Kansas Field Conference
August 17–18, 2016

West-Central Kansas

Natural Resources, Economics, and Decisions for the Future

Field Guide

Susan Stover and Catherine S. Evans

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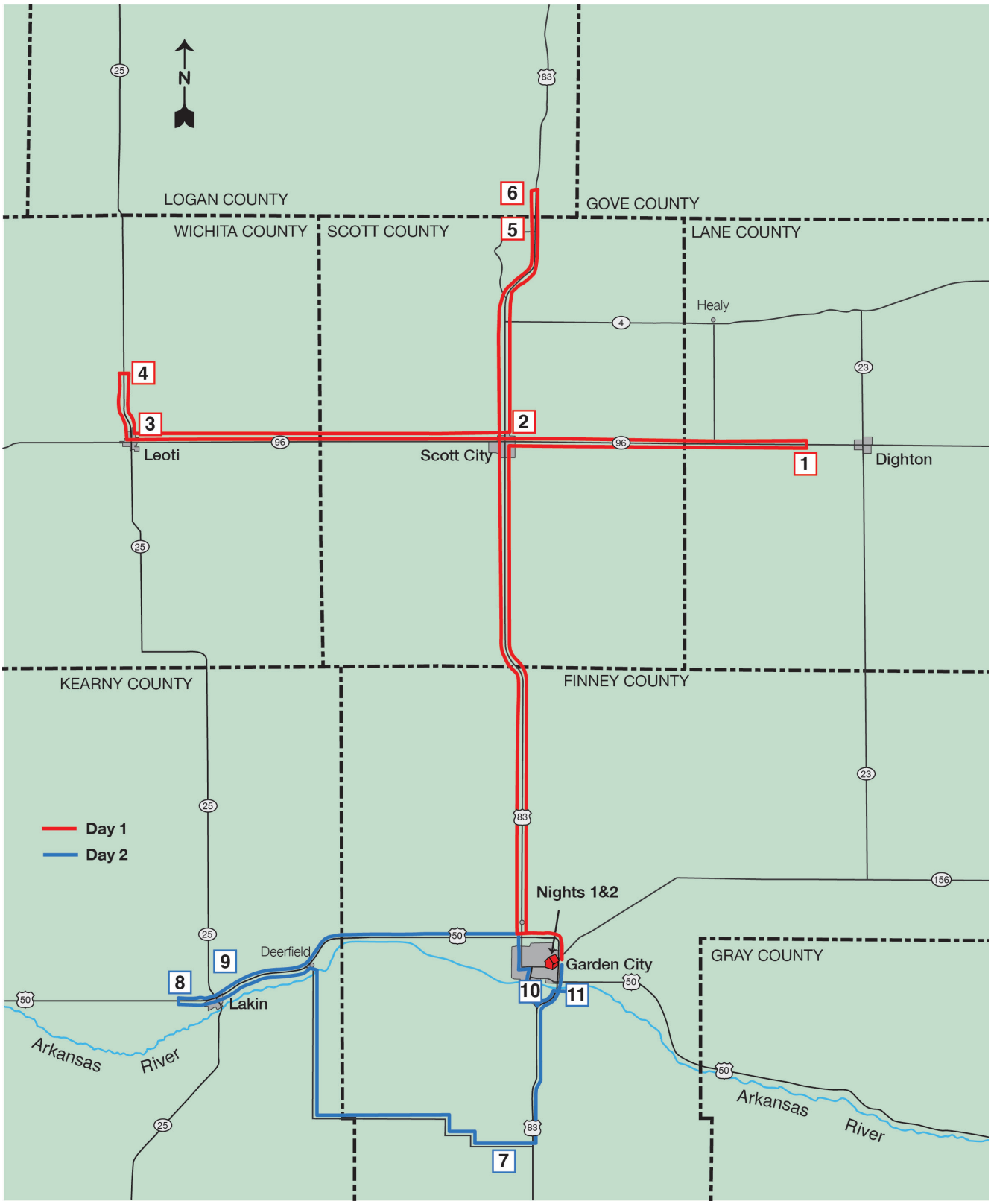
Kansas Geological Survey
Geology Extension
The University of Kansas
1930 Constant Avenue
Lawrence, KS 66047-3724
785-864-3965
www.kgs.ku.edu

Cover photo: Lake Scott State Park from Friends of Lake Scott State Park



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Participants

Steve Adams, Chief of Planning, Kansas Department of Wildlife, Parks and Tourism

Rick Billinger, Representative, Goodland

Bill Busby, Associate Scientist, Kansas Biological Survey

John Carmichael, Representative, Wichita

Tom Christy, KGS Advisory Council (GSAC) member

Bud Estes, Representative, Dodge City

Marci Francisco, Senator, Lawrence

Raney Gilliland, Director, Kansas Legislative Research Department

Greg Graff, Kansas Water Authority

Gary Harshberger, Chair, Kansas Water Authority

Tom Hawk, Senator, Manhattan

Randy Hayzlett, Kansas Water Authority member

Dave Heinemann, Past Chair, KGS Advisory Council (GSAC)

Chad Hendricks, KGS Advisory Council (GSAC) member

Larry Hibbard, Representative, Toronto

Don Hineman, Representative, Dighton

Kyle Hoffman, Representative, Coldwater

Mitch Holmes, Senator, St. John

Robin Jennison, Secretary, Kansas Department of Wildlife, Parks and Tourism

Tamera Lawrence, Assistant Revisor of Statutes, Kansas Office of Revisor of Statutes

