife Refuge, 2013). The USFWS also manages the Great Plains Nature Center in Wichita, which compliments the refuge and provides educational support, in cooperation with the Kansas Department of Wildlife, Parks and Tourism and the City of Wichita

Located mainly in Stafford County, but overlapping into Rice and Reno counties, the 22,135-acre refuge lies in a transitional zone between eastern tallgrass and western shortgrass prairie, where eastern and western bird species mix with Great Plains grassland species. More than 340 species of birds, including both the eastern and western meadowlark, have been observed at the refuge (USFWS, 2014). The refuge is in a mixed-grass sand prairie ecosystem consisting of grasslands, marshes, stream corridors, salt flats, sand dunes and hills, and agricultural land (Quivira National Wildlife Refuge, 2013). The 7,000 acres of wetlands include Big Salt Marsh, Little Salt Marsh, and more than 30 smaller marshes (fig. 1).

Figure 1—Big Salt Marsh.

Salt Marshes, Groundwater, and Surface Water

Figure 2—Rattlesnake Creek is a main source of water for the refuge.

Salty surface waters and salt flats in the refuge are the result of natural saltwater in the underlying bedrock moving upward and discharging through springs, seeps, and stream-groundwater interaction in areas with poor drainage. Salinity at Quivira is not related to the Hutchinson Salt Member, although that rock layer does underlie the area, but comes from the shallower Cedar Hills Sandstone and sandstone layers in the Salt Plain Formation. These rocks contain the evaporate minerals halite, or common table salt, and anhydrite, which is similar to gypsum.

The Cedar Hills Sandstone aquifer is recharged in southwestern Kansas and becomes increasingly saline as it flows slowly eastward until it discharges near the surface into an overlying freshwater aquifer west of the Quivira marshes. A north-south-trending ridge of Permian bedrock below the marshes restricts the easterly movement of groundwater toward the Arkansas River and forces saltwater to discharge into the low-lying streams and marshes.

Salt concentrations are further increased at the surface through evaporation. Average salinity is 2,500 parts per million (ppm) chloride in Little Salt Marsh and between 5,000 and 10,000 ppm in Big Salt Marsh. In comparison, seawater averages 19,000 ppm chloride and drinking water 250 ppm (Sawin and Buchanan, 2002). Many areas in the marshes have a high enough salinity to support salt-tolerant plant species, such as inland salt grass, alkali sacaton, and seepweed (USFWS, 2014).

Hydrology at the refuge is complex, largely because of fluctuating precipitation and surface-water flow, regular interaction between surface water and groundwater, and a highly altered landscape. The main sources of surface water are precipitation, groundwater discharge, and inflow from Rattlesnake Creek (fig. 2). The causes of surface-water dissipation include evaporation, plant transpiration, groundwater recharge, and surface drainage. The refuge lies in the eastern part of the Rattlesnake Creek watershed, which is approximately 95 miles long and 18 miles wide. A system of canals and water-control structures divert water from the creek to the wetlands (fig. 3). The Rattlesnake Creek watershed overlies the Great Bend Prairie aquifer, which is part of the High Plains aquifer system. Groundwater is pumped in the surrounding area to irrigate crops, and the refuge lies within the Big Bend Ground Water Management District No. 5 (Quivira National Wildlife Refuge, 2013).

Water Rights and Management

Quivira National Wildlife Refuge has water rights on Rattlesnake Creek, which allows for the use of 14,632 acre-feet of surface water per year, not exceeding 300 cubic feet per second (cfs). When flow is available, USFWS can control flooding and dewatering and move water between the various wetland units through the canals and other water-flow infrastructure. In high-flow years, excess water may be transferred downstream or used to increase water levels in impoundment or wetland areas. Occasional dewatering of the

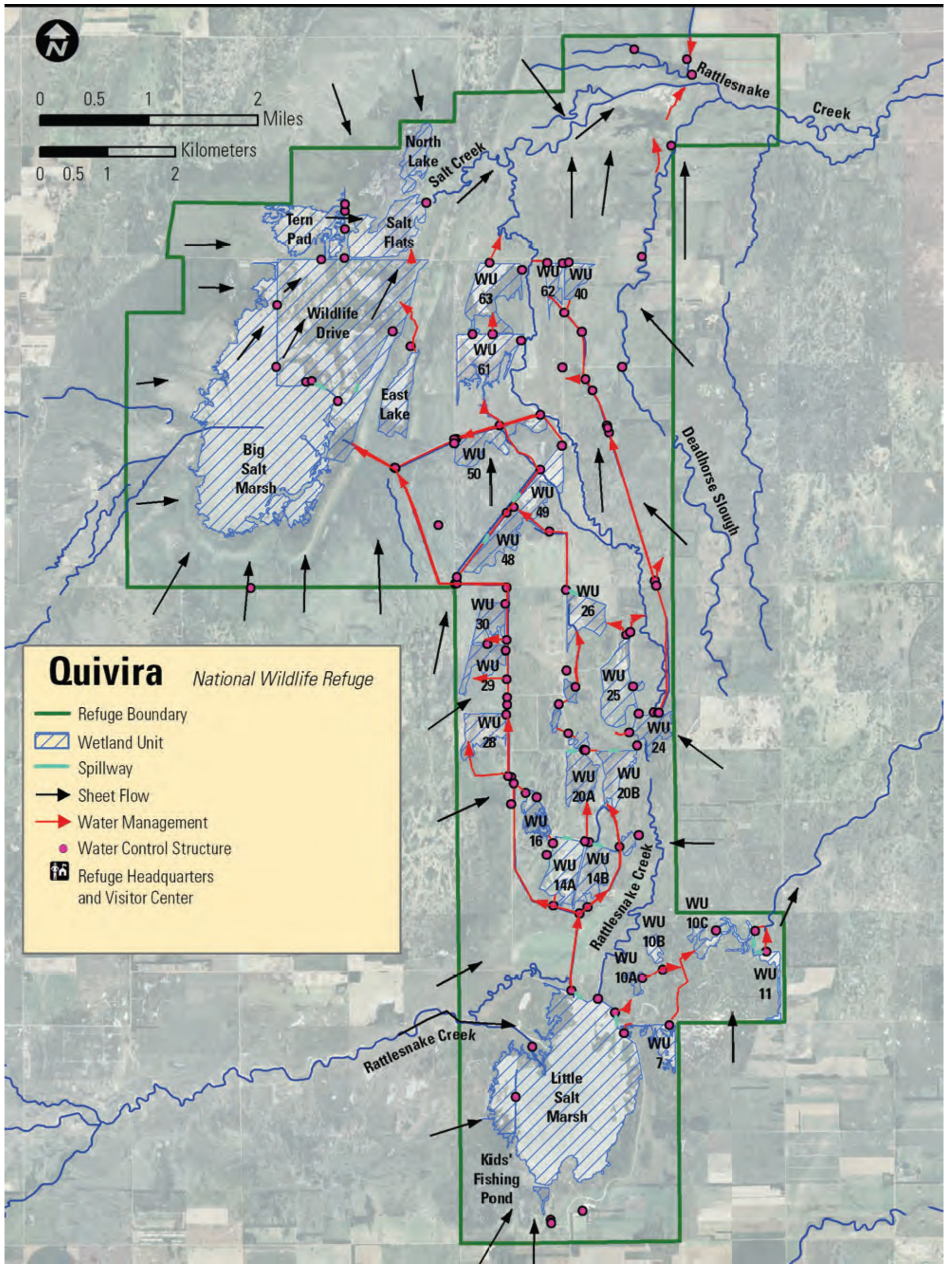

Figure 3—Water control structures at the refuge (Quivira National Wildlife Refuge, 2013).

wetlands allows nutrient cycling and helps manage plants with different germination and growth needs. Water depths are regulated to manage food sources and bird habitats (Quivira National Wildlife Refuge, 2013).

Wetland and Sand Prairie Restoration

Before and after the refuge was established, dozens of water impoundments, mostly deep-water units, were constructed. Because the deep structures were difficult to quickly drain and refill, a process called "re-contouring" has been used to alleviate problems. With that process, large quantities of soil fill are spread evenly throughout a unit to create a shallower basin of equal depth. Other management practices to restore or enhance the wetlands include controlling cattails and other invasive species through prescribed burning, mowing, and herbicide application and cattle grazing to compact soil and control stem regrowth.

The uplands at the refuge are mainly sand prairie, a unique and uncommon ecosystem in North America (fig. 4). Farming, grazing

Figure 4—Sand hills cover much of the refuge uplands.

by cattle, and tree planting have all affected the sand prairie community, much of which has been encroached upon by woody—often non-native—plants, such as Russian olive, honeylocust, and Siberian elm. Thick stands of native sand plums have also expanded, crowding out native grasses and forbs. Restoration efforts include removal of unwanted vegetation through prescribed fire, mechanical removal, grazing, and herbicides. To restore a more natural environment, native grasses such as little bluestem are planted along with blazing star, coreopsis, and other native forbs with a seed drill or through broadcast seeding (USFWS, 2014).

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The Arkansas River and Diversion of Water to Cheyenne Bottoms Wildlife Area

After water for irrigation was successfully diverted from the Arkansas River in Kansas near Garden City in 1880, the practice spread downstream. Many of the efforts did not last long. One short-lived canal system was built in Barton County at the turn of the century for irrigation and to supplement water levels in the marshlands north of Great Bend now known as Cheyenne Bottoms. Backers of that plan aspired to transform the intermittent wetlands into "Grand Lake," a tourist destination complete with luxurious beachfront hotels (Harvey, 2009). By 1903, the project had gone bust and the canal was abandoned.

In 1927, a burst of heavy rain upstream temporarily created a 64-square-mile lake, helping thwart plans to drain the marsh for farmland (Harvey, 2009). The flooding prompted a three-decade state effort with help from federal funding to convert Cheyenne Bottoms into a wildlife refuge, in part by diverting water from the Arkansas River. In 1957, the Kansas Forestry, Fish and Game Commission—later merged into the Kansas Department of Wildlife, Parks and Tourism (KDWPT)—completed a diversion dam on the Arkansas River at Dundee southwest of Great Bend (fig. 1) and an inlet system that would carry water from the river to the newly developed Cheyenne Bottoms Wildlife Area (KDWPT, 2011). Streamflow in the river gradually dropped as irrigation in the Arkansas River valley increased, and today water is rarely available for diversion. When river water is available and needed to supplement natural sources, however, it is still occasionally diverted to Cheyenne Bottoms, and upgrades have recently been completed on the system.

Figure 1—Dam on the Arkansas River near Dundee southwest of Great Bend used to divert water to Cheyenne Bottoms Wildlife Area.

Water Flow in the Arkansas River

Writing about the Arkansas River in a 1913 report, Kansas Geological Survey Director Erasmus Haworth surmised that “the water table throughout the valley is so near the surface an inexhaustible amount of water is available, and therefore there is no practical need of being concerned as to the actual amount of water-bearing sand, for the water will never become exhausted by pumping.”

Haworth’s prediction did not hold true. Throughout the 20th century, the Arkansas River flow decreased. By the late 1960s and early 1970s, stretches of the river in western Kansas were mainly dry. Except during extremely wet years or after heavy snow-melt in the Rocky Mountains, today the river is usually dry from about western Finney County to near Great Bend. That lack of streamflow is due to a combination of factors. Increased irrigation in eastern Colorado and southwestern Kansas lowered water tables in the alluvial and Ogallala aquifers so that less water returns from the aquifers back into the river during times of low flow. In addition, construction of several large reservoirs in eastern Colorado increased evaporation and made less water available in Kansas.

In 1985, Kansas filed suit against Colorado for failing to live up to terms of an interstate compact between the two states concerning water in the river. In May 1995, the U.S. Supreme Court ruled in favor of Kansas when it determined that wells in eastern Colorado were pumping too much water from the alluvial aquifer and causing the lessened streamflows. In April 2005, Colorado agreed to pay Kansas a settlement of $34.7 million dollars. Court rulings have also forced Colorado to restrict well use and release water from John Martin Reservoir.

Water Diversion to Cheyenne Bottoms

Two streams—Deception Creek and Blood Creek—flow into Cheyenne Bottoms. Neither creek is controlled by KDWPT. The wetlands also receive water from direct precipitation and overland flow. Diversion of water from the Arkansas River into Cheyenne Bottoms was instigated to supplement the natural precipitation and streamflow from Blood and Deception creeks (KDWPT, 2011). Discussion of a diversion system began in the 1930s, and by 1957 water flowed from the dam at Dundee via canals and the Wet Walnut and Dry Walnut creeks. Besides the larger dam on the Arkansas River, the system includes smaller diversion dams on the Wet and Dry Walnut creeks, inlet and outlet canals, and a system of dikes (fig. 2).

Problems encountered during and after

Figure 2—Inlet control structure at Cheyenne Bottoms Wildlife Area.

construction of the system include land right-of-way issues, drought, seepage, evaporation, declining streamflow on all three waterways, and deterioration (Harvey, 2009). Renovation efforts in the 1990s included installation of several flow meters on the inlet system and the outlet canal. By 2009, all the meters were outdated and three new outlet meters were installed. In addition, maintenance work was done on the Wet Walnut Creek dam in 2006 and the Dry Walnut Creek dam in 2009 (KDWPT, 2011). By April 2014, contracted work was finished on a project to convert the open canal to buried pipe on the seven-mile stretch from Dundee to Dry Walnut Creek. The conversion from canal to pipeline will keep the water from seeping into the ground, reduce illegal dumping, eliminate the loss of water to trees, and reduce maintenance demands. KDWPT has also recently carried out maintenance work at the Dundee Diversion Dam (KDWPT, 2014).

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Air Quality Planning and Standards

The Clean Air Act is a federal law that specifies air quality standards for the United States. It was created in response to air pollution events such as the sudden build up of deadly smog over the industrial town of Donora, Pennsylvania, in October 1948. The pollution killed 20 people and sickened 6,000 of the town's 14,000 residents (Schrenk, 1948). The Clean Air Act was passed in 1963, revised in 1970, and revised again in 1990, providing the U.S. Environmental Protection Agency (EPA) broad authority to create and enforce rules that reduce air pollutant emissions (EPA, 2007).

The EPA sets National Ambient Air Quality Standards for six air pollutants, known as "criteria pollutants," to protect human health, environment, and private property. The criteria pollutants are particulate matter, ground-level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, and lead. Of the six, ground-level ozone and particulate matter have the most widespread detrimental health effects (EPA, 2014a).

Criteria pollutants are either byproducts of chemical reactions or direct emissions from sources such as industrial or agricultural activities. Carbon monoxide, sulfur oxides, nitrogen oxides, and lead are directly emitted from a variety of different sources (fig. 1). Ground-level ozone is not directly emitted but is formed when nitrogen oxides and volatile organic carbons react in the presence of sunlight. Volatile organic compounds are emitted as gases from chemical products and industries. Particulate matter is a complex mixture of small liquid droplets and particles. Particulates originate from direct sources—such as acids, organic chemicals, metals, forest fires, and dust—or through secondary reactions between industry and vehicle emissions and the atmosphere. Inhalable particulates less than 10 micrometers in diameter are directly linked to health risk (EPA, 2008; EPA, 2014a).

State Implementation Plans

States and the EPA work together to ensure

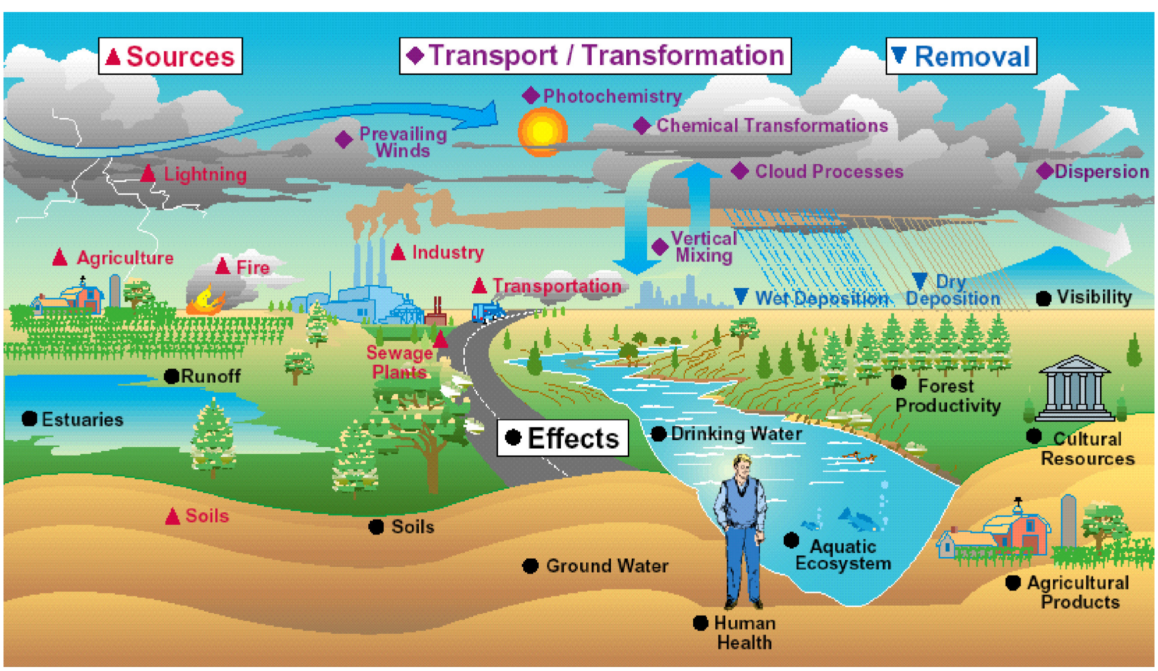

Figure 1—Air pollution source, processes, and exposure path conceptual model (EPA, 2008).