Lane Letourneau, Water Appropriation Program Manager, Division of Water Resources, Kansas Department of Agriculture

Greg Lewis, Representative, St. John

Brad Loveless, Executive Director, Environmental Services, Westar Energy

Karma Mason, Kansas Water Authority member

Peggy Mast, Representative, Emporia

John Mitchell, Director, Division of Environment, Kansas Department of Health and Environment

Ralph Ostmeyer, Senator, Grinnell

Larry Powell, Senator, Garden City

Michael Ramsey, KGS Advisory Council (GSAC) member

Rob Reschke, Executive Director, Division of Conservation, Kansas Department of Agriculture

Richard Rockel, Water Resource Planner, Kansas Water Office

Melissa Rooker, Representative, Fairway

Mark Rude, Executive Director, Southwest Kansas Groundwater Management District 3

Tracy Streeter, Director, Kansas Water Office

Susie Swanson, Representative, Clay Center

Mary Jo Taylor, Superintendent of Schools, Stafford

Larry Thompson, Director of Operations, Kansas Department of Transportation

Jim Ward, Representative, Wichita

Julie Westhoff, KGS Advisory Council (GSAC) chair

John Wheeler, Former Finney County Attorney

Kansas Geological Survey Staff

Susan Stover

Rex Buchanan

Cathy Evans

Bob Sawin

Biographical Information

Steve Adams
Chief of Planning
Kansas Department of Wildlife, Parks and Tourism
1020 S. Kansas Avenue
Topeka KS 66612
785-296-2281 Business
steve.adams@ksoutdoors.com
Responsibilities and Experience: KDWPT, 1989–present. Education: Northeastern State University, BS; Oklahoma State University, MS

Rick Billinger
Kansas House of Representatives, District 120
Box 594
Goodland KS 67735
785-899-4700
rb_rick@hotmail.com
Responsibilities and Experience: Member, Pensions and Benefits, Commerce, Labor, and Economic Development, and Insurance and Financial Institutions committees; Rural Caucus vice chair. Education: Fort Hays State University, General Business

Bill Busby
Associate Scientist
Kansas Biological Survey
2101 Constant Ave
Lawrence KS 66047
785-864-1530 Business
Responsibilities and Experience: Associate scientist, Kansas Biological Survey; Courtesy associate professor, KU Department of Ecology and Evolutionary Biology; Zoologist with the Kansas Natural Heritage Inventory at KBS and conducts research on animals of conservation concern, particularly grassland birds and endangered species; More than 25 years of field experience in vertebrate ecology of the Great Plains; Author of more than 50 scientific publications; Senior author of Kansas Breeding Bird Atlas; Kansas coordinator for the North American Breeding Bird Survey. Education: Colorado College, BA, Biology; University of Florida, PhD, Zoology

John Carmichael
Kansas House of Representatives, District 92
1475 N Lieunett St
Wichita KS 67203
316-264-3300 Business
316-250-0969 Cell
john.carmichael@house.ks.gov
Responsibilities and Experience: Member, Energy and Environment, Local Government, and Elections committees; Attorney, Conlee, Schmidt & Emerson, LLP. Education: University of Kansas, BGS; Wichita State University, BS; University of Kansas, JD

Tom Christy
KGS Advisory Council
1835 Wall St.
Salina KS 67401
785-825-1842 Business
christyt@geoprobe.com
Responsibilities and Experience:
Vice President, Geoprobe System, with responsibilities in soil sensor design, sampling tools design, and international sales; Kansas Geological Survey Advisory Council (GSAC) member. Education: Missouri Institute of Science and Technology, BS, Civil Engineering

Bud Estes
Kansas State Representative, 119th District
1405 Elbow Bend
Dodge City KS 67801
620-338-1381
bud.estes@btiequip.com
Responsibilities and Experience: Member, House Agriculture and Natural Resources, Health and Human Services, and Federal and State Affairs committees; Owner and board of directors, BTI (John Deere dealership); JAG-Kansas (Jobs for America's Graduates) board of directors; Chairman, Dodge City Development Corporation board of directors; Commissioner representing state of Kansas on Midwest Passenger Railway Commission. Education: Fort Hays State University, BS, Business

Marci Francisco
Kansas State Senate, District 2
1101 Ohio Street
Lawrence KS 66044
785-766-1473 Cell
785-842-6402 Home
maf@sunflower.com
Responsibilities and Experience: Ranking Minority Member, Senate Agriculture, Natural Resources, and Utilities committees; Member, Senate Ways and Means committee; Member, Joint Committee on State Building Construction. Education: University of Kansas, BA, Environmental Design, and BA, Architecture

Raney Gilliland
Director
Kansas Legislative Research Department
300 SW 10th Ave, Rm 68–West
Topeka KS 66612-1504
785-296-7878 Business
raney.gilliland@klrd.ks.gov
Responsibilities and Experience: Director, KLRD; Staff for House Agriculture and Natural Resources and Joint Committee on Administrative Rules and Regulations. Education: Kansas State University, BS, Political Science; Kansas State University, MS, Agricultural Economics