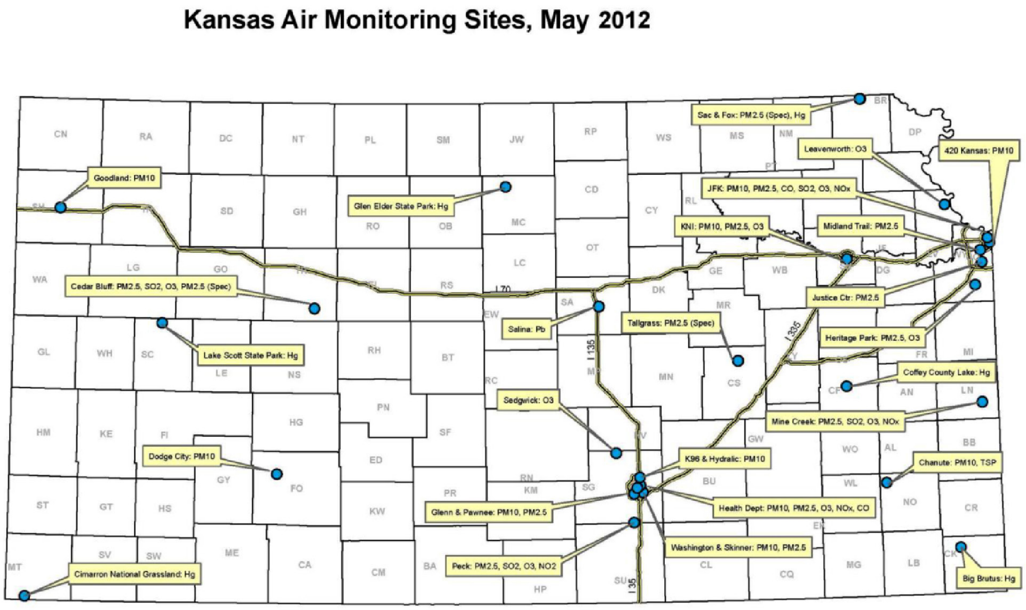

Figure 2—Kansas' air monitoring network (KDHE, 2013).

that the EPA's National Ambient Air Quality Standards (NAAQS) are achieved and maintained. States must develop a general plan to attain and maintain NAAQS as well as a specific plan(s) for nonattainment areas. These plans, called State Implementation Plans (SIPs), ensure an adequate air quality program and emission controls to reduce air pollutants. In Kansas, SIPs are prepared and submitted by the KDHE for review and approval by the EPA (KDHE, 2013).

The EPA designates or describes air quality in areas of attainment (i.e., compliance), nonattainment (i.e., noncompliance), or as unclassifiable with insufficient air monitoring data. The regulatory status of the air in different areas in the state is determined with monitoring data collected by state, local, and tribal governments. In Kansas, KDHE in cooperation with two local agencies collects air-monitoring data from 20 sites across the state (KDHE, 2013). The Kansas network also includes six mercury (Hg) sites, where weekly samples of rain or snow are collected to evaluate the atmospheric fate and transport of mercury (fig. 2).

If the EPA revises the NAAQS, state governments have three years to develop a revised SIP to attain and maintain clean air thresholds (KDHE, 2013). States must involve the public and industries through hearings and public comment during development of a SIP. If a SIP does not meet necessary requirements, the EPA can sanction a state or federally enforce the Clean Air Act for the state (EPA, 2014b).

Air Emission Sources

The EPA tracks contributing sources of the six common air pollutants and their emission volumes. Sources vary from one region to another but are generally classified into eight major groups. These groups are agriculture, dust, fires, fuel combustion, industrial processes, mobile (e.g., trains, aircraft, or vehicles), solvents, and miscellaneous sources (EPA, 2014c).

Ozone NAAQS Revision

The Clean Air Act requires periodic review and update of the NAAQS standards every five years. The NAAQS for ozone was last revised to 75 parts per billion (ppb) in 2008. In January 2010, the EPA released new draft rules that recommended lowering the standard to 60–70 ppb. Implementation of the rule was delayed by public comment, and the EPA missed its five-year deadline when the Obama Administration directed the EPA to put a hold on revising the rule until 2013 (EPA, 2014d).

Environmental groups sued the EPA to establish deadlines for the new standard. A U.S. district court directed the EPA to issue its draft proposal by December 2014 and a final rule by October 2015. A second draft policy assessment released by the EPA recommends lowering the 75 ppb ozone standard to between 60 and 70 ppb to protect the public health from smog (Coomes, 2014; EPA, 2014e).

Public health groups support lowering ozone's NAAQS standard to 60 ppb to protect human health. Industry and manufacturing groups caution that 60 ppb is too low and would put cities and large areas of the country at risk of being out of attainment, forcing revisions to state SIPs to capture emissions from contributing sources to meet the new standard. The EPA administrator will make the final decision on the new standard (Coomes, 2014; EPA, 2014e).

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Wetlands Management at Cheyenne Bottoms

Near the geographic center of Kansas, Cheyenne Bottoms is a historically intermittent marshland set in a natural 64-square-mile basin. The Kansas Department of Wildlife, Parks and Tourism (KDWPT) manages about 30-square miles, or about 20,000 acres, of land in the southern portion as the Cheyenne Bottoms Wildlife Area by manipulating water levels with a system of dikes, pools, and canals (fig. 1). To the north, The Nature Conservancy, a nonprofit conservation organization, owns and manages nearly 8,000 more acres as the Cheyenne Bottoms Preserve, which is being restored to mirror natural wet-dry cycles. KDWPT and The Nature Conservancy work together to ensure their management techniques are complementary.

Prior to development, runoff from the watershed around Cheyenne Bottoms generally flowed into the lowest areas of the basin, resulting in intermittent wetlands. Because runoff was relatively low and sporadic, the area was likely dry about two years in every five before settlement became prevalent in the late 1800s. During wet periods, such as August 1927, however, water would fill much, if not all, of the 41,000-acre basin. After an effort to turn the marsh into a resort lake at the turn of the 20th century failed, developers contemplated draining the land for farming. Before that could happen, the Kansas Forestry, Fish and Game Commission (KFFGC)—predecessor to KDWPT—was given oversight of the wetlands and advanced plans to create a permanent, more stable wetlands and wildlife area.

Cheyenne Bottoms Wildlife Area

After a 15-year effort to get financing, KFFGC was granted federal funds following passage of the 1937 Pittman-Robertson Act, which provided support for state conservation projects. KFFGC began acquiring land in 1942 (Harvey, 2009). Much of the development was done in the 1950s and the Cheyenne

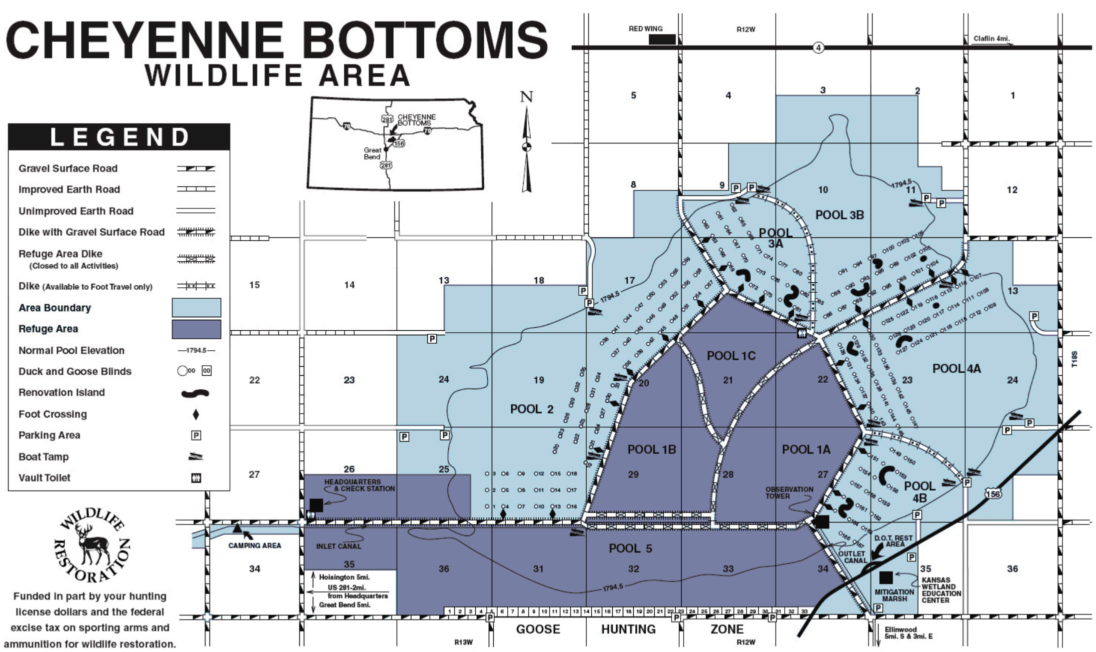

Figure 1—Cheyenne Bottoms Wildlife Area map showing pools, dikes, and other structures used to manipulate water levels (Kansas Wetlands Education Center, 2014).

Bottoms Wildlife Area was dedicated in 1957. The marsh was divided into a series of pools by dikes, and control gates were installed to facilitate water movement into the marsh, between pools, and to an overflow canal. Dams and canals were built to divert water from nearby Arkansas River and Wet Walnut Creek to supplement intermittent flow from Blood and Deception creeks (fig. 2). The primary goal of development was to maintain water levels that would provide suitable habitat for both indigenous and migratory waterfowl. A secondary goal was to provide recreational opportunities, such as hunting, fishing, and bird watching.

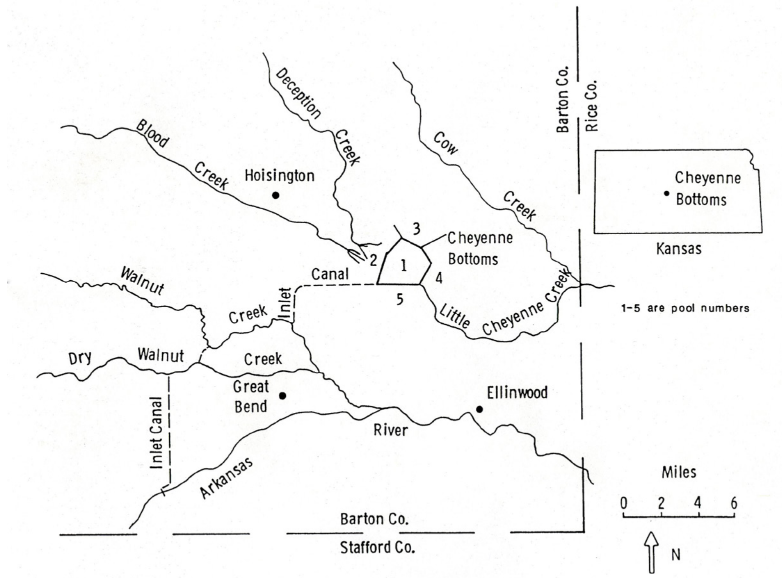

Figure 2—Cheyenne Bottoms Wildlife Area map showing inlet canal system via the Arkansas River and Walnut Creek (Kansas Biological Survey and Kansas Geological Survey, 1987).

Of the 20,000 acres operated by KDWPT, about 12,000 acres are reliable wetlands (fig. 3). Over the years, however, managers were sometimes frustrated by the cyclical availability of water for the marsh. Unanticipated consequences caused by alteration of the marsh's complex natural cycles also surfaced. Dikes eroded, water evaporated from open canals or seeped into the ground, and wind-whipped wave action in the deepest pool churned up sediment that killed off vegetation and invertebrates essential for migratory birds (Harvey, 2009).

Several studies have been conducted to identify problems and solutions, and remedial actions continue to be taken to improve management of the area. Assessments in the late 1950s led to the practice of water manipulation, which included water drawdown and re-flooding at appropriate times to allow for growth of food plants for wildlife and structural repairs and to improve waterfowl hunting (Harvey, 2009).

In the 1990s, a multi-million-dollar renovation substantially enhanced the ability to manage water and vegetation. Pumps were installed to facilitate water transfer between pools, pools were divided into smaller units, dikes were improved so that water could be stored in deeper pools, and water measurement devices were installed. These updates were designed to assure that enough water would be available in storage at all times to maintain at least 3,000 acres of wetlands and, consequently, meet the needs of wildlife even during dry periods.

Manipulation of water levels in the pools remains a major tool in managing the marsh for water birds. Each year, one or more pools are drained. Dry pools may be burned, mowed, or disked to control undesirable vegetation and may also be seeded to millet or wheat (KDWPT, 2014a).

In 2006 and 2009, maintenance work was completed on the two smaller diversion dams on the Wet and Dry Walnut creeks, and in 2009, the now-outdated water measurement devices installed in the 1990s were removed and new flow meters added. A five-year management plan was drawn up for 2010–2014 that outlined goals and strategies for water, vegetation, wildlife, silt, and people

Figure 3—Wetlands at Cheyenne Bottoms Wildlife Area.

management at the Cheyenne Bottoms Wildlife Area (KDWPT, 2011). Among other issues, the plan highlighted the need for repairs on the inlet canal from the diversion dam on the Arkansas River at Dundee to the Walnut Creek. Problems with the canal included erosion, a compromised lining, vegetation growth, and silting. By early 2014, contracted work was completed to replace the open canal with a buried pipe to alleviate these problems.

The Nature Conservancy Cheyenne Bottoms Preserve

The Nature Conservancy began purchasing marshland in the northwest portion of Cheyenne Bottoms in 1990. Its goal is to protect waterfowl and shorebirds by restoring and maintaining the natural marshes, mud flats, and adjoining grasslands (The Nature Conservancy, 2014).

Most of the year, the Conservancy land is completely dry, in contrast to the wildlife area managed by KDWPT. The Conservancy's priorities are to restore the original hydrology of the area to the extent possible by plugging drainage systems put in place for past agricultural pursuits; to make the site more accessible to the public, especially for educational purposes; and to allow grazing that will help re-create habitat conditions preferable to birds and other wildlife. Replicating the impact of bison, the Conservancy uses controlled rotational livestock grazing management as an effective and inexpensive way to alter the plants and soil conditions in the wetlands. The Conservancy is also removing invasive, non-native plants—mainly musk thistle, salt cedar, and Russian olive—that compete with native species for sunlight, soil, and water resources. It believes the most cost-effective and environmentally benign way to remove these invaders is by hand (The Nature Conservancy, 1995).

Wildlife at Cheyenne Bottoms

KDWPT estimated that about 70,000 ducks—mostly blue-winged teal—were at Cheyenne bottoms during the spring of 2014 (KDWPT, 2014b). Of the 417 species of birds documented in Kansas, at least 328 have been observed at Cheyenne Bottoms (fig. 4). The wetlands and surrounding area are also home to numerous species of mammals, reptiles, amphibians, fish, invertebrates, and plants. Wildlife in the marsh and surrounding farmland, creek bed, and shelterbelt habitats includes raccoons, deer, beavers, muskrats, and mink. Threatened or endangered species observed at the wetlands include the piping plover, least tern, whooping crane, bald eagle, and peregrine falcon. The International Shorebird Survey (Manomet Bird Observatory) estimates that 45% of North America's shorebird population stops at Cheyenne Bottoms when migrating north in spring. Waterfowl numbers can approach several hundred thousand (KDWPT, 2011).

Bird watching is one of the more popular activities in the Cheyenne Bottoms Wildlife Area. Hunting is allowed except in the designated refuge areas. In addition to waterfowl, game that may be legally hunted includes pheasant, snipe, rail, quail, and deer. When whooping cranes are present, the pool they are in is closed to all hunting and the goose hunting zones are closed to crane and light goose hunting. Fishing is mainly limited to carp and bullheads, although channel catfish, crappie, and bass are occasionally caught after several consecutive wet years. Trapping is allowed, with a special permit, in the state wildlife area except during the waterfowl season.

Figure 4—Northern shoveler ducks stopover at Cheyenne Bottoms during migration (Kansas Wetlands Education Center, 2014).

Kansas Wetlands Education Center at Cheyenne Bottoms

The Kansas Wetlands Education Center is a state-of-the-art facility that focuses on the Cheyenne Bottoms Wildlife Area, The Nature Conservancy's Cheyenne Bottoms Preserve, and nearby Quivira National Wildlife Refuge. Cheyenne Bottoms and Quivira are two of the 34 sites in the United States designated as Wetlands of International Importance because they often host more than 90% of the world's population of such species as stilt sandpipers and white-rumped sandpipers, as well as hundreds of thousands of geese and cranes (Kansas Wetlands Education Center, 2014).

Exhibits at the Center highlight the diversity of wetlands; the benefits of wetlands to wildlife, humans, and the environment; and the management of wetland wildlife, vegetation, and environments. The Center was developed through a partnership of state and private entities, including KDWPT and Fort Hays State University, and provides educational programs. It is operated by Fort Hays State University as a branch of the Sternberg Museum.

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Crop Selection and Water Requirements

Crop selection in much of the Great Plains is generally influenced by low precipitation and the likelihood of periodic drought. However, groundwater irrigation from the High Plains aquifer is widely used to supplement precipitation shortfalls to produce crop varieties not normally grown under natural or "dry land" conditions (Stewart et al., 1983). The amount of water removed during irrigation in western Kansas and other areas of the Great Plains exceeds the amount of natural recharge to the aquifer, resulting in a net loss or decline to the aquifer (fig. 1). If unabated irrigation continues, in the next 50 years the High Plains aquifer in western Kansas will be 70% depleted and 40% of the area irrigated by the aquifer won't support high-capacity irrigation wells necessary to grow irrigation-intensive crops (KWO, 2014).

Since there is limited groundwater recharge, irrigation supply is essentially static, and excessive pumping reduces the economic life and returns of farming operations (Amosson et al., 2009). As a result, policy-makers and the agricultural industry are examining alternative ways to grow crops that better conserve water resources and sustain agriculture production in semi-arid regions of Kansas. One option is to adopt more water-efficient crops, such as grain sorghum, which is more suited to growing in marginal land and dry environmental conditions (Ahamadou et al., 2012).

Grain Sorghum

Sorghum, also known as milo, is already an important crop in many semi-arid regions of the world, such as Asia and Africa, where the

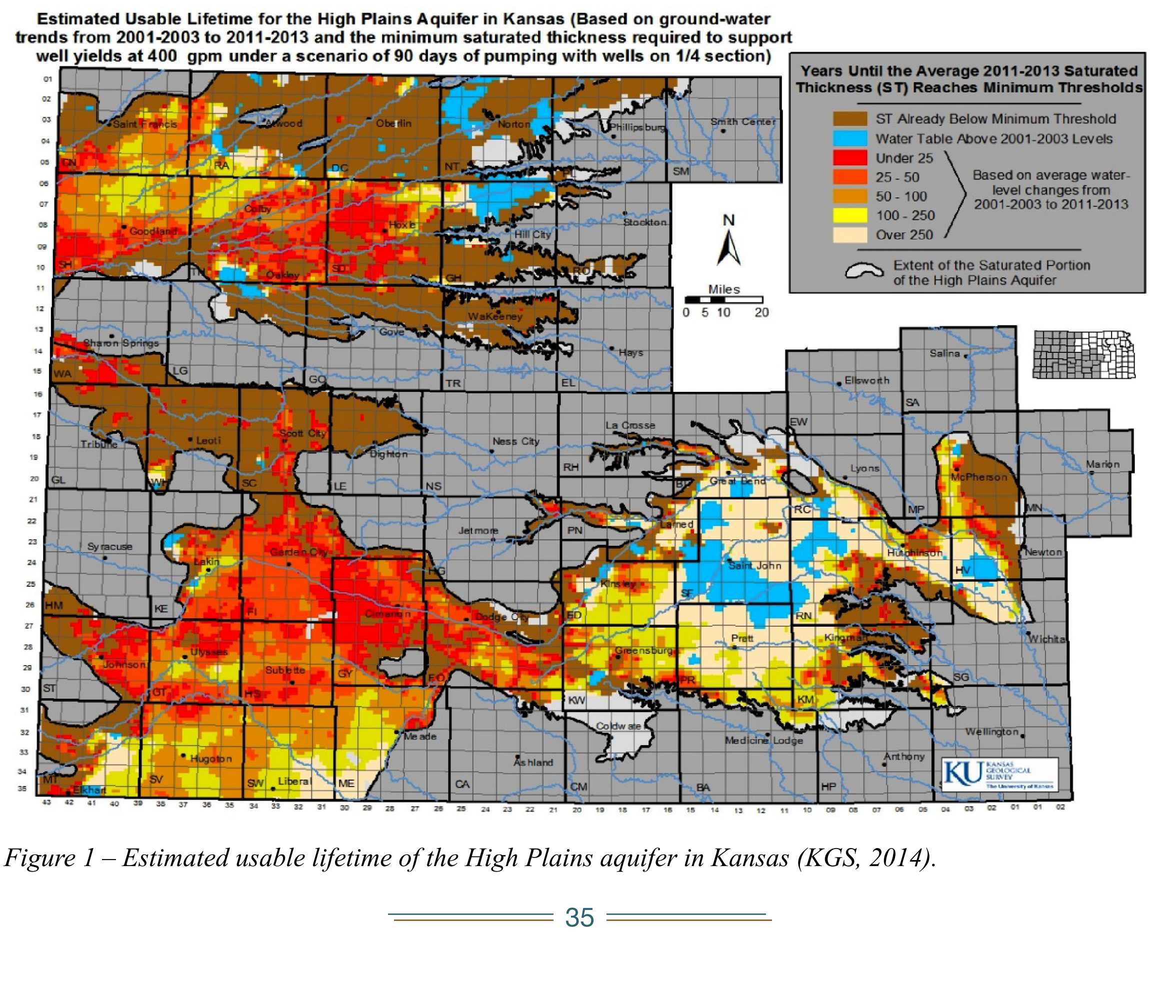

Figure 1 – Estimated usable lifetime of the High Plains aquifer in Kansas (KGS, 2014).

climate is too hot and dry to grow corn. Within the United States, the plains stretching from South Dakota to southern Texas is a natural sorghum growing belt (Sorghum Checkoff, 2014).

Sorghum requires warm day and nighttime temperatures for high yields and is therefore well-adapted to the growing conditions on the Great Plains. Low temperature, not heat or growing season, is typically the limiting factor for much of the region. Some of sorghum's climate-adapted traits include lower transpiration ratios, lower irrigation requirements, plant dormancy, finely branched root systems, and foliage with a thick cuticle or wax coating. Sorghum production has several advantages over corn production in the Great Plains. Short drought periods do not seriously damage sorghum pollination; plant populations are more resistant to soil moisture stress; sorghum foliage resists drying and wilting; and sorghum recovers better after drought (Ahamadou et al., 2012; Carter et al., 2014).

Sorghum is cultivated in 14 states throughout the central United States (Carter et al., 2014). Total sorghum production for all uses, such as grain and silage, within the United States increased from 6.24 million acres in 2012 to 8.06 million acres in 2013 (USDA, 2014). In 2012, Kansas and Texas lead the country in harvested acres for the grain, with 2.1 million and 1.9 million acres, respectively. That accounted for about 81% of the sorghum grain crop in the United States (fig. 2). However the two states' production rankings were switched as Texas produced 112.1 million bushels and Kansas produced 81.9 million bushels (USDA, 2013). In 2013, Kansas led the country in both cultivation acreage and production, at 2.8 million acres and 165.2 million bushels of grain sorghum (USDA, 2014). Other states with significant quantities of sorghum include Louisiana, Arkansas, South Dakota, and Oklahoma (fig. 2).

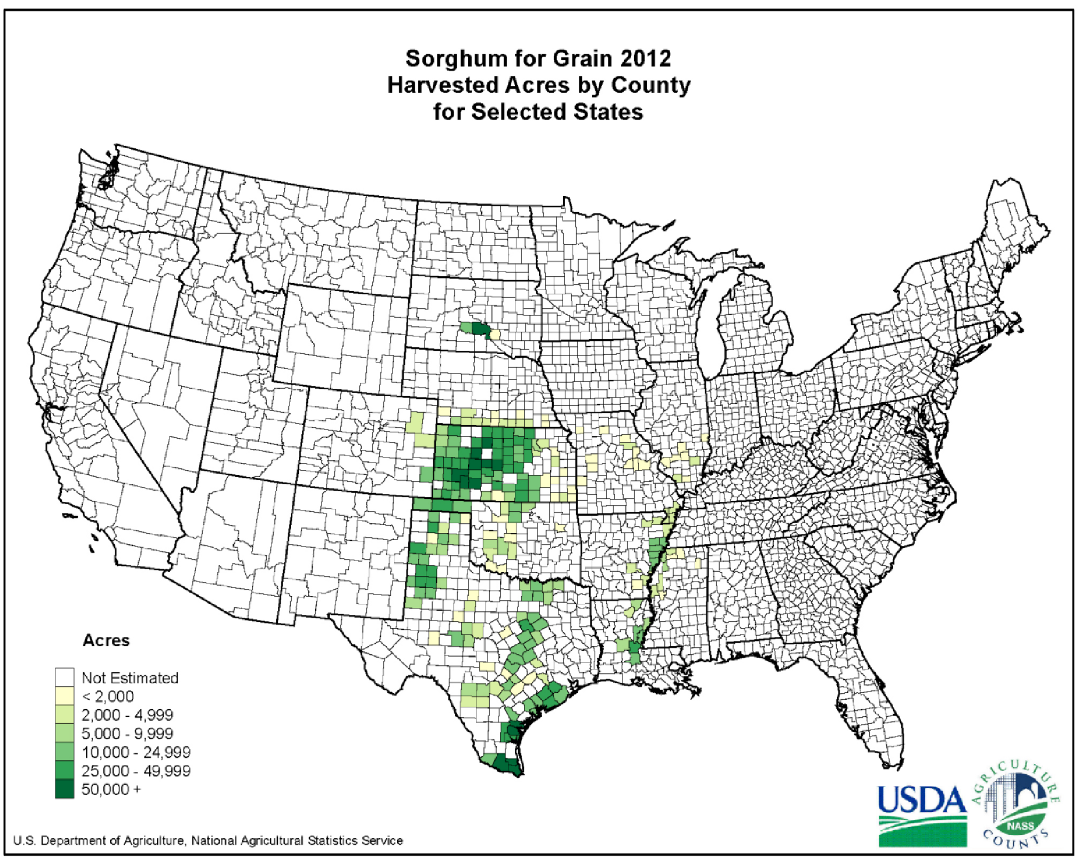

Figure 2 – Sorghum acres harvested for grain by county in 2012 (USDA, 2013).

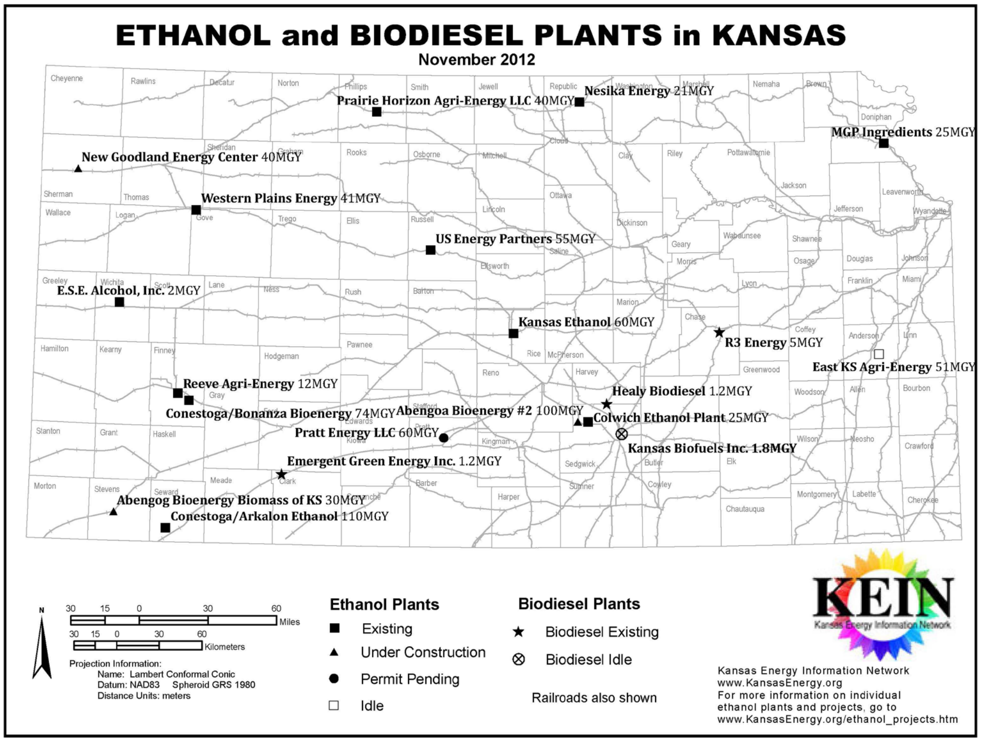

Figure 3 – Kansas ethanol and biodiesel plants (Kansas Energy Information Network 2014).

Sorghum Exports and Imports

The United States is the leading exporter of sorghum to world markets, generally accounting for more than 65% of the world trade of this commodity. In 2012, shipments to Mexico, Japan, and Sudan were valued at $488.8 million. Recent years have seen an expansion of sorghum imports into United States markets. In 2012, the United States purchased and imported about $6 million worth of grain sorghum from Argentina (Agricultural Marketing Resource Center, 2014).

Sorghum Markets

In addition to international exports for human food consumption and domestic livestock feed, sorghum is increasingly being used in ethanol production. Approximately 12% of the U.S. sorghum crop is used for ethanol production (Agricultural Marketing Resource Center, 2014). In Kansas, according to the Kansas Energy Information Network (2014), 11 dry mill ethanol plants produce about 440 million gallons per year, creating a market for about 157 million bushels of sorghum and corn (fig. 3).

Crop research has produced other sorghum markets, such as a food-grade sorghum that is being used in the snack food industry and gluten-free baking products. Sorghum is also used for industrial products, such as wallboard and biodegradable packing materials (Agricultural Marketing Resource Center, 2014).

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Wednesday, June 4, 2014

6:00 a.m.	Breakfast—Fairfield Inn & Suites Conference Room, Hutchinson Catering Service by Catering For You (starting time is informal)
8:00 a.m.	**Bus leaves Fairfield Inn & Suites, Hutchinson for Site 7**
8:15 a.m.	**SITE 7**—Emplacement of Salt-Impacted Materials for Cavern Stabilization, Hutchinson *Cynthia Khan,* UIC Director, Kansas Department of Health & Environment *Craig Pangborn,* Partner, Underground Cavern Stabilization, LLC
9:00 a.m.	Bus to Site 8
9:15 a.m.	Restroom Break, Nickerson High School
10:00 a.m.	**SITE 8**—Oil Field Treating Chemicals, Sterling *Dr. Gene H. Zaid,* Founder and CEO, Jacam
11:00 a.m.	Bus to Site 9
11:15 a.m.	**SITE 9**—Natural Gas Liquids Collection, Storage, and Distribution, Conway *Allison G. Bridges,* Senior Vice President, Williams *Randy Heinrichs,* Operations Manager, Williams *David Bohnenblust,* OPPL Area Engineer, Williams
12:00 p.m.	Bus to Lunch and Site 10
12:15 p.m.	Lunch—National Cooperative Refining Association, McPherson Meal provided courtesy of NCRA. **SITE 10**—Oil Transport and Refining, McPherson *Galen Menard,* VP Supply and Trading, National Cooperative Refining Association
2:00 p.m.	Bus to Site 11 Bus Session—Legislative Update: Induced Seismicity *Rex Buchanan,* Interim Director, Kansas Geological Survey

2:30 p.m.	**SITE 11**—Maxwell State Game Refuge, McPherson County *Secretary Robin Jennison,* Kansas Department of Wildlife, Parks and Tourism *Stuart Schrag,* Regional Supervisor, Kansas Department of Wildlife, Parks and Tourism
4:00 p.m.	Bus to Ambassador Hotel, Wichita
	Bus Session—Legislative Update: Lesser Prairie Chicken Listing *Secretary Robin Jennison,* Kansas Department of Wildlife, Parks and Tourism
5:00 p.m.	Arrive at Ambassador Hotel, Wichita
6:00 p.m.	Social Gathering—Regent Room (2nd Floor), Ambassador Hotel
6:30 p.m.	Supper—Regent Room (2nd Floor), Ambassador Hotel Meal provided courtesy of the City of Wichita and Surrounding Businesses
7:30 p.m.	After-hours tour of Union Station (optional event)

Underground Cavern Stabilization, LLC Facility

The Underground Cavern Stabilization, LLC (UCS) facility south of Hutchinson provides an environmentally safe containment option for non-hazardous high-chloride materials such as chloride-contaminated soils, drill mud, drill cuttings, excess cement, and other inert materials derived from various industrial activities. The materials are placed in a cavern void created for a now-defunct propane storage facility (UCS, 2014). Containment and emplacement of materials by this method help stabilize salt caverns and eliminate a potential waste stream that may have otherwise been land farmed or sent to a landfill, reducing the landfill's capacity and life. The salt cavern at the UCS facility is completed in the Hutchinson Salt Member, which is extensively mined for salt and the storage of liquid natural gasses in Kansas (fig. 1).