Greg Graff
Kansas Water Authority
PO Box 1587
Leoti KS 67861
620-375-4676 Business
gkgraff@fairpoint.net
Responsibilities and Experience: Farmer; Member, Kansas Wheat Growers, Kansas Sorghum Growers, and Kansas Corn Growers; Groundwater Management District #1 board; Kansas Water Authority (representing GMD 1, 3, and 4); Western Kansas Weather Modification Program board; Garden City Experiment Station advisory board; Tribune Experiment Station advisory board; Kansas Grain Sorghum Commission board. Education: Kansas State University, BS

Gary Harshberger
Chair
Kansas Water Authority
1302 University
Dodge City KS 67801
620-338-0888 Business
gary@he.kscoxmail.com
Responsibilities and Experience: Chair, Kansas Water Authority; Operates Harshberger Enterprises, Double H Farms, Inc., Harshberger Land LLC, Hatcher Holdings, and Harshberger Seeds; Director, Farm Credit of Southwest Kansas; Board of Directors, Conestoga Energy Holdings, LLC. Education: Dodge City Community College, AA, Science; Kansas State University, BS, Electrical Engineering

Tom Hawk
Kansas State Senate, District 22
2600 Woodhaven Ct
Manhattan KS 66502
785-537-8000 Business
785-341-4162
tom@tomhawk.com
Responsibilities and Experience: Ranking Democrat, Financial Institutions and Insurance committee; Member, Natural Resources, Agriculture, and Utilities committees. Education: Kansas State University, BS, MS, and PhD

Randy Hayzlett
Kansas Water Authority
1112 Road T
Lakin KS 67860
620-355-7499 Business
hayzlett@pld.com
Responsibilities and Experience: Represents Kansas senate president on Kansas Water Authority; Past president and current board member, Southside Ditch Association; Vice chair, Arkansas River Compact Administration; Chair, Arkansas River Litigation Fund Advisory Committee; Board member, Southwest Kansas GMD 3; Owner/operator of irrigated farm and cow-calf operation. Education: Attended Fort Hays State University

Dave Heinemann
Past Chair, Kansas Geological Survey Advisory Council (GSAC)
3826 SW Cambridge Court
Topeka KS 66610
785-213-9895
daveh123@cox.net
Responsibilities and Experience: Legislative representative for American Cancer Society, American Heart Association, High Plains Public Radio, Schools for Quality Education, and Smoky Hills Public Television. Education: Augustana College, BA; University of Kansas; Washburn Law School, JD

Chad Hendricks
KGS Advisory Council
885 Road 25
Bird City KS 67731
785-734-7001
chad@hendricksfarms.com
Responsibilities and Experience: Farmer/ irrigator; Director, Farm Credit of Western Kansas; FSA county committee member; KGS Advisory Council (GSAC) member. Education: Kansas State University, BS, Agriculture Economics; Purdue University, MS, Agriculture Economics

Bob Henthorne
Chief Geologist
Kansas Department of Transportation
2300 Van Buren Street
Topeka KS 66611
785-291-3860
roberth@ksdot.org
Responsibilities and Experience: Chief geologist; Geologist member and elected secretary, Kansas State Board of Technical Professions; President, National Association of State Boards of Geology. Education: University of Kansas, BS

Larry Hibbard
Kansas House of Representatives, District 13
858 EE 75 Road
Toronto KS 66777
620-583-3334 Business
620-637-2454
larryphibbard@gmail.com
Responsibilities and Experience: Lifetime rancher; Member, Agriculture and Natural Resources, Agriculture and Natural Resources Budget, and Utilities and Telecommunications committees. Education: Kansas State University, Animal Science

Don Hineman
Kansas House of Representatives, District 118
116 S. Longhorn Rd
Dighton KS 67839
620-397-2504 Business
620-397-3242
dhineman@st-tel.net
Responsibilities and Experience: Member, Taxation, Federal and State Affairs, and General Government Budget committees. Farmer in partnership with son in Lane County; Rancher, 1973–2010; Part owner and director, Lane County Feeder, Inc., 1998–2011. Education: University of Kansas, BS; University of Michigan, MBA & MS, Natural Resources

Kyle Hoffman
Kansas House of Representatives, District 116
1318 Avenue T
Coldwater KS 67029
620-635-5844
kyle@kylehoffman.net
Responsibilities and Experience: Chair, Agriculture Budget Committee; Member, Judiciary and Appropriations committees. Education: Kansas State University, BS, Agriculture

Mitch Holmes
Kansas Senate, District 33
211 SE 20th Ave.
St. John KS 67576
620-549-3444 Business
620-234-5834
mitch.holmes@senate.ks.gov
Responsibilities and Experience: Chair, Ethics and Elections Committee; Member, Agriculture, Local Government, Public Health and Welfare, and Federal and State Affairs committees; Member, Select Committee on KPERS and Joint Committee on Kansas Security; Member, Kansas Board of EMS and Rural Health Task Force. Education: Hutchinson Community College, AA, Music Education; Friends University, BS, Human Resource Management; DePaul University, Computer Programming

Robin Jennison
Secretary
Kansas Department of Wildlife, Parks and Tourism
1020 S. Kansas Avenue, Room 200
Topeka KS 66612
785-296-2282 Business
robin.jennison@ksoutdoors.com
Responsibilities and Experience: Secretary, Kansas Department of Wildlife, Parks and Tourism, 2011–present. Education: Fort Hays State University, Animal Science

Tamera Lawrence
Assistant Revisor of Statutes
Kansas Office of Revisor of Statutes
Statehouse
300 SW 10th, STE 24-E
Topeka KS 66612
785-296-2321 Business
tamera.lawrence@rs.ks.gov
Responsibilities and Experience: Staff, Senate Natural Resources Committee and House Education, Veterans, Military and Homeland Security committees. Education: University of Kansas, BS, JD