Hutchinson Salt Member

Salt in Kansas is mined from the Hutchinson Salt Member of the Wellington Formation, which was deposited during the Permian Period about 275 million years ago. The Hutchinson Salt Member covers about 37,000 square miles in the subsurface of central and south-central Kansas. Its maximum thickness is more than 500 feet (fig. 1). Salt units also occur in the Permian-age Flower-pot Shale, Ninnescah Shale, and Blaine Formation, but those are deeper and have never been mined (Sawin and Buchanan, 2002).

Room-and-pillar mining and solution mining are two common techniques used in Kansas to mine salt. Both methods have been employed to extract salt from the Hutchinson Salt Member in mines or storage caverns ranging in depth from 600 to 1,000 feet. With the room-and-pillar method, a mine shaft is constructed to reach the salt formation and the salt is blasted with explosives and excavated in a checkerboard pattern. Pillars of salt are left standing to support the roof rock of the mine.

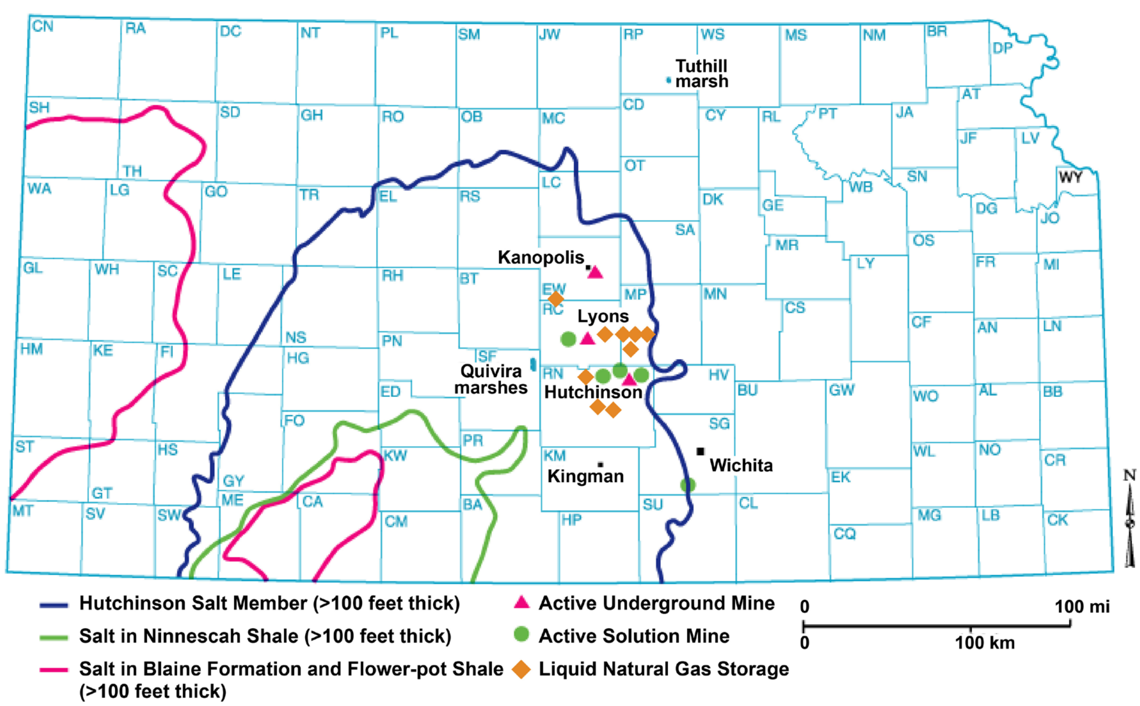

Figure 1—Approximate limits of major salt deposits in Kansas (modified from Bayne, 1972) and active salt mining locations (Sawin and Buchanan, 2002).

The rock is conveyed to crushers then hauled in lifts to the surface through the mine shaft. Active underground salt mines are located in Lyons, Kanopolis, and Hutchinson (Sawin and Buchanan, 2002).

Although excavation is used in room-and-pillar mining, freshwater injection is used in solution mining. The water is injected down a cased well into a salt formation to create an artificial brine. The brine is pumped to the surface and evaporated to recover the salt or used as fluid ballast to move liquid natural gas, such as propane, in and out of storage. Dissolution and removal of the salt creates an irregular-shaped underground void, or salt "jug" (fig. 2). Because solution mines cannot be entered, seismic surveys are typically used to estimate a cavern's dimensions (Lomenick, 1972; Sawin and Buchanan, 2002). Salt solution mines are located around Lyons, Hutchinson, and Wichita. Liquid natural gas storage caverns are located near Hutchinson west of Lyons.

Class V Wells

The UCS facility uses a salt jug in an abandoned propane storage field, which was filled with brine, plugged, and abandoned in the early 1990s (Cochran, 2013) (fig. 2). After acquiring the salt-solution field, the UCS drilled out the plugged well and retrofitted it with a tubing string and injection wellhead (fig. 3). The well was permitted after application, inspection, and public notice as a Kansas Department of Health and Environment Class V Underground Injection Control well for emplacement of salt and mineral impacted materials. The aquifer storage and recovery wells being used at the City of Wichita's Equus Beds aquifer storage and recovery project southeast of Hutchinson are another type of Class V well.

Most Class V wells are shallow disposal systems that rely on gravity to inject non-

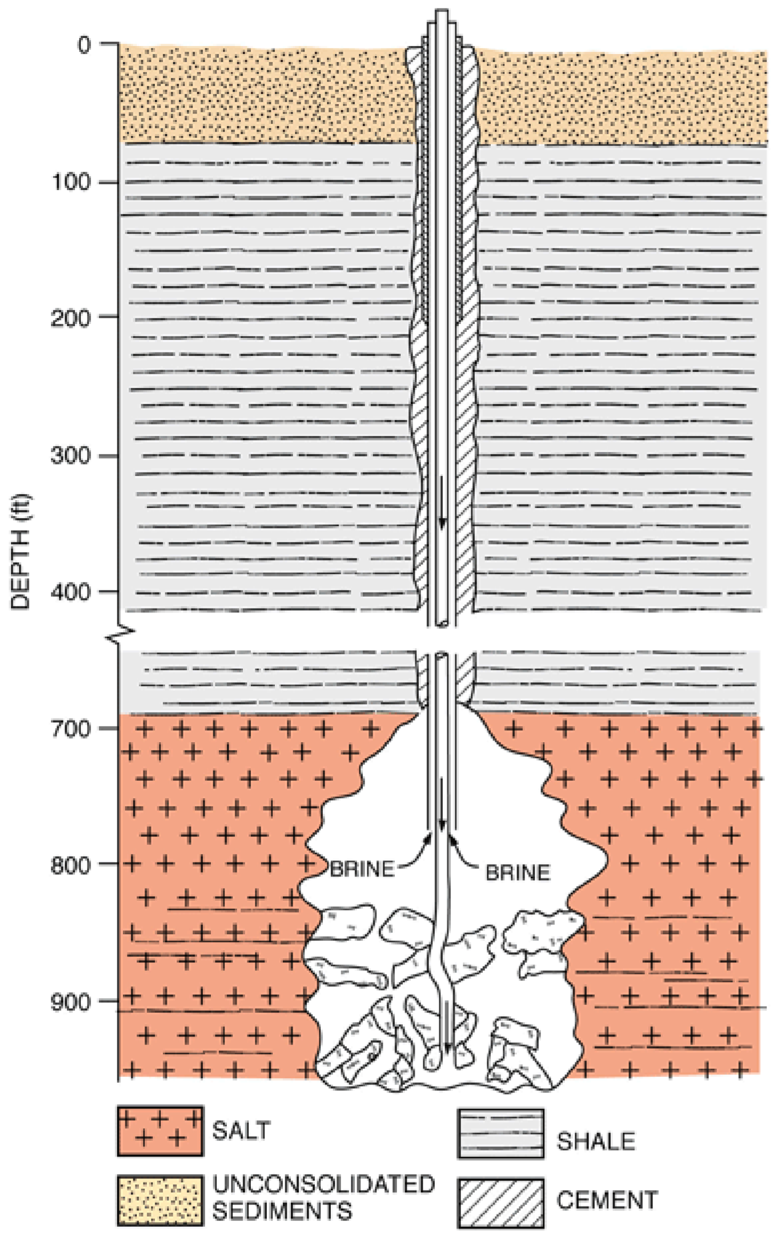

Figure 2—Example of a salt solution mine where water is injected into a salt formation and brine is withdrawn, leaving a solution cavity or salt "jug" (modified from Lomenick, 1972, and KDHE, 2013).

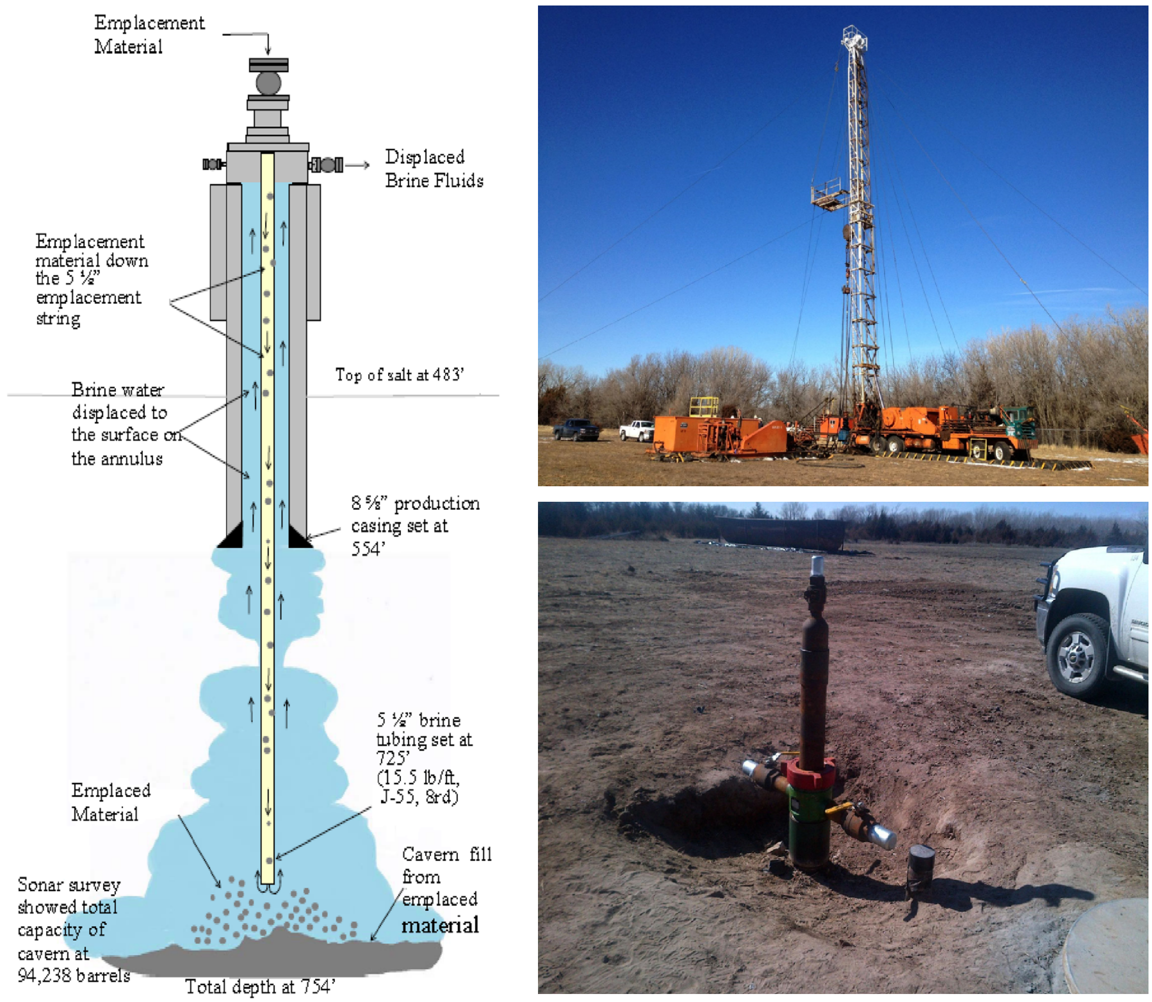

Figure 3—Retrofit drilling, injection wellhead and emplacement process of UCS's Class V well (Pangburn, 2013).

hazardous fluids into the ground. Because these shallow systems—often completed in or above fresh groundwater—can pose a threat to drinking-water supplies, they are carefully managed and permitted (EPA, 2014). The UCS well is periodically tested for integrity and continuously monitored by a computer-controlled monitoring system (Cochran, 2013). Other permits for the UCS well were acquired for water rights, storm-water runoff, zoning, and highway access from the Division of Water Resources—Kansas Department of Agriculture, Groundwater Management District No. 2, Reno County, Kansas Corporation Commission, and Kansas Department of Transportation.

Prior to injection, chloride-impacted material is mixed with salt brine to form a slurry, which is injected into the salt cavern under slight pressure. Brine displaced from the salt cavern is captured and stored on site for future slurry operations, sold as a commercial high-chloride brine, or used in enhanced oil recovery injection wells (Cochran, 2013). The emplaced material will eventually fill the solution void and provide long-term stability to the void's roof rock.

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Oil Field Treating Chemicals

Jacam, founded in 1982 and based in Sterling, manufactures and sells oil-field-related chemicals and services to the petroleum industry in the United States and internationally. Oil and natural gas producers are its primary consumers, but products are also marketed and sold to the pipeline industry. Jacam has more than 350 employees and operates in nine states (Bloomberg Businessweek, 2014; Jacam, 2014). In 2013, Canadian Energy Service & Technology Corporation, a drilling fluids manufacturing company, acquired Jacam. The combined operations of the two companies provide chemicals and services for all phases of petroleum-production, including technically advanced consumable chemical solutions at the drill bit, well stimulation, completion, wellhead or pump jack, and through to the pipeline market in most production basins in the United States and Canada (Canadian Energy Services, 2014) (fig. 1).

Chemical Production and Products

Oil field chemicals at Jacam are produced from a modern, zero-emission chemical blending and reacting facility with a 72,000,000-gallon annual production capacity. Small chemical batches are blended to match site-specific locations and well field or pipeline characteristics. Jacam manufactures chemicals across 35 product lines. Its products include surfactants, scale and corrosion inhibitors, biocides, gas sweeteners, emulsion breakers, paraffin and asphaltene inhibitors, demulsifiers, stimulation products, salt inhibitors, specialty chemicals, foamers and defoamers, desalt products, and water treating products (Bloomberg Businessweek, 2014; Jacam, 2014).

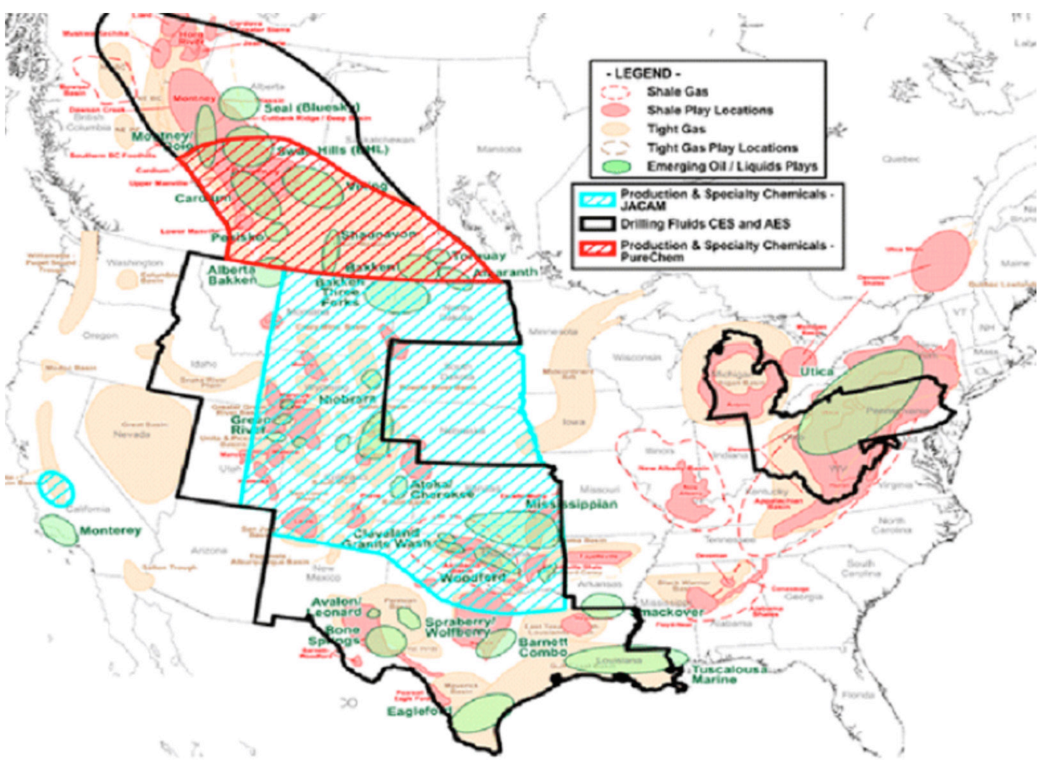

Figure 1—Jacam service areas in the United States and Canadian production basins (Canadian Energy Services, 2014).