Lane Letourneau
Water Appropriation Program Manager
Kansas Department of Agriculture, Division of Water Resources
1320 Research Park Dr.
Manhattan KS 66502
785-564-6700 Business
lane.letourneau@kda.ks.gov
Responsibilities and Experience: Manager, Water Appropriation Program, which administers the Kansas Water Appropriation Act (provides a framework for water allocation to ensure full beneficial use of water resources while protecting private property rights); Vision Team member. Interests: hunting, fishing, calf roping, and outdoorsman. Education: Fort Hays State University, BS, Geology

Greg Lewis
Kansas House of Representatives, District 113
910 NE 30th Ave.
St. John KS 67576
620-546-4177 Cell
620-458-3541 Home
greg.lewis@house.ks.gov
Responsibilities and Experience: Fourth generation farmer/rancher. Member, Agriculture and Natural Resources, Local Government, and Vision 2020 committees; Served eight years on St. John-Hudson School Board, three years as president. Education: Kansas State University, BA, Landscape Architecture

Brad Loveless
Executive Director
Environmental Services
Westar Energy
818 S Kansas Avenue
Topeka KS 66601
785-575-8115 Business
brad.loveless@westarenergy.com
Responsibilities and Experience:
Responsible for air, water, waste, environmental compliance as well as environmental protection, infrastructure siting, impact avoidance; Member, Kansas Forest Service Advisory Council, Kansas Water Authority; Chair, Kansas Alliance for Wetlands and Streams (KAWS). Education: Ohio State University, BS; University of Kansas, MS

Karma Mason
Kansas Water Authority
215 Laura
Wichita KS 67211
316-264-7050 Business
kmason@isienvironmental.com
Responsibilities and Experience: CEO/ President of iSi Environmental, a full-service consulting and facility support firm with more than 150 employees; Serving fourth term on the Kansas Water Authority. Education: Wichita State University, MS, Geology

Peggy Mast
Kansas House of Representatives, District 76
765 Road 110
Emporia KS 66801
785-291-3500 Business
620-343-2465
pmast@me.com
Responsibilities and Experience: Speaker Pro-Tem; Vice Chair, Social Services Budget Committee; Member, Legislative Post-Audit. Education: Butler County Community College, Emporia State University, and Flint Hills Tech College

John Mitchell
Director
Division of Environment
Kansas Department of Health and Environment
1000 SW Jackson, Suite 400
Topeka KS 66612
785-296-1535 Business
jmitchell@kdheks.gov
Responsibilities and Experience: Direct day-to-day operations of all environmental programs within KDHE, Division of Environment—air, water, waste, remediation, district office, and laboratories; Division has about 400 employees statewide; At KDHE for more than 36 years. Education: University of Kansas, BA, Biology and Microbiology; University of Kansas, MS, Environmental Health Science

Ralph Ostmeyer
Kansas State Senate, District 40
P.O. Box 97
Grinnell KS 67738
785-673-9083 Cell
rostmey@gmail.com
Responsibilities and Experience: Member, Agriculture, Natural Resources, Corrections and Juvenile Justice, and Joint Rules and Regulations committees; Chair, Federal and State Affairs Committee; Farmer and rancher. Education: Fort Hays State University

Larry Powell
Kansas State Senate, District 39
2209 Grandview Dr E
Garden City KS 67846
620-506-7161
lpowell18@cox.net
Responsibilities and Experience: Chair, Natural Resources Committee; Member, Ways and Means, Agriculture, Utilities, and Assessment and Taxation committees; Ranch manager/owner. Education: Garden City Community College, AA, Agriculture

Michael Ramsey
KGS Advisory Council
8105 N. Jennie Barker Rd
Garden City KS 67846
620-276-3203 Business
ramsey.hmbcr@sbcglobal.net
Responsibilities and Experience: Attorney; Areas of practice: water law, oil and gas, real estate, business, estate planning, and taxation. Co-own farm; Kansas Geological Survey Advisory Council (GSAC). Interests: Natural sciences, birds, native plants, hiking, and camping. Education: Kansas State University, BS, Agricultural Engineering; University of Arizona, MS, Water Resources and Irrigation; University of Kansas, JD

Rob Reschke
Executive Director
Division of Conservation
Kansas Department of Agriculture
1320 Research Park Drive
Manhattan KS 66502
785-564-6621 Business
robert.reschke@kda.ks.gov
Responsibilities and Experience: Executive Director, Division of Conservation—administer cost-share and incentive programs focusing on soil and water conservation and associated best management practices. Education: Emporia State University, BSE, Biology

Richard Rockel
Water Resource Planner
Kansas Water Office
900 SW Jackson, Suite 404
Topeka KS 66612
785-296-0876 Business
richard.rockel@kwo.ks.gov
Responsibilities and Experience: Water planner for Upper Republican and Upper Smoky Hill regions; Formerly, water quality enforcement at Kansas Department of Health and Environment Bureau of Water and supervisor of new water appropriations unit at Kansas Department of Agriculture, Division of Water Resources. Education: University of Kansas, BS, Environmental Geology