Well Stimulation

Jacam provides field services and engineering staff to diagnose and research site-specific chemicals to inhibit corrosion and also well stimulation treatments to revive corroded pipelines and old wells in existing reservoirs. Corrosion in down-hole equipment often results from the presence of carbon dioxide and hydrogen sulfide in oil and gas wells. Well stimulation (i.e., hydraulic fracturing, or "fracking") with site-specific chemicals tailored to the rock formation and geochemistry can clean the reservoir rock without damaging the permeability of the well. A correctly designed stimulation program will not damage permeability by pushing the corroding material farther into the rock and clogging it (Jacam, 2014).

Acid treatments are a common stimulation method used to remove corrosion and improve well production. Acid treatments typically have a short stimulation period, only 30 to 45 days, because they break down the rock matrix or mineral cement in sandstones or shale. Fragments may be pushed back into the rock as acid is injected or carried back to the well interface with the flow of oil and gas (Jacam, 2014).

In contrast to acid treatments, Jacam's well stimulation program uses nano-technology chemistry. Formation material at a nano scale responds very differently, enabling unique chemical applications that work within the formation instead of at its surface. Benefits include increased production, lower injection pressures, greater safety, and chemicals that won't corrode chrome or steel equipment or wells (Jacam, 2014).

The case history of the Hall #8A well in Osage County, Oklahoma, illustrates the typical well performance difference between an acid treatment and nano-scale treatment. Completed in the Bartlesville sand at 2,000 feet, the well was stimulated with 500 gallons of hydrochloric acid pumped down the well annulus. After treatment, the well produced 250 barrels of water and less than one barrel of oil per day. The produced water was black and emulsified with oil. The well was then treated with a stimulation designed by Jacam. After that treatment, the well produced 300 barrels of water and five barrels of oil. The produced water was clean and free of solids. Production at five barrels per day was still consistent after 26 months. The cost of the stimulation program was recovered within 17 days and the producer realized $233,454.56 in new oil revenue (Jacam, 2014).

Truck and Rail Distribution

Jacam Carriers, a division of Jacam, owns and operates a fleet of over-the-road semi-trucks that make daily deliveries from the

Figure 2—Jacam rail spur service and treating vehicles (Jacam, 2014).

manufacturing plant in Sterling to company warehouses and wholesale customers across Kansas and the United States (Jacam, 2014). Another fleet of delivery and treating vehicles delivers site-specific chemical treatments directly to well sites (Jacam, 2014). The railroad spur at the manufacturing facility allows for improved raw material deliveries and bulk shipping opportunities, lowering manufacturing costs passed on to customers (fig. 2).

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Transport, Fractionation, and Underground Storage of Natural Gas Liquids

One of the state's largest Natural Gas Liquid (NGL) storage areas is near Conway in western McPherson County. There, five of the state's nine underground NGL storage facilities are located along a major pipeline terminal that connects oil- and gas-producing fields in the western United States to the energy markets throughout the rest of the country. The four other facilities are near Bushton in Rice County and Hutchinson in Reno County. One of the four, the Yaggy site in Reno County, is currently closed and under monitoring (KDHE, 2013).

NGLs are transported to storage caverns that have been created in the Hutchinson Salt Member of the Wellington Formation. The Hutchinson salt is thick and fairly predictable throughout, making it suitable for hydrocarbon storage. The storage caverns are large voids created by salt dissolution. Propane, butane, and other NGLs can be introduced into and removed from these caverns relatively quickly in response to supply and consumer demand in the energy market.

The National Cooperative Refining Association maintains an approximate 5-million-barrel NGL storage facility east of Conway used to supply feedstock to its refinery in McPherson. ONEOK Partners operates a 26.5-million-barrel storage facility west of Conway with gathering pipelines from production basins in Oklahoma, Kansas, Wyoming, Colorado, and Texas.

Williams, through its subsidiary Williams Partners, L.P., owns and operates three underground NGL storage facilities. The fractionator is used to separate the raw natural gas into its component parts. The storage facilities—Conway Underground East, Conway West, and Mitchell—provide about 21 million barrels of storage. The Mitchell facility is 14 miles to the west of Conway in Rice County (Williams, 2014).

In conjunction with its storage facilities, Williams operates the Overland Pass Pipeline, which is jointly owned by Williams L.P. and ONEOK Partners. The pipeline extends from Opal, Wyoming, to Conway and has extensions into the Piceance and Denver-Julesberg basins in Colorado (fig. 1). It can transport about 245,000 barrels of NGL per day from oil and gas production fields to Conway. Williams also operates the Conway Fractionator, which is jointly owned by Williams L.P., ONEOK Partners, and ConocoPhillips. The fractionator can process about 107,000 barrels per day of NGLs into separate products for market through pipeline, truck, and rail terminals (Williams, 2014).

Natural Gas Liquids

Petroleum wells with a natural gas component produce (1) methane, commonly referred to as natural gas, or dry gas, and (2) NGLs, which are commonly referred to as wet gas and consist of varying mixtures of propane, butane, ethane, and traces of other hydrocarbons. The dry and wet gas streams are typically separated at the wellhead or at a nearby gas processing plant. NGLs are then gathered through pipelines (as a liquid called "raw feed") and delivered for processing at fractionators. In the past, raw feed was a waste byproduct of oil and gas production. Now it is fractionated (or broken into its components) and sold for use in commercial energy and petrochemical industries. Williams does not store methane at any of the three storage facilities near Conway.

Conway Fractionator

At some point along the pipeline between the producing fields and the end consumer and industrial users, the raw feed must be fractionated. The fractionator at Conway is designed to process about 107,000 barrels per day of NGLs into different components or

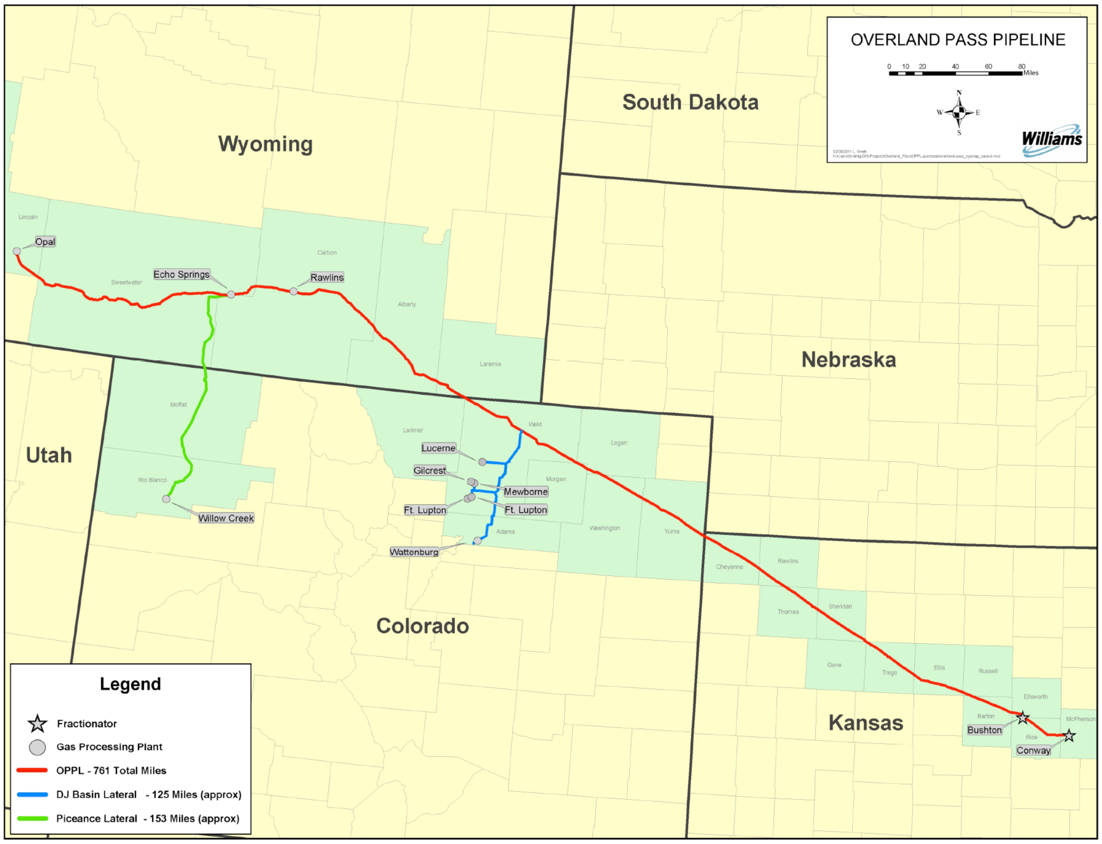

Figure 1—The Overland Pass Pipeline transports LNG from Wyoming and Colorado to the Mid-continent Fractionation & Storage facility near Conway (Williams, 2014).

fractions such as ethane, propane, isobutane, normal butane, and natural gasoline. The components are temporarily stored in underground caverns for subsequent use or for delivery to the energy marketplace through interstate pipelines, railcars, and tanker trucks. Because large volumes of NGLs can be stored in caverns at Conway, meeting seasonal demands for NGL energy products is not limited by the production rates of fractionators and production fields.

NGL Storage in Salt Caverns

NGLs can be stored on the surface in large steel spherical tanks or underground in solution-mined storage caverns in salt formations, such as the bedded salt that underlies most of central Kansas. Underground storage is more economical because the tanks take up considerable land area and are expensive, which add cost to the consumer products.

Figure 2 illustrates an NGL storage cavern in bedded salt similar to the salt formations in Kansas. The storage cavern is created by first drilling down to the salt formation. The drill hole is then sealed off from the overlying units by cementing a steel casing pipe in place. Freshwater is injected through the pipe into the salt formation to dissolve some of the salt. The process is roughly analogous to melting a hole in an ice cube with hot water. Dissolution of the salt creates a nearly saturated brine solution, which completely fills the cavern.

To facilitate hydrocarbon storage in the newly solution-mined cavern, a steel pipe is "hung" from the wellhead inside the cemented steel casing. This central pipe is called the brine injection string or tubing. Because NGLs are lighter than saturated saltwater brine, they "float" on the brine, and the movement of the NGLs out of the storage cavern is controlled by the injection of brine. Conversely, when NGLs are pumped into the cavern, brine is displaced

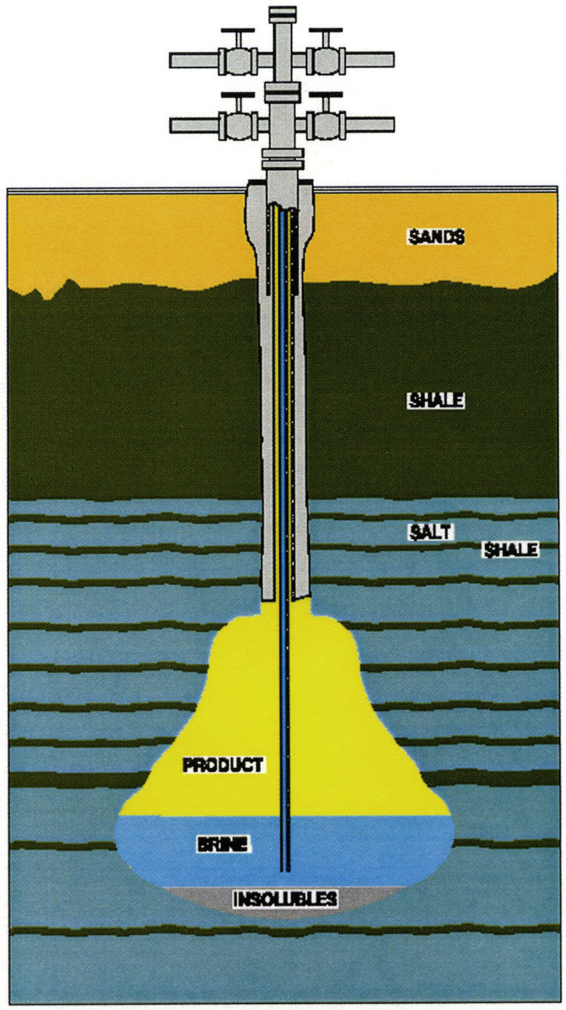

Figure 2—NGL storage cavern in a bedded salt formation.

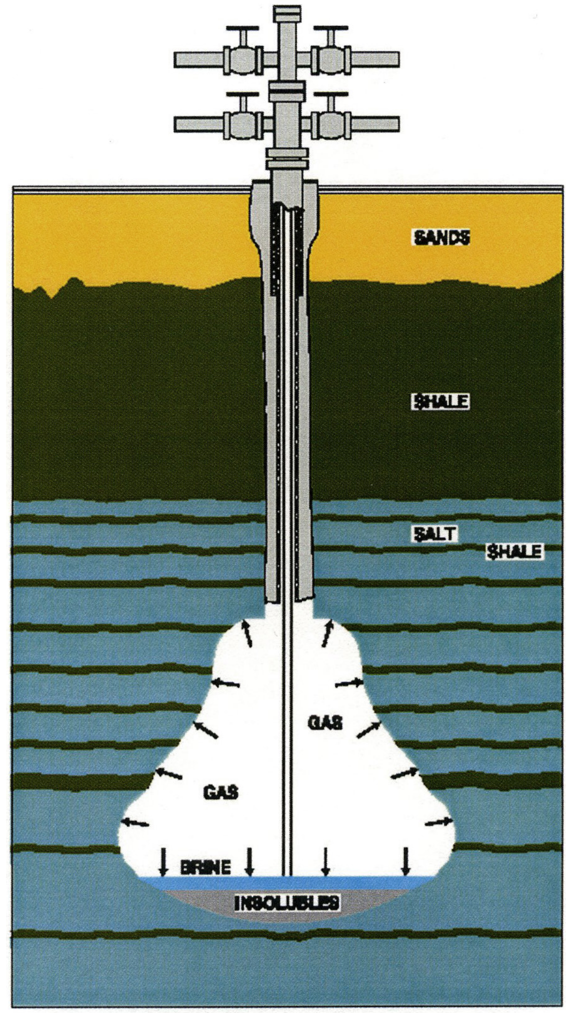

Figure 3—A natural gas storage cavern in a bedded salt formation.

out of the cavern and piped to lined surface storage ponds. To remove a barrel of NGL product from a storage cavern, a barrel of brine must be pumped in to the cavern to displace it.

How NGL Cavern Storage Differs from Natural Gas Cavern Storage

Figure 3 illustrates a natural gas, or methane, storage cavern in bedded salt. Although natural gas is not stored at Conway, natural gas can be stored in solution-mined caverns to buffer production from seasonal demand. Natural gas was stored in salt caverns at Yaggy beginning in the early 1990s until the facility was shut down in 2001 after a natural gas leak resulted in offsite gas migration, explosions, injuries, and two deaths in Hutchinson (Allison, 2001). Natural gas is not presently stored in salt caverns in Kansas and the Yaggy site is closed and under monitoring (KDHE, 2013). Natural gas storage caverns in Kansas differ from liquid storage caverns in Kansas in four significant ways:

1. NGL storage caverns have a history of nearly 50 years of use while natural gas storage caverns were used in Kansas for less than 11 years. Many of the salt caverns at Conway were originally constructed in the 1950s.
2. All Kansas NGL caverns were originally designed and constructed as NGL caverns and, except for at Yaggy, have never been re-entered for gas storage after being plugged and abandoned. Solution-mined

salt caverns that were used in Kansas to store natural gas were originally designed for NGL storage.

3. Movement of NGL products in and out of caverns is facilitated by pumping brine solution into the well to displace the hydrocarbons. Natural gas is compressed and stored at pressures high enough to induce the product to flow out through pipes on demand.
4. Virtually the entire volume of product in an NGL cavern can be displaced by pumping in an equivalent volume of brine. Natural gas caverns must be operated above a minimum pressure to provide a "base gas" volume that supports the weight of the overlying rocks. The base gas volume cannot be recovered under normal conditions.

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NCRA Refinery

The National Cooperative Refinery Association (NCRA) is an 85,000 barrel-per-day operation in McPherson (fig. 1). The company's refining operations include a product tank farm, a products pipeline, truck loading facility, warehouses, laboratory, and a waste-water treatment facility. The refinery operates 24 hours a day, seven days a week, except for periodic shut downs for repairs and maintenance (KDHE, 2014). In addition to the refining operations, the NCRA has more than 80 trucks and 1,000 miles of pipelines that move crude oil and finished products to various tanks and terminals.

Crude Oil

Crude oil is a mixture of naturally occurring hydrocarbons. It exists as a liquid phase in underground production reservoirs as well as when it is at atmospheric pressure after passing through production wells and surface processing facilities prior to distillation. Crude oil comes in a variety of chemical compositions, colors, and densities. Colors range from black to brown to greenish. Density is measured against an API gravity scale developed by the American Petroleum Institute. Denser and heavier oil, called "heavy crude," has a low API number. Less dense and lighter oil, or "light crude," has a high API number. Naturally light or runny fluids with low viscosity are easier to refine and have more economic value. Heavy crudes that are thick and viscous are more difficult to refine. Specialized refineries are required to split or crack the heavier, long-chain hydrocarbons into shorter ones, which are more useful and economically valuable (API, 2014; EIA, 2014).

Crude oil is also often described in terms of its sulfur content. If it has a small quantity of sulfur, it is "sweet" and if it has a large quantity, it is "sour." Sweet crude is cheaper to refine

Figure 1—The NCRA refinery, McPherson, Kansas (NCRA, 2014)

because less sulfur has to be removed at the refinery (API, 2014; EIA, 2014).

The types of products and the volume a specific crude oil yields are dependent on the composition of the decaying organic material from which the oil formed and the temperature and pressure under which it was formed. Distilled petroleum products and volume will vary for supplies of crude oil recovered from different production fields (API, 2014; EIA, 2014).

NCRA Crude Oil Sources and Products

The NCRA annually processes 31 million barrels of oil at a rate of about 85,000 barrels per day. Crude oil supply includes about 60,000 barrels per day of Kansas crude, 20,000 barrels per day of heavy Canadian crude, and 5,000 barrels per day of crude from the Bakkan field in North Dakota. These petroleum streams annually produce about 33.3 million barrels of gasoline and diesel, which are sold to the NCRA's cooperative members (NCRA, 2013).

Refinery Expansion

The NCRA is constructing two new projects at its McPherson facility, a $327 million refining capacity expansion and a $555 million coker. Phased construction is ongoing, with new production expected to come online in early 2016 (McPherson Sentinel, 2013).

The expansion project will increase refining capacity from 85,000 barrels per day to 100,000 barrels per day and enable the NCRA to increase its feed of sour Canadian crude from 20,000 to 50,000 barrels per day. Operating units throughout the refinery will be added or upgraded to handle the greater capacity and process additional sulfur from the Canadian crude (A Barrel Full, 2014).

The new coker will replace the NCRA's current coker, which was built in 1952 (fig. 2). Cokers convert the heaviest part of the crude stream, otherwise sold as asphalt, into petroleum coke and other liquid products that can be refined into gasoline and diesel fuel. The coker will not increase refining capacity, but it will allow more flexibility in the crude types

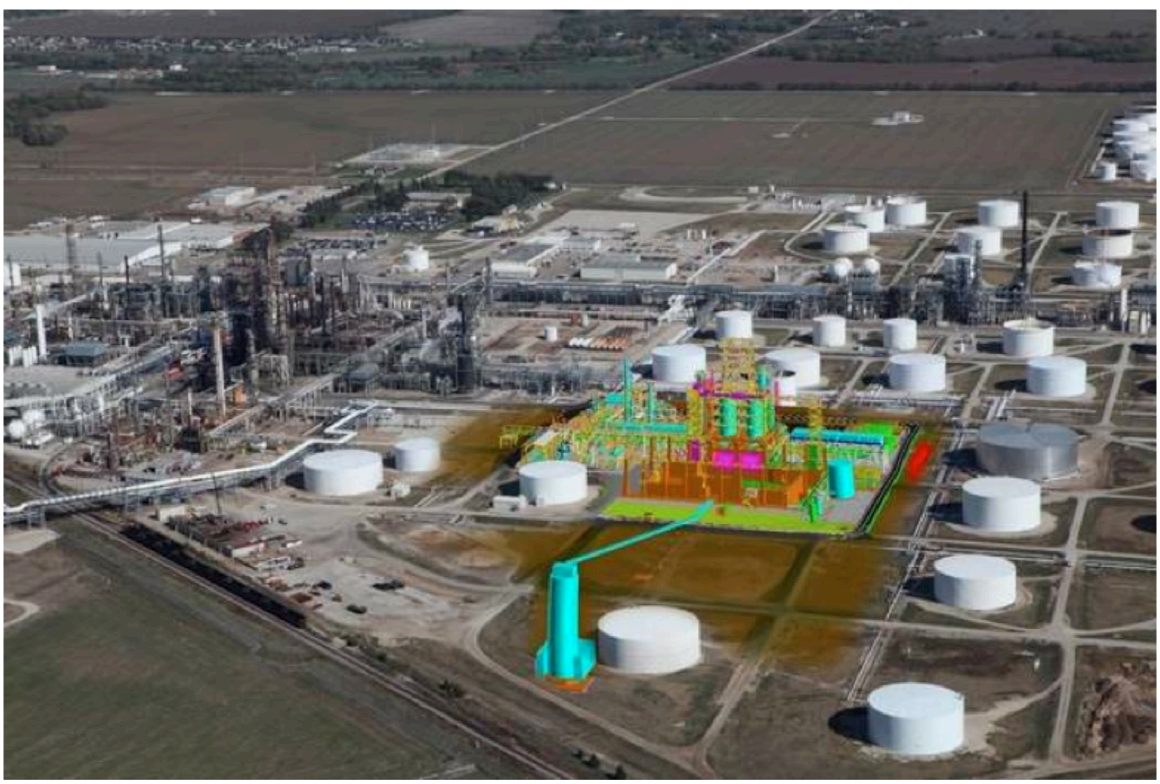

Figure 2—Conceptual illustration of the new $555 million coker that will be located in the southwest portion of the NCRA refinery (Janney, 2013).

that are processed in the refinery, including heavier Canadian crudes (Janney, 2013).

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Induced Seismicity: The Potential for Triggered Earthquakes in Kansas

Rex C. Buchanan, K. David Newell, Catherine S. Evans, and **Richard D. Miller,** Kansas Geological Survey

Introduction

Earthquake activity in the Earth's crust is known as seismicity. When linked to human activities, it is commonly referred to as "induced seismicity." Industries that have been associated with induced seismicity include oil and gas production, mining, geothermal energy production, construction, underground nuclear testing, and impoundment of large reservoirs (National Research Council, 2012). Nearly all instances of induced seismicity are not felt on the surface and do not cause damage.

In the early 2000s, concern began to grow over an increase in the number of earthquakes in the vicinity of a few oil and gas exploration and production operations, particularly in Oklahoma, Arkansas, Ohio, Colorado, and Texas. **Horizontal drilling** in conjunction with **hydraulic fracturing** has often been singled out for blame in the public discourse. Hydraulic fracturing, popularly called "fracking," does cause extremely low-level seismicity, too small to be felt, as do explosions associated with quarrying, mining, dam building, and other industrial activities. Although the actual process of hydraulic fracturing has been suspected of inducing larger earthquakes a few times worldwide, the U.S. Geological Survey has found no evidence to suggest that it has contributed much to increases in the rate of earthquakes (Hayes, 2012).

Felt earthquakes associated with any oil and gas production activities are rare. In the United States, only a small fraction of the hundreds of thousands of wells currently in operation have been suspected of inducing earthquakes large enough to be felt or cause damage (National Research Council, 2012). Most often, detected seismic activity associated with oil and gas operations is thought to be triggered when wastewater is injected into a disposal well. In the disposal process, waste products—such as saltwater produced with oil and gas and recovered hydraulic fracturing fluids—are injected into deep and confined porous rock.

Identifying a link between earthquakes and human activities is difficult. Complex subsurface geology and limited data about that geology make it hard to pinpoint the cause of many seismic events in the midcontinent, particularly in regions historically prone to naturally occurring low-level seismic activity. In south-central Kansas, for example, several small earthquakes have been recorded near disposal wells starting in September 2013, about three years after horizontal drilling activities in the **Mississippian limestone play**—and associated water disposal—had crossed over the state line into Kansas from Oklahoma. However, the region also experienced several small historical earthquakes long before the increased oil activity, making it difficult to determine the cause of the recent seismic events. Although some areas of Kansas are at greater risk of seismicity than others, whether natural or induced, none of the state is in a high-hazard earthquake zone (fig. 1).

Scientists continue to monitor and evaluate possible instances of induced seismicity. In states with significant increases in seismic activity, including Oklahoma, monitoring has increased in localized areas where unusually high rates of seismicity have occurred near oil and gas production activities. To

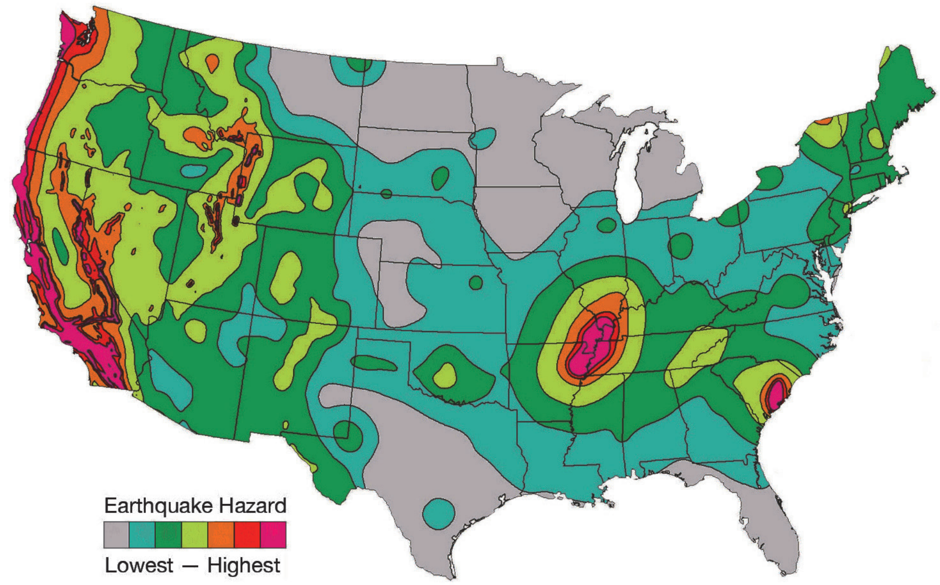

Figure 1—Earthquake hazard maps show the probability that ground shaking, or motion, will exceed a certain level, over a 50-year period. The low-hazard areas on this map have a 2% chance of exceeding a low level of shaking and the high-hazard areas have a 2% chance of topping a much greater level of shaking (modified from USGS, 2008).

Terms in **bold** *are defined in the glossary.*

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help reduce the potential for induced seismicity related to the rate of injection of wastewater into disposal wells, scientists and others have developed some best-practice recommendations that would help prevent activation of stressed faults.

Natural vs. Induced Seismicity

Most seismic activity occurs when stress within the Earth's crust causes a fault or faults in subsurface rocks to slip and release enough energy to generate tremors. The vast majority of earthquakes are instigated naturally and generally happen where the Earth's **tectonic plates** interact. For the United States, that means most seismic activity is on the west coast along the boundary between the Pacific and North American plates.

Away from plate boundaries, earthquakes are most often triggered when geological processes, such as the deposition and erosion of surface rock, alter the balance of opposing stresses on subsurface rocks. Change in stress increases or decreases strain—the amount of rock deformation brought about by stress—which weakens the stability of faults confined by the stress. Faults may then slip and release pent-up energy, which rolls in waves through the Earth's crust (Ellsworth, 2013).

The U.S. Geological Survey estimates several million earthquakes occur around the world each year, although many small ones go undetected (USGS, 2014). Seismic events too small to be felt on the surface are known as microearthquakes, or microseisms.

The term "induced seismicity" is popularly used for any seismic activity linked to human activity. Some researchers, however, more narrowly define "induced seismicity" as seismicity caused solely by human activity and use the term "triggered seismicity" to define human activity that sets off a small transient event, which then instigates or contributes to a larger earthquake controlled by natural stresses (Cesca, 2012). Because the amount of influence a human activity has on a seismic event is hard to establish, that distinction is not always made. "Induced seismicity" is used throughout this circular to refer to any seismic event influenced by human activities.

Measuring Earthquake Magnitude and Intensity

Earthquakes can be measured in two different ways. One method is based on magnitude—the amount of energy released at the earthquake source. The other is based on intensity—how much the ground shakes at a specific location. Although several scales have been developed over the years, the two commonly used today in the United States are the Modified Mercalli scale, which measures intensity, and the moment magnitude scale, which measures magnitude (M), or size. The moment magnitude scale is now preferred to the older, more familiar Richter scale because it overcomes some of the limitations of the Richter scale (USGS, 2014).

Measurements on the moment magnitude scale are determined using a complex mathematical formula to convert motion recorded with a **seismometer** into a number that represents the amount of energy released during an earthquake. Energy released for each whole number measurement is about 31 times greater than that released by the whole number before (USGS, 2014). The smallest earthquakes recorded today have negative magnitudes (e.g., M -2.0) on the moment magnitude scale because the scale's range is based on that of the Richter scale, developed in the 1930s when monitoring equipment was less sensitive. Scientists are now able to detect earthquakes smaller in magnitude than the "0" used as the Richter scale baseline.

Measurements of intensity on the Modified Mercalli scale range from I to XII and are based solely on damage assessment and eyewitness accounts. Intensity measurements near the source of an earthquake are generally higher than those at a distance. They can also remain high in the direction the waves of energy travel and may be magnified in areas underlain by loose gravels and unconsolidated sediments. Determining intensity can be difficult in sparsely populated areas with few buildings because intensity is calculated largely on the effects that tremors have on human-made structures.

Although an earthquake's magnitude and intensity measurements are not precisely comparable, they can, in general, be correlated when intensity measurements nearest the epicenter are used in the comparison (fig. 2; Steeples and Brosius, 1996). Seismologists categorize earthquakes by their magnitude, not by their perceived intensity.

Earthquakes and the Potential for Induced Seismicity in Kansas

The majority of seismic events are microearthquakes, too small to be felt or to cause damage. The largest documented earthquake in Kansas, centered near Wamego east of Manhattan in 1867, rocked buildings, cracked walls, stopped clocks, broke windows, and reportedly caused ground to sink and endanger the bank of a canal near Carthage, Ohio (Parker, 1868). That earthquake was likely associated with the Nemaha Ridge, a 300-million-year-old buried mountain range extending roughly from Omaha to Oklahoma City. The Humboldt fault zone on the eastern boundary of the Nemaha Ridge is still slightly active (Steeples and Brosius, 1996). Based on damage and reports, the Wamego earthquake was estimated to have a magnitude of 5.2 (Niemi et al., 2004). Smaller faults and fault systems also have been identified in the state, mainly during oil and gas exploration, but none have been connected with large earthquakes.

At least 25 earthquakes in Kansas were documented in newspaper accounts and other sources between 1867 and 1976. A few of the later ones were recorded with seismic equipment. Between 1977 and 1989, the Kansas Geological Survey recorded more than 200 small earthquakes with a temporary seismic network as part of a study to identify seismic risk in the state (fig. 3). The monitoring equipment was sensitive enough to detect artillery fire at Fort Riley from 30 miles (50 km) away and large earthquakes as far away as Japan (Steeples and Brosius, 1996). Today, two seismic monitoring stations, operated by the U.S. Geological Survey, are located in Kansas. One is at Cedar Bluff Reservoir in western Kansas and the other is at the Konza Prairie Biological Station south of Manhattan in northeastern Kansas. The Oklahoma Geological Survey monitors earthquakes in Oklahoma at about a

Modified Mercalli Intensity Scale

- I Not felt except by a very few under especially favorable conditions. Below M 1 never felt.
- II Felt only by a few persons at rest, especially on upper floors of buildings.
- III Felt noticeably indoors but not always recognized as an earthquake. Vibrations similar to the passing of a truck.
- IV Felt indoors by many, outdoors by few. Dishes, windows, doors disturbed. Standing vehicles rocked.
- V Felt by nearly everyone. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
- VI Felt by all. Some heavy furniture moved. Falling plaster and chimneys. Damage slight.
- VII Damage varies from negligible in well-designed and/or built structures to consequential in poorly built and/or designed structures.
- VIII Damage slight in well-designed structures, consequential in ordinary buildings. Chimneys, factory stacks, and walls may fall.
- IX Damage considerable in well-designed structures. Partial collapse in substantial buildings. Buildings shifted off foundations.
- X Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.
- XI Few, if any, masonry structures remain standing. Bridges destroyed. Rails bent greatly.
- XII Damage total. Lines of sight and level are distorted. Objects thrown into the air.

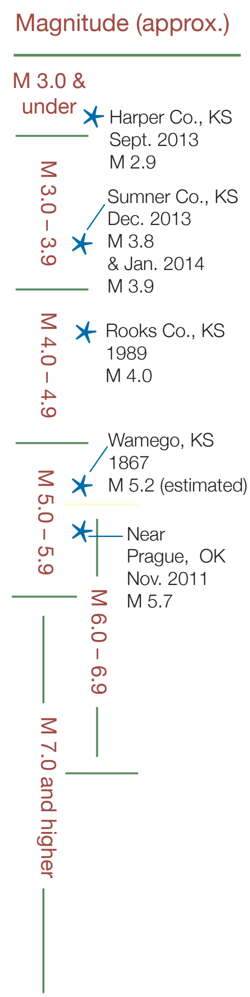

Figure 2—The magnitude (M), or size, of an earthquake does not correlate directly with intensity or damage, but an approximate comparison can be made between the magnitude and the felt intensity and damages—enumerated on the Modified Mercalli Intensity scale—near the epicenter (USGS, 2014).

dozen seismic stations, which also pick up some seismic events in Kansas.