Melissa Rooker
Kansas House of Representatives, District 25
4124 Brookridge Dr
Fairway KS 66205
913-961-1555 Cell
913-384-7371 Home
melissa@melissarooker.com
Responsibilities and Experience: Member, Transportation, Transportation & Public Safety Budget, and Vision 2020 committees; Vice president of development for Clint Eastwood, Malpaso Productions, 15 years; Community volunteer; Member, Kansas Forestry Advisory Council. Education: University of Kansas, BFA, Art History

Mark Rude
Executive Director
Southwest Kansas Groundwater Management District 3
2009 E. Spruce St
Garden City KS 67846
620-275-7147 Business
mrude@gmd3.org
Responsibilities and Experience: Direct activities of GMD3. Education: Wichita State University, BS

Tracy Streeter
Director
Kansas Water Office
900 SW Jackson, Suite 404
Topeka KS 66612
785-296-3185 Business
tracy.streeter@kwo.ks.gov
Responsibilities and Experience: Agency head since 2004; 30 years state service; Western States Water Council; MoRAST; Chair, Governor's Drought Response Team; Chair, Kansas GIS Policy Board; Private pilot. Education: Highland Community College, AA; Missouri Western State University, BS, Agricultural Economics; University of Kansas, MPA

Susie Swanson
Kansas House of Representatives, District 64
1422 5th Street
Clay Center KS 67432
785-587-7483 Business
svswan@twinvalley.net
Responsibilities and Experience: Member, Vision 2020, Children and Seniors, Corrections and Juvenile Justice, and Agriculture and Natural Resources committees; Member, EMS Board; Member, Community Corrections Advisory Board, Head Start Board, and Clay County Arts Council Board; Employed part-time at Presbyterian Manor. Education: Emporia State University, BA, Sociology; University of Kansas, MSW, Social Work

Mary Jo Taylor
Superintendent of Schools, Stafford
114 N. Union
Stafford KS 67578
620-546-3215
taylor4senate82@gmail.com
Responsibilities and Experience:
Superintendent of schools, Stafford, Kansas. Education: Fort Hays State University, BA; Wichita State University, MA, Ed.D

Larry Thompson
Director of Operations
Kansas Department of Transportation
121 N. Campus Dr
Garden City KS 67846
620-276-3241 Business
larry.thompson@ksdot.org
Responsibilities and Experience: Statewide responsibility for KDOT field activity; District engineer for SW Kansas District Six in Garden City for 21 years; Licensed professional engineer in Kansas. Education: Kansas State University, BSCE, Civil Engineering

Jim Ward
Kansas State House of Representatives, District 86
3100 E Clark
Wichita KS 67211
316-210-3609
repwardks86@gmail.com
Responsibilities and Experience: Attorney; Member, Judiciary and Pensions and Benefits committees. Education: Creighton University, BA; Washburn School of Law, JD

Julie Westhoff
KGS Advisory Council
5800 Foxridge Drive, Suite 304
Mission KS 66202
913-643-4951 Business
juliewesthoff@kennedyjenks.com
Responsibilities and Experience: Geologist in Kansas and Missouri; Manages a number of environmental projects in an engineering and environmental consulting company; Chair, Kansas Geological Survey Advisory Council (GSAC). Education: University of Kansas, BS, Biology and Geology

John Wheeler
Former Finney County Attorney
902 Anderson St.
Garden City KS 67846
620-272-7081 Cell
john.wheeler1@cox.net
Responsibilities and Experience: Finney County Attorney, 1993–2013; Private law practice in Garden City, 1976–1992. Education: Fort Hays State University; Washburn University School of Law, 1976.

Kansas Geological Survey Staff

Rex Buchanan
Interim Director
Kansas Geological Survey
1930 Constant Avenue
Lawrence KS 66047-3724
785-864-2106
rex@kgs.ku.edu
Responsibilities and Experience: Responsible for operations and direction of the Kansas Geological Survey. Education: Kansas Wesleyan University, BA, Biology and History; University of Wisconsin–Madison, MA, History of Science, and MS, Agricultural Journalism

Cathy Evans
Writer/Communications Coordinator
Outreach and Public Service
Kansas Geological Survey
1930 Constant Avenue
Lawrence KS 66047-3724
785-864-2195
cevans@kgs.ku.edu
Responsibilities and Experience: Write news releases and educational materials; oversee writing and editing aspects of KGS Outreach and Public Service. Education: University of Kansas, BA, Art History, and MS, Journalism

Bob Sawin
Geologist/Stratigraphic Research
Kansas Geological Survey
1930 Constant Avenue
Lawrence KS 66047-3724
785-864-2099
bsawin@kgs.ku.edu
Responsibilities and Experience: Stratigraphic research, geologic mapping, Stratigraphic Nomenclature Committee chair. Education: Kansas State University, BS and MS, Geology

Susan Stover
Geologist/Outreach Manager
Outreach and Public Service
Kansas Geological Survey
1930 Constant Avenue
Lawrence KS 66047-3724
785-864-2063
sstover@kgs.ku.edu
Responsibilities and Experience: Outreach Manager; Kansas Field Conference; Professional licensed geologist. Education: University of Nebraska, BA, Geology; Louisiana State University, graduate work, Geology; University of Arizona, graduate work, Hydrology; University of Kansas, MS, Geology

West-Central Kansas

Natural Resources, Economics, and Decisions for the Future

August 17–18, 2016

The 22nd Kansas Field Conference heads to west-central and southwest Kansas, a region in transition with new opportunities, shifting economics, and changing resource conditions. Crops and cattle production remain strong, and pork production, dairies, and milk processing are growing. Wind energy growth potential is high. Yet the region faces severe declines in groundwater, limited surface water, and congested power lines. During the conference, we will address these and other economic and environmental issues. We also will experience the beauty, history, and geology of the land, from the open High Plains vistas at Fairleigh Ranch to the spring-fed oasis at Lake Scott State Park.

On Wednesday, August 17, the first stop is at the Ehmke Playa west of Dighton. This playa is a good example of the tens of thousands of small, intermittent wetlands in Kansas that provide wildlife habitat and groundwater recharge for the High Plains aquifer. The Ehmke Playa is one of the larger playas in the state and includes a lunette—a crescent-shaped dune formed downwind from the playa during the Pleistocene—that contains archeological evidence of human occupation at least 10,000 years ago. This playa is being studied for its contributions to groundwater recharge. The next stop will be at the McCarty Family Farms dairy near Scott City, the first of three animal agriculture stops of the conference. McCarty Family Farms exemplifies the growing dairy industry in western Kansas. Moving operation from Pennsylvania to Kansas in 2000, McCarty Family Farms now has four dairy farms—near Rexford, Bird City, and Scott City in Kansas and Beaver City in Nebraska—and a plant to process milk from those operations.

Lunch will be catered at the Leoti 4-H building. A panel consisting of a feedlot operator, an irrigator, and a groundwater management district manager will discuss the need, tools, and options to extend the useful life of the Ogallala aquifer. Local Enhanced Management Areas (LEMAs) and Water Conservation Areas are two water conservation programs currently in place. After lunch, we head to Cargill Feeders, one of the state's largest fed cattle operations. Cattle feedlots are a major industry in western Kansas.

Late afternoon, the conference continues to historic Lake Scott State Park. With its canyon landscapes and 100-acre lake fed by natural springs and Ladder Creek, the area offers a variety of recreational opportunities and abundant historical and prehistoric evidence that people have long been drawn to the well-watered oasis. Archeological sites there include the ruins of the only known pueblo occupied by Southwestern Indians in Kansas. Dinner will be served at the Fairleigh Ranch, a cow-calf and stocker operation just north of Lake Scott.

Day 2 of the conference, Thursday, August 18, begins with a visit to a water technology farm owned by T&O Farms LLC in Finney County south of Garden City. T&O Farms started a three-year pilot program in the spring of 2016 to test new technology for the management of crop water applications to maintain profitability with significantly less irrigation water. After this stop, we travel west through the sandhills south of the Arkansas River toward Lakin. The first stop in Lakin is at the newly rebuilt Amazon ditch flume used to divert water from the river over Sand Creek and convey it to irrigation ditches. There, Arkansas River Compact Commissioners will

explain compact compliance by Kansas and Colorado and will discuss projects undertaken to improve deliveries of water released from John Martin Reservoir. Next is the new water treatment plant the city of Lakin built to reduce uranium levels in the water supply, alleviate water hardness, and install technology needed to address future drinking-water standards. Several communities along the upper Arkansas River corridor experience poor quality water. Like lakin, other communities may face the challenge of finding an alternate source of water or a way to treat it effectively and affordably.

Lunch will be served at the Finnup Center for Conservation Education in Garden City. This stop includes a discussion with representatives from the Southwest Power Pool, Sunflower Electric, and Westar Energy about the growing need for transmission-line planning as aging infrastructure becomes more congested and wind farms take on a greater role in electrical energy production in western Kansas.

The day concludes with a drive-by tour of recent economic development projects in Garden City. One coming development is a transload site where goods will be transferred between trains and trucks during the shipping process. Still in the planning stages, the Garden City U.S. 50 Industrial Park was selected in 2015 as one of two transload sites by the Kansas Department of Transportation from among 111 site applicants. The tour goes by a large staging area for wind turbine components. The last stop of the tour is the construction site of a 214,000-square-foot dairy ingredients plant. The plant will provide processing for large dairies in western Kansas that now have to ship their milk out of state.

Detailed itineraries for Wednesday and Thursday can be found in this guidebook at the front of each daily section.

Optional Tours and Social

Before the Field Conference officially begins, participants may tour the historic Windsor Hotel in Garden City at 4:30 p.m. Tuesday, August 16. Opened in 1887 featuring 125 rooms and a three-story atrium with vaulted skylight, the four-story hotel is now owned by the Finney County Preservation Alliance and is under renovation. To carpool from the hotel, meet in the Clarion Inn lobby at 4:10 p.m. or join the tour at 4:30 p.m. at the Windsor Hotel gift shop, 413 N. Main Street.

Conference participants are invited to a reception from 5 to 7 p.m. Tuesday at the Poky Room, Clarion Inn. Drinks and light snacks will be provided.

Participants are encouraged to visit Monument Rocks north of Scott City on their own either before or after the conference. A vestige of the Cretaceous sea that covered the area about 80 million years ago, the site is the first in Kansas to be designated a National Natural Landmark. Remaining upright long after the surrounding rock eroded away, the pillars at Monument Rocks, also called the Chalk Pyramids, are composed of Niobrara Chalk. The chalk in western Kansas is well known internationally as a source of invertebrate and vertebrate marine fossils—from clams to huge swimming and gliding reptiles. Travelers may also want to stop at the Keystone Gallery on Highway 83 near Monument Rocks; owners Chuck and Barbara Bonner display a number of the area fossils and are knowledgeable about the region's prehistoric past.

About the Kansas Field Conference

The Kansas Field Conference is designed to give a diverse group of policymakers who have a range of legislative, government, education, and private-business expertise the opportunity to explore and discuss natural-resource issues. The objective is to give participants a chance to see 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, the annual field guides furnish background about sites and issues and can serve as handy references long after the 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 conference, we do not seek to resolve policy or regulatory conflicts. 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 and discussions about 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 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.

The co-sponsors appreciate your attendance at this year's conference. Participant input in the past has helped make the Kansas Field Conference a model that has been adopted by other state geological surveys. 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 2016 Kansas Field Conference:

Susan Stover, Geologist/Outreach Manager
Cathy Evans, Writer/Communications Coordinator
Rex Buchanan, Interim Director
Bob Sawin, Geologist/Stratigraphic Research

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

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, bicycles, and pedestrians. Mike King is former Secretary of Transportation, Bob Henthorne is Chief Geologist, and Larry Thompson is Director of the Division of Operations.

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

Kansas Department of Wildlife, 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's 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 while 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. A seven-member Wildlife and Parks Commission advises KDWPT. Robin Jennison is Secretary of Wildlife, Parks and Tourism, and Steve Adams is Chief of Planning.

Kansas Department of Wildlife, Parks and Tourism
Secretary
1020 S. Kansas Avenue, Rm 200
Topeka, KS 66612-1327
785-296-2281
www.kdwp.state.ks.us

Kansas Department of Wildlife, Parks and Tourism Operations Office
512 SE 25th Avenue
Pratt, KS 67124-8174
620-672-5911
www.kdwp.state.ks.us

Kansas Water Office

The Kansas Water Office (KWO) is the water planning, policy, coordination, and marketing agency for the state. The KWO evaluates and develops public policies, coordinating the water-resource operations of agencies at all levels of government. The KWO administers the Kansas Water Plan Storage Act, the Kansas Weather Modification Act, and the Water Assurance Act. The KWO advises the governor on drought conditions and coordinates the governor's drought-response team. The KWO develops the Kansas Water Plan, which addresses the management, conservation, and development of water resources in the state. The Kansas Water Authority, a 13-member appointed board, along with 11 nonvoting ex officio members who represent various state water-related agencies, is statutorily within and a part of the KWO. The Authority advises the governor, legislature, and director of the KWO. Tracy Streeter is Director, and Earl Lewis is Assistant Director.

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

Supporting Organizations and KGS Staff

The KGS would like to acknowledge the help of others who have contributed to the 2016 Kansas Field Conference. Our co-sponsors, Director Tracy Streeter and Earl Lewis of the Kansas Water Office; Secretary Robin Jennison and Steve Adams of the Kansas Department of Wildlife, Parks and Tourism; and former Secretary Mike King and Bob Henthorne of the Kansas Department of Transportation, provided advice on topics, speakers, and locations. KGS editor Julie Tollefson edited and laid out the field guide. KGS graphic designer Mark Schoneweis prepared the route map. In addition, we thank the many

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Tuesday, August 16, 2016

4:30 p.m.	Tour Windsor Hotel restoration Meet at Windsor Hotel gift shop, 413 N. Main Street, Garden City **OR** to car pool, meet at 4:10 p.m. in Clarion Inn lobby
5–7 p.m.	Informal Social Poky Room, Clarion Inn, 1911 E. Kansas Ave., Garden City
	Dinner on own

Wednesday, August 17, 2016

6 a.m.	Buffet breakfast Poky Room, Clarion Inn (start time is informal)
7:15 a.m.	Welcome, introductions, and conference overview Poky Room, Clarion Inn
	Susan Stover, Outreach Manager, Kansas Geological Survey *Rex Buchanan*, Interim Director, Kansas Geological Survey
7:45 a.m.	**Bus Leaves Garden City**
8:50 a.m.	**Site 1**: Ehmke Playa *Bill Johnson,* Geography Professor, University of Kansas *Vance and Louise Ehmke,* landowner hosts
10:10 a.m.	Bus to Site 2
	Bus Session—Highway 83: A Corridor of Significance *Larry Thompson*, Kansas Department of Transportation
10:45 a.m.	**Site 2**: McCarty Family Farms Dairy *Brock Peters*, Manager, McCarty Family Farms
11:40 a.m.	Bus to Site 3
12:15 p.m.	**Site 3**: Leoti Fairgrounds, 4-H Building Restroom Break Lunch
	Panel: Ogallala High Plains Aquifer Conservation Moderator: *Rex Buchanan,* KGS *Lonnie Busch,* Feedlot General Manager, Cargill Feeders *Danny Welsh,* Farmer, GMD1 Board Member *Ray Luhman,* Manager, Northwest Kansas Groundwater Management District 4
1:55 p.m.	Bus to Site 4
2:10 p.m.	**Site 4:** Cargill Feeders *Jimmie Butt,* Feedyard Manager, Cargill Feeders *Lonnie Busch,* Feedlot General Manager, Cargill Feeders
3 p.m.	Bus to Site 5

4 p.m. **Site 5:** Lake Scott State Park
Restroom Break

a) Beach House
Greg Mills, Park Superintendent, Kansas Department of Wildlife, Parks and Tourism
b) Big Spring
Rex Buchanan, Kansas Geological Survey
Greg Mills, Park Superintendent, KDWPT
c) El Cuartelejo Pueblo
Jerry Thomas, Artist, Historian, and Preservationist
Robin Jennison, Secretary, Kansas Department of Wildlife, Parks and Tourism

5:20 p.m. Bus to Site 6

5:30 p.m. **Site 6:** Fairleigh Ranch
Greg Glunz, CEO, Fairleigh Companies
Representative, Kansas Livestock Association

5:50 p.m. Social—co-sponsored by Westar Energy

6:20 p.m. Dinner—sponsored by Kansas Livestock Association

7 p.m. Bus to Clarion Inn, Garden City (about an hour)

The Role of Playas in Wildlife Habitat and Aquifer Recharge

Tens of thousands of playas—small, intermittent wetlands—are scattered across the High Plains, providing critical wildlife habitat and groundwater recharge for a region where precipitation averages less than 20 inches a year. Also called lagoons, buffalo wallows, or mud holes, playas are relatively round, shallow depressions (fig. 1) lined with clay-rich soils that differ in composition from surrounding soils.

The naturally occurring wetlands are not stream fed and rely solely on precipitation and runoff, if left undisturbed. They also have no drainage systems. Unless water is removed for irrigation or other human activities, all water that enters a playa sustains wildlife and plants, leaves through evapotranspiration, or infiltrates the ground. The High Plains playas, most less than 3 feet deep, may remain dry for years during a drought then hold water for weeks, months, or even years when precipitation is above average.

After periods of abundant precipitation, playas retain water much longer and support a greater variety of animal and plant life than the adjacent semiarid, shortgrass prairie and agricultural land. In Meade County, Kansas, alone, 168 species of birds—from nesting Golden Eagles to migrating Sandhill Cranes—have been counted in playa settings (Flowers, 1996). Other wildlife ranges from invertebrate dragonfly larvae to toads, turtles, rabbits, raccoons, bats, and deer. Many seeds, invertebrates, and amphibians have adapted to the unpredictability of playa cycles and can remain dormant in soil for years (Smith, 2003). Because most plant and animal species in the High Plains depend in some way on the playas, the region's diversity would be severely limited without them.

Playas are also a source of recharge for the extensive High Plains aquifer, which includes the Ogallala aquifer. Although some

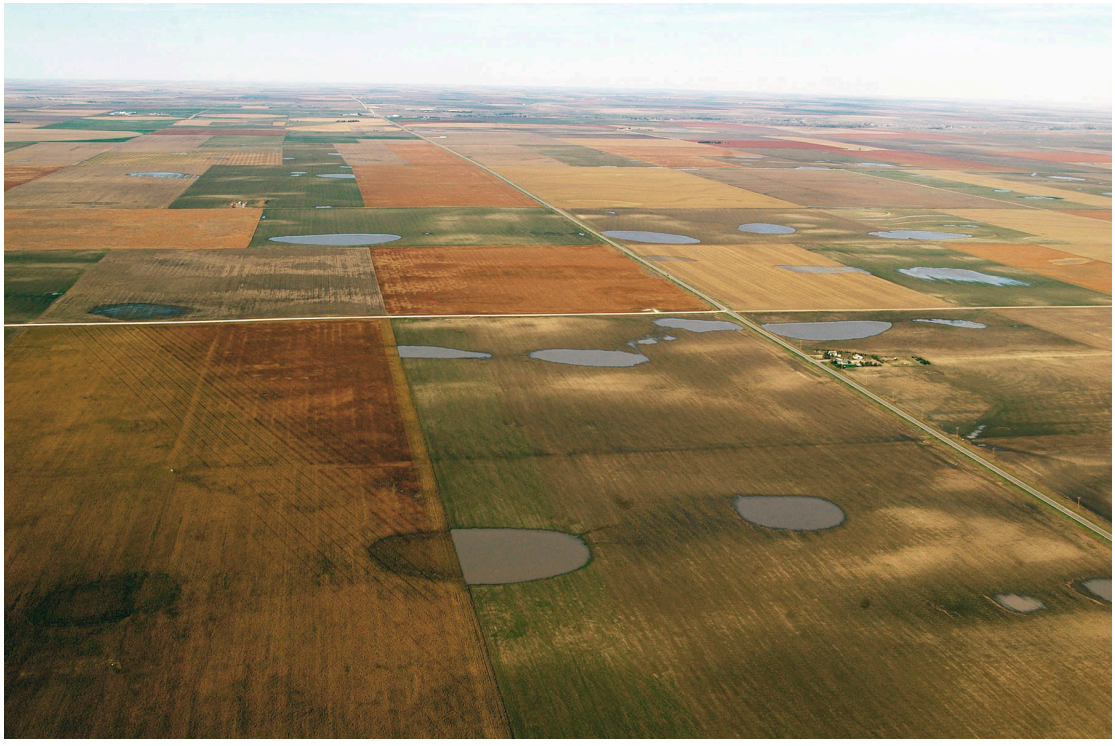

Figure 1. Playa lakes in Scott County, Kansas (photograph by Bill Johnson).

early studies and models predicted that playa basins were impermeable and all water stored eventually evaporated, current evidence shows that water infiltrates down through basin cracks or percolates around the edges to help replenish the aquifer. How much recharge the playas provide is under investigation.

The origin of playas, still somewhat of a mystery, also is being studied. Most scientists agree they formed through some combination of subsidence, wind, water erosion, surface irregularities, animal activities, climatic influences, irregular soil formation, chemical processes, and biologic processes.

The High Plains has the highest