Although oil and gas drilling and production, and corresponding wastewater injection, increased in south-central and western Kansas as interest in the Mississippian limestone play grew, the state has not experienced the same rise in seismic activity as neighboring Oklahoma. That may be due to the lower level of drilling and production activity in Kansas, differences in geology between the two states, or both. Oklahoma has historically had more natural earthquakes than Kansas. Also, the Oklahoma Geological Survey, which has been monitoring seismic activity for more than three decades, increased the size of its monitoring network in 2009 (Oklahoma Geological Survey, 2014). That led to the detection of a greater number of low-level earthquakes. Similar-sized events go unrecorded in Kansas.

In Oklahoma, a number of seismic episodes are suspected of being associated with induced seismicity. The largest, a M 5.7 earthquake, was recorded near Prague in 2011 (Keranen et al., 2013). Researchers are investigating whether injected fluid precipitated a M 5.0 foreshock that then triggered the M 5.7 mainshock and thousands of aftershocks along the Wilzetta fault system in central Oklahoma. The locations of the foreshock, mainshock, and a M 5.0 aftershock suggest that three separate portions of the complex fault system were activated (Sumy et al., 2014). A definitive connection between wastewater disposal and seismicity near Prague and several other Oklahoma locations with previous natural earthquake activity, however, has not been confirmed (Oklahoma Geological Survey, 2014).

Before 2013, the only documented instance of possible induced seismicity in Kansas occurred in 1989 when small earthquakes were recorded near Palco in Rooks County, about 30 miles northwest of Hays. The largest, a M 4.0, caused minor damage (Steeples and Brosius, 1996). Several injection wells used for the disposal of wastewater—extracted during conventional vertical oil well operations—were located in the area, and one well in particular may have been close to a deeply buried fault zone. Based on that well's injection history, local geology, and low level of prior earthquake activity in the area, scientists speculated that the seismicity could have been induced (Armbruster et al., 1989).

In 2013 and early 2014, several earthquakes were recorded in south-central Kansas in the vicinity of wastewater injection wells. In Harper County, a M 2.9 earthquake was recorded in September 2013, and in Sumner County earthquakes measuring M 3.8 and M 3.9 were recorded in December 2013 and February 2014, respectively (USGS, 2014). Whether oil activities played a role has not been determined. Naturally occurring earthquakes have been recorded in the region in the past, dating back to 1956. Further understanding of the complex subsurface geology in the region is needed to estimate what impact wastewater disposal might have had.

Geology, Faults, and Induced Seismicity

The Earth's crust is full of fractures and faults. Under natural conditions, widespread faults deep in the crust are able to sustain high stresses without slipping. In rare instances, pressure from wastewater injected into deep wells can counteract the frictional forces on faults and cause earthquakes (Hayes, 2012). In other words, fluid injected near a fault can, in effect, change pore pressure—the amount of pressure that fluid in a rock's pores exerts on the rock—allowing a fault to move.

For that to happen, a combination of human activities, natural conditions, and

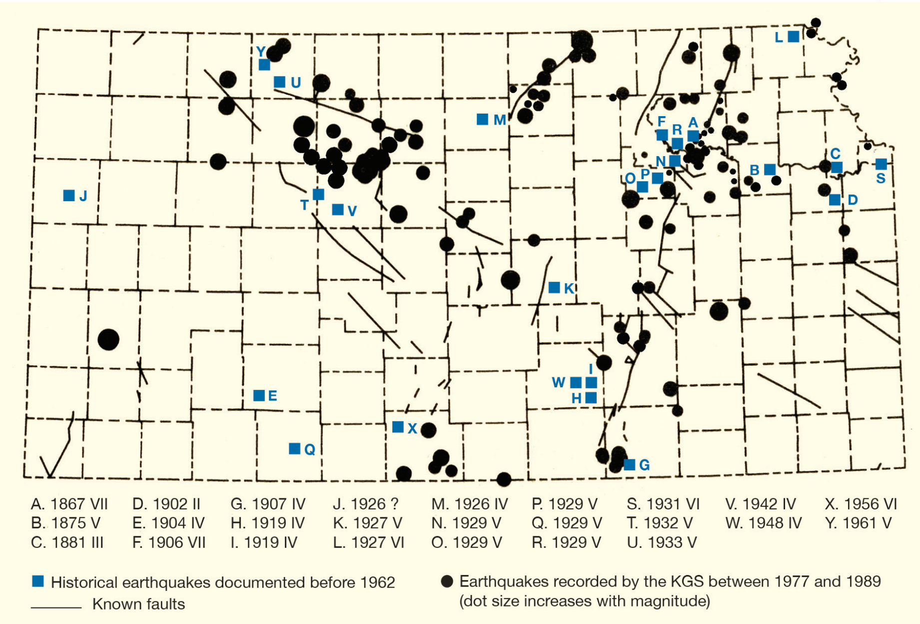

Figure 3—Historical earthquakes in Kansas before 1962 and seismic events recorded by the Kansas Geological Survey between 1977 and 1989 (modified from Steeples and Brosius, 1996).

geologic events must occur at the same time. To begin, the Earth's crust at the injection well site must be near a critical state of stress and an existing fault has to be nearby—within about 10 km (6 mi). Most faults are small and only generate small earthquakes. For a fault to slip and release energy, the location and orientation of the fault is critical. No matter how close a fault is to an injection well, its orientation within the ambient stress field and the properties of the surrounding subsurface rocks determine whether it has the potential to fail (National Research Council, 2012). If a fault does fail, the depth at which it ruptures influences its effect.

Even when all the natural conditions are favorable for induced seismicity near a disposal well, an earthquake is not a certainty. Under most circumstances, a significant amount of water must be injected over a prolonged period to activate a fault. As fluid is injected into the porous subsurface rock, the pore pressure would then have to increase to the point that it caused the volume of the rock to expand and destabilize a fault. Likewise, a decrease in pore pressure when fluid is extracted from rock can affect fault stabilization (National Research Council, 2012).

Many of the Earth's faults are in the Precambrian-age basement rock, which in Kansas lies beneath the deep and confined porous formations used for wastewater storage. Formed 500 million or more years ago, the basement rock is overlain by thousands of feet of **sedimentary rock**. Injected wastewater does not reach the basement rock, but if pressure created by the injection of fluid is transmitted into the basement through surrounding rocks, the potential for induced seismicity increases (Ellsworth, 2013).

Because of their depth, faults within the basement rock are hard to locate. Oil and gas exploration companies, which provide much of the data about the state's subsurface geology, rarely drill that deep. Seismic-reflection techniques used to identify subsurface rocks and faults are expensive and difficult to employ at that depth. Until more is known about the geology of Precambrian rocks, scientists will not be able to determine with certainty what effect wastewater disposal and other oil and gas field activities have on seismicity. A close spatial relationship between a wastewater disposal site and increased seismic activity, although it raises legitimate questions, does not prove cause and effect.

Hydraulic Fracturing, Wastewater Disposal, and Induced Seismicity

Hydraulic fracturing is at the center of the debate over induced seismicity in the United States. Microseisms, usually less than a magnitude of zero (M 0), do occur during hydraulic fracturing. In fact, geologists often record them to help identify the location of the newly made fractures and to measure stress. However, felt earthquakes have rarely been linked to hydraulic fracturing, and the ones that have been are relatively small (National Research Council, 2012). Two confirmed cases of felt seismic activity caused by hydraulic fracturing have been documented—a series of seismic events measuring up to M 2.3 in England in 2011 and a series of events ranging from M 2.2 to M 3.8 in a remote area of the Horn River Basin in British Columbia, Canada, between 2009 and 2011 (Holland, 2013; BC Oil and Gas Commission, 2012). Hydraulic fracturing also has been suspected of causing a M 2.9 earthquake in south-central Oklahoma in 2011, but that has not been confirmed (Holland, 2013).

Hydraulic fracturing is unlikely to cause felt seismicity because pressurization that occurs during the process usually lasts only a few hours and affects only rocks in the area immediately surrounding the well bore (Zoback, 2012). Wastewater disposal, in which fluids are injected over a longer period, is more often associated with induced seismicity. It has long been recognized that fluid injection can trigger earthquakes. Seismic activity following wastewater disposal at the **Rocky Mountain Arsenal** near Denver in the early 1960s and by water injection at the **Rangely oil field** in western Colorado in the late 1960s and early 1970s has been well studied (Zoback, 2012). However, although a large quantity of fluids is injected into hundreds of thousands of wells every year, only a small number of those wells have been associated with induced seismicity.

Wastewater Injection and Class II Disposal Wells

There are approximately 172,000 fluid-injection wells in the United States used to dispose of wastewater or to extract additional oil out of fields nearly depleted by traditional production methods. Of those wells, designated Underground Injection Control (UIC) Class II wells by the U.S. Environmental Protection Agency (EPA), about 20% are used for the disposal of saltwater that is produced along with oil and natural gas. In the disposal process, saltwater is injected into a deep formation selected for wastewater disposal and not into the formation from which it was originally produced. Non-potable water and chemicals used in the hydraulic fracturing process, which must be disposed of under State of Kansas requirements, are also injected into these wells.

Most of the rest of the Class II wells are used during **secondary** and **enhanced oil recovery** operations to squeeze additional oil out of underground rocks (EPA, 2012). For these operations, saltwater is commonly injected back into the formation from which it was produced. The injected water, ideally, moves toward the production well, transporting additional oil to the well.

The EPA regulates the licensing and operation of Class II disposal wells under the Safe Drinking Water Act or delegates authority to state agencies. The act is primarily designed to protect aquifers and other drinking water sources from contamination by injected fluids. Class II well operators submit a form annually indicating total monthly injected volumes and the maximum monthly recorded surface injection pressure.

The Kansas Corporation Commission (KCC) regulates the approximately 16,800 Class II wells in Kansas. About 5,000 of those wells are for wastewater disposal and 11,800 for secondary and enhanced oil recovery (KCC, 2014). Class II wells are used only for the injection of fluids associated with oil and gas production. Hazardous and non-hazardous industrial waste, regulated by the Kansas Department of Health and Environment (KDHE), is disposed of in UIC Class I wells. There are 47 Class I wells in Kansas (KDHE, 2012).

In general, waste fluids from oil and gas production in Kansas are injected back into deep subsurface formations "under gravity." That is, because the formations can accept substantial amounts of fluid, fluids are not injected under additional pressure but are simply allowed to flow into these rock formations under the force of gravity. Gravity injection limits the possibility of pressure build-up in the disposal formation and reduces the potential for fault slippage. Often, any pressure increases that do occur from gravity injection are limited to the vicinity of the well, although the effects of gravity injection may extend farther out than anticipated. Force from fluid weight, independent of injection pressure, also can have an impact.

When fluids are pumped into a rock formation under pressure, rather than being allowed to flow more slowly under the force of gravity, the added pressure may lower the frictional resistance between rocks along an existing fault system. That allows the rocks to slide. In the Rocky Mountain Arsenal case, where chemical fluid waste was injected under pressure numerous times, seismic activity continued for several years after injection was discontinued (National Research Council, 2012).

Preventive and Remedial Measures

The authors of a National Research Council (NRC) report and others have suggested steps that could be taken to alleviate induced seismicity associated with Class II wastewater disposal wells. The recommendations are based on a protocol advanced by the U.S. Department of Energy to address induced seismicity associated with enhanced geothermal systems. To establish a protocol in a specific location, an evaluation would first have to be made to determine whether following suggested recommendations would be feasible in that location. Enactment would require coordination between industry, government agencies, and the research community; monitoring seismicity and collecting data; assessing hazards and risks; and developing mitigation plans (National Research Council, 2012).

The protocols are often referred to as "traffic light" systems. Under the systems, operators would continue injection as long as earthquakes did not occur (green light), would slow injection rates and take other precautions if seismicity occurred (yellow light), and would abandon wells if seismicity associated with injection did not slow significantly or stop after precautions were taken (red light). In instances of suspected induced seismicity in Arkansas and Texas, injection was terminated and seismicity subsided (Zoback, 2012).

An essential element of the traffic light system is the capacity to monitor seismicity and collect data. The current monitoring network in the United States, with its widely spaced stations in Kansas and many other states, can detect moderate to large earthquakes. However, it is less effective at pinpointing the epicenters of, or even recording, smaller events far from monitoring stations. Determining whether a connection exists between recent earthquakes and fluid injection wells in Kansas and elsewhere will require increased and more densely spaced monitoring stations closer to injection sites. Increased access to data pertaining to the injection process, especially the volume of fluid injected over a specified period and the amount of pressure used to inject it, is also vital.

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Glossary

Enhanced oil recovery—Production of trapped oil left in the ground following primary and secondary recovery operations. Gases, steam, or chemicals are injected through a Class II fluid-injection well into a producing formation to lower the viscosity of the remaining oil and allow it to flow to the producing wells.

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.

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.

Mississippian limestone play—A complex group of oil and gas reservoirs within a shared geologic and geographic setting that extends from north-central Oklahoma into south-central and western Kansas.

Rangely oil field—An oil field in northwestern Colorado where the U.S. Geological Survey experimented with adjusting fluid pressure in injection wells between 1969 and 1973 to determine how changing injection rates could control seismicity.

Rocky Mountain Arsenal—Established in WWII, the RMA north of Denver was used by the U.S. Army to develop chemical weapons and was later used to produce agricultural chemicals. A deep injection well drilled there in 1961 for the disposal of hazardous chemicals was abandoned in 1966 after 13 earthquakes of M 4 or larger occurred. Earthquake activity declined but continued for two decades (Ellsworth, 2013).

Sedimentary rocks—Rocks formed from sediment, broken rocks, or organic matter, often deposited by wind or water and then compacted into layers after being buried under other sediment.

Secondary oil recovery—Production of residual oil and gas from fields whose reservoir pressures have dropped after initial, or primary, recovery using natural underground pressure and pumping. Water or gas is injected into a Class II fluid-injection well to increase pressure and force oil and gas to the surface through production wells.

Seismometer—Instrument used to measure ground motion and seismic waves generated by earthquakes and other seismic sources.

Tectonic plates—Massive, rigid plates in the lithosphere—Earth’s outer shell—that are propelled from below by molten rock and that interact with one another along their boundaries, which can cause seismic activity.

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.

Public Information Circular 36
April 2014

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Maxwell Wildlife Refuge and McPherson State Fishing Lake

McPherson businessman Henry Maxwell's family was among the earliest settlers of McPherson County. In 1943, his estate deeded 2,560 acres (4 square miles) of land six miles north of Canton to what was then the Kansas Forestry, Fish, and Game Commission. The land was to be used as a refuge for American bison—also popularly called American buffalo—elk, and other prairie species (fig. 1). Fencing and corrals were constructed, and in 1951 seven bison cows, three bison bulls, and a small herd of elk were released on the property. Today, with about 200 bison, the Maxwell Wildlife Refuge is home to the largest public bison herd in the state and a herd of about 50 elk. The primary use of the refuge, managed by the Kansas Department of Wildlife, Parks and Tourism (KDWPT), is wildlife viewing. The property also contains a state fishing lake.

In 1954, an earthen dam was constructed to impound the 46-acre lake on a 306-acre section of the deeded property designated for the McPherson State Fishing Lake. Stocked with channel catfish, largemouth bass, black crappie, bluegill, black bullhead, and several native sunfishes, the lake has fishing piers, fish feeders, a boat ramp, and camping and picnic facilities. It is managed by KDWPT in conjunction with the Maxwell Wildlife Refuge (KDWPT, 2014c). A 1.5-mile nature trail south of the lake winds through woodlands near Gypsum Creek and also provides a panoramic view of the surrounding prairie (Hauber and Young, 1999), and a shooting range is located on the southeastern corner of the refuge (fig. 2; KDWPT, 2014b).

Bison and Elk

Before the 19th century, bison populations ranged from central Mexico to northern Canada and nearly coast to coast from east to west. The bison population in the Great Plains

Figure 1—Bison at Maxwell Wildlife Reserve.

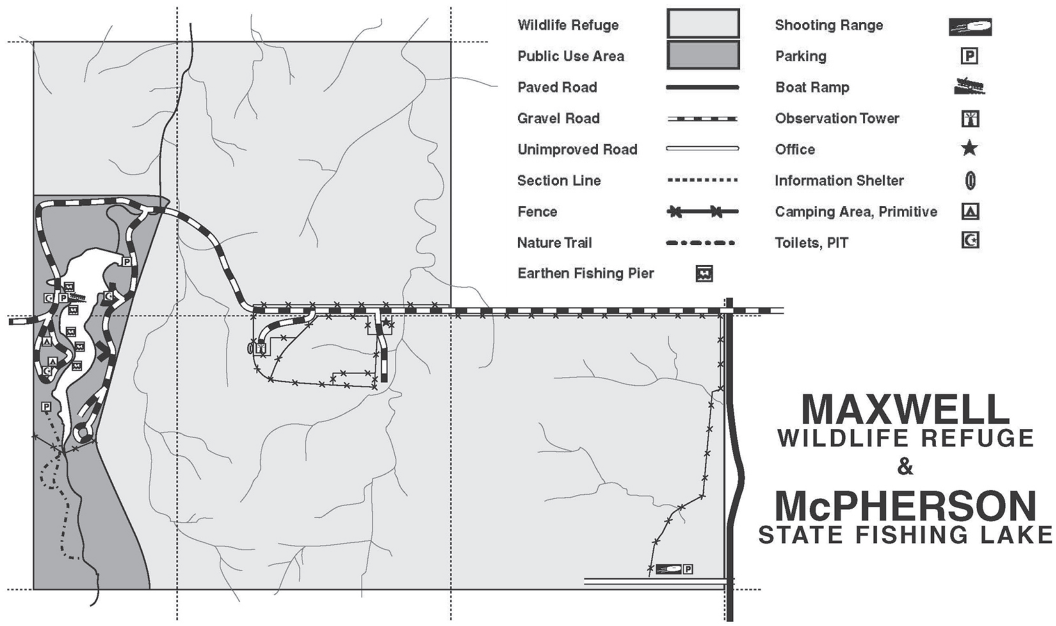

Figure 2—Maxwell Wildlife Reserve locator map (KDWPT, 2014b).

alone is estimated to have been between 25 and 40 million. In the 1820s, the population was already in decline, and by the 1880s fewer than 1,000 American bison remained. That total included members of both subspecies—the plains bison prevalent in Kansas and the Great Plains and the wood bison, whose range was mainly in Canada and Alaska. The American bison was saved from extinction when, between 1873 and 1904, individual citizens preserved six captive herds and the U.S. and Canadian governments put two remnant wild herds under protection at Yellowstone National Park and what would become Wood Buffalo National Park in Canada. All bison in the world today descend from fewer than 500 bison in those herds (Halbert et al., 2006). The 10 original bison at Maxwell Wildlife Refuge obtained in 1951 came from the Wichita Mountains National Wildlife Refuge in Oklahoma (KDWPT, 2014b).

Mature male plains bison generally weigh between 1,600 and 1,900 pounds but can weigh up to a ton and stand about 5 to 6 feet tall at the shoulder. Cows weigh 900 to 1,200 pounds and stand about 5 feet tall (fig. 3; KDWPT, 2014b). Bison can run up to 35 miles per.

By the early 1900s, native elk had disappeared from the state. In 1981, elk from the small herd introduced at Maxwell 30 years earlier were released at the Cimarron National Grassland in southwestern Kansas. Later in the 1980s, Maxwell elk were released on the Fort Riley Military Reservation. Today, elk in these free-ranging herds can be hunted by permit. They are primarily hunted on and around Fort

Figure 3—Female bison and calf.

Riley, but individual elk or small herds may be found at other locations around the state. Hunting is permitted everywhere except in Morton County (KDWPT, 2014a).

Geology, Vegetation, and Management

The Maxwell Wildlife Refuge is at the southeastern tip of the Smoky Hills, a region delineated by outcrops of sandstones deposited about 65 million years ago in Cretaceous-age seas. In the refuge, sandstone boulders litter the pastures and small outcrops of Dakota Formation sandstone are visible along some of the ridge tops (Hauber and Young, 1999). The majority of the surface rock and sediment in the area is much younger, having formed in the past one million years (Buchanan and McCauley, 2010).

Mainly a warm-season mixed grass prairie, the refuge is dominated by big bluestem, little bluestem, Indiangrass, switchgrass, and sideoats grama. Forbs are abundant and numerous clumps of native sand plum and smooth sumac are scattered throughout the area. Soils are mostly moderately deep sandy loams. Principal management techniques are prescribed fire and grazing by bison and elk. Herd sizes are managed to maintain proper grazing levels, and KDWPT holds a public auction annually to sell surplus bison (KDWPT, 2014b).

Friends of Maxwell, a local nonprofit organization, was formed in 1993 to provide educational opportunities at the refuge and to promote preservation of the environment and the area's history. The organization gives guided tram tours on request (Friends of Maxwell, 2011).

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Thursday, June 5, 2014

6:00 a.m.	Breakfast—Regent Room (2nd Floor), Ambassador Hotel (starting time is informal)
7:30 a.m.	**Bus leaves Ambassador Hotel for Site 12** Bus Session—Legislative Update: Harmful Algal Blooms *John Mitchell,* Director, Division of Environment, Kansas Department of Health & Environment
8:15 a.m.	**SITE 12**—Cheney Reservoir Cyanobacteria Water Quality Assessment and Monitoring *Jennifer L. Graham,* U.S. Geological Survey sUAV Monitoring of Harmful Algal Blooms *Deon van der Merwe,* Associate Professor, Head of Toxicology, Kansas State University
9:30 a.m.	Restroom Break, Cheney Reservoir
9:45 a.m.	Bus departs for Site 13
10:30 a.m.	**SITE 13**—K&O Railroad, Wichita to Hutchinson Passenger, Agriculture, and Industrial Rail Transportation *Secretary Mike King,* Kansas Department of Transportation *Pat Cedeno,* Vice President of Sales & Marketing, Watco Companies, LLC Geotechnical Concerns for Roadway Construction Over the Equus Beds Aquifer *Bob Henthorne,* Chief Geologist, Kansas Department of Transportation
10:30 a.m.	Board K&O Railroad, Wichita
12:00 p.m.	Lunch, provided courtesy K&O Railroad
1:00 p.m.	Depart K&O Railroad, Hutchinson
1:15 p.m.	Bus departs for Fairfield Inn & Suites, Hutchinson
1:30 p.m.	End Field Conference at Fairfield Inn & Suites, Hutchinson

Harmful Algal Blooms

Harmful Algal Blooms (HABs) are caused by the rapid accumulation of a type of bacteria called cyanobacteria, commonly known as "blue-green algae," that can quickly increase in surface water. Although they are not true algae, cyanobacteria are often referred to as "blue-green algae" because, like plants, they use photosynthesis to convert light energy to chemical energy (UCMP, 2014). Under the right conditions, cyanobacteria bloom and produce taste-and-odor compounds that affect drinking-water supplies or toxins that can cause illness and death in humans and animals (fig. 1; Graham, 2006; KDHE, 2014).

A HAB may look like foam, scum, or paint floating on the water and be blue, bright green, brown, or red. HABs are affected by many different environmental variables, including water quality, hydrology, nutrients, light, and weather conditions (KDHE, 2014).

Cyanobacteria

Cyanobacteria behave much like simple aquatic plants. They live in marine and fresh water and are photosynthetic. They are small and usually unicellular, though colonies can grow large enough to see (fig. 2). Certain cyanobacteria produce taste-and-odor compounds, mostly geosmin and 2-methylisoborneol (MIB), which impart an earthy and musty odor to water that is unpalatable for drinking. The compounds are considered to be algal byproducts with no known cellular function. Taste-and-odor compounds may also signal the presence of toxic algae (Christensen et al., 2006).

Many cyanobacteria species also produce potent toxins, called cyanotoxins, that affect fundamental cell processes in many different organisms. Cyanotoxins implicated in human illness include microcystin, cylindrospermopsin, anatoxin, β-methylamino alanine (BMAA), and saxitoxin (USGS, 2014)

Health Risks

A HAB can produce toxins in water bodies used for recreation and public water supply. HABs in Kansas have been implicated in human illnesses and animal deaths after contact or ingestion of water with cyanobacteria cells or cyanotoxins. Small children have a higher risk of acute exposure. The most common health complaints include vomiting, diarrhea, skin rashes, eye irritation, and respiratory symptoms (KDHE, 2012).

Figure 1—Cyanobacteria bloom at Cheney Reservoir, June 2003. Photo courtesy of KDHE.

Figure 2—Cyanobacteria drift with wind and wave action and can accumulate along near-shore areas. Photo courtesy J. L. Graham.

unsafe for humans and animals under these conditions. Swimming activities and watering of animals or livestock are discouraged and should be avoided, but boating and fishing are permitted. Warning signs and information are posted at points of entry to the water, such as beaches, marinas, and boat ramps. The advisory will be sent to media outlets, local health departments, veterinarians, hospitals, and public water suppliers with water intakes on the affected water body.

A Public Health Warning is issued when microcystin toxin is greater than or equal to 20 ug/L or cyanobacteria counts are greater than or equal to 100,000 cells/mL. A warning may also be issued if visible cyanobacteria scum is present. The water body is unsafe for humans and animals under these conditions. All direct-water contact activities and watering of animals or livestock is prohibited. Warning signs and information are posted at points of entry to the water, such as beaches, marinas, and boat ramps. The advisory will be sent to media outlets, local health departments, veterinarians, hospitals, and public water suppliers with water intakes on the affected water body.

KDHE will routinely sample and test water bodies under either an advisory or warning until cyanobacteria are under the 4 ug/L and 10,000 cell/mL advisory threshold (KDHE, 2012).

KDHE HAB Policy

The Kansas Department of Health and Environment (KDHE) adopted policy guidelines in April 2013 to address public health risks associated with HABs. The policy was established from KDHE data collection and epidemiological study of HABs in Kansas and outlines KDHE response and lake restrictions in the event of a HAB. The policy addresses publicly accessible or public drinking-water supplies only. Non-public water owners with HABs will be directed to the Kansas State Veterinary Diagnostic Laboratory in Manhattan, Kansas, for identification of cyanobacteria in a water sample.

After notification and alert of a potential HAB on a public water body, KDHE performs sampling and analysis to verify the cyanobacteria cell count and microcystin toxin quantity. Upon confirmation, KDHE issues either a Public Health Advisory or Public Health Warning. Any response actions needed to restrict public exposure is the responsibility of the water body's governing authority, although KDHE will provide examples of alert, warning, or closure signs.

A Public Health Advisory is issued when microcystin toxin is 4 ug/L to less than 20 ug/L or cyanobacteria counts are 20,000 to less than 100,000 cells/mL. A water body is potentially

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The Short Line Rail Industry and the Kansas and Oklahoma (K&O) Railroad

The earliest U.S. commercial railroads, starting in 1826, were all short lines built to serve local communities and commerce. As local lines began to interconnect and routes got longer, states became involved in rail development and the federal government lent support to the western trans-continental railroads. Railroads that were not incorporated into the larger system became the core of the short line railroad industry. In the 1920s, trucking competition increased as the U.S. highway system grew and short line rail transportation declined.

In 1976, with the passage of the 4R Act by Congress, the United States Railroad Association was established to oversee reorganization of multiple, bankrupt eastern railroads into Conrail. Under the law, marginal branch lines that operators had been required to keep running could now be sold off to new, entrepreneurial short line companies, which often got support from state and local governments. In 1980, the Staggers Rail Act significantly deregulated the rail industry, giving major railroads the opportunity to sell unproductive branches, greatly expanding the short line railroad industry. Today there are 550 short line companies in the United States. In 2004, a new tax incentive program was established, and Congress provided some assistance for the short line industry to upgrade tracks so that companies could transport heavier and more cost-efficient freight loads (ASLRRA, 2014).

In early 2014, the Kansas Department of Transportation (KDOT) established the Kansas Freight Advisory Committee. The committee advises KDOT and the Kansas Turnpike Authority and helps identify freight transportation issues, priority highway and rail freight corridors of significance, and multimodal freight infrastructure improvement needs (KDOT, 2014).

Figure 1—K&O train in Wichita (Watco Companies, 2014).

Watco Companies and the K&O Railroad

Watco Companies, LLC, based in Pittsburg, Kansas, provides freight rail, switching, mechanical, warehousing, real-estate, equipment leasing, intermodal, terminal, and port services. The company was founded in 1983 with an industrial switching operation in Louisiana. Soon after, a railcar repair shop was opened in Coffeyville, Kansas. Now as one of the largest short line operators in the country with 30 railroads in 21 states and Australia and 4,500 miles of track, Watco transports agricultural products, infrastructure metals and minerals, lumber and forest products, chemicals, paper, plastics, energy products, and other commodities (Watco Companies, 2014).

Watco's Kansas and Oklahoma (K&O) Railroad is the largest short line railroad in Kansas and carries more than 50,000 carloads annually of both agricultural commodities and industrial products (fig. 1). It began operations in July 2001 and now has 840 miles of track that services dozens of towns in central and western Kansas (fig. 2). Watco also operates the South Kansas and Oklahoma Railroad (SKOL) administered from Cherryvale, Kansas. SKOL carries more than 50,000 carloads annually on 404 miles of track (Watco Companies, 2014).

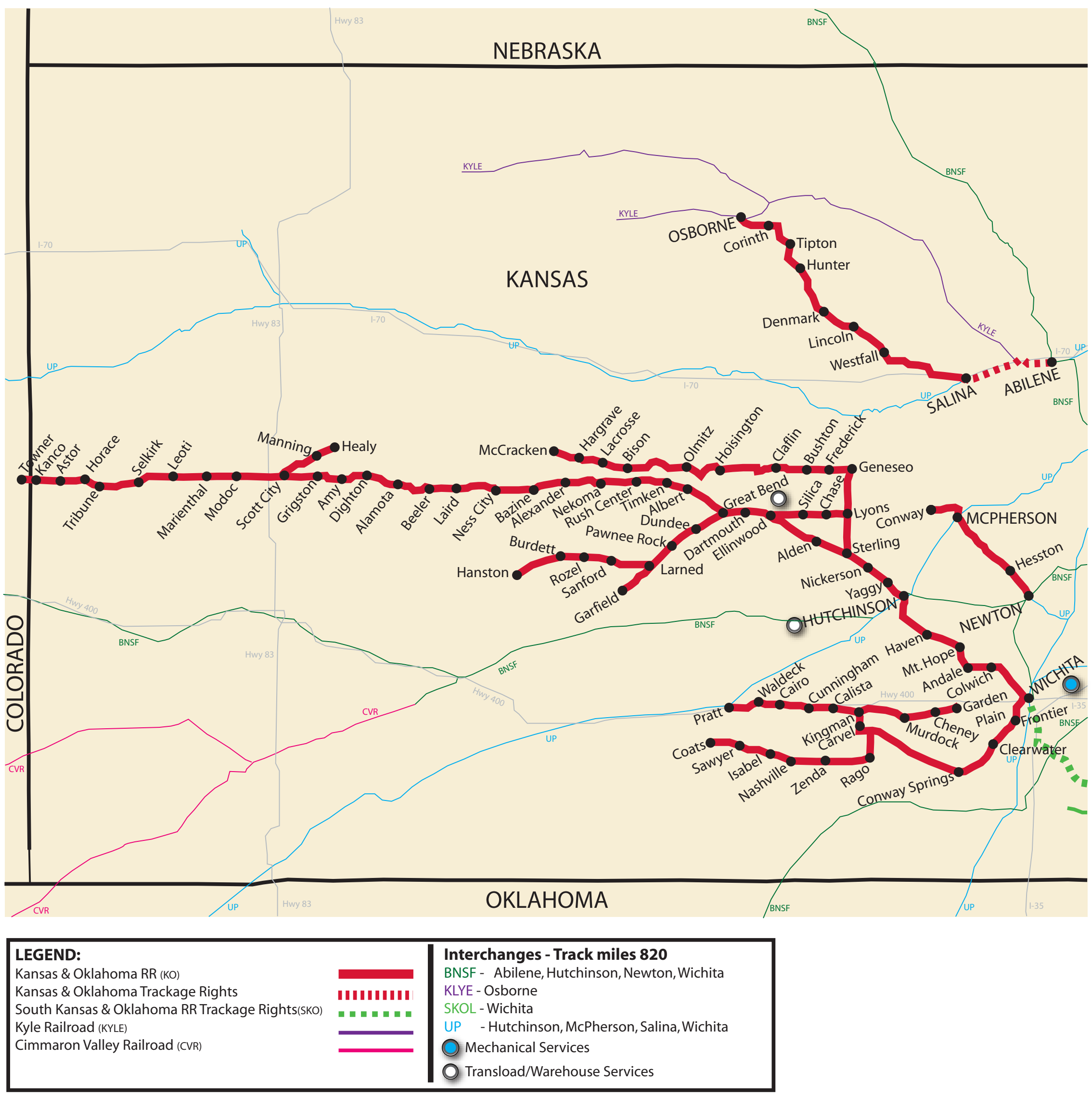

Figure 2—Kansas and Oklahoma (K&O) Railroad routes (Watco Companies, 2014).

Sources

ASLRRA, 2014, American Short Line and Regional Railroad Association, http://www.aslrra.org/home/index.cfm.

KDOT, 2014, Kansas Freight Advisory Committee: Kansas Department of Transportation, http://www.ksdot.org/burRail/rail/KFAC.asp.

Watco Companies, 2014, http://www.watcocompanies.com.

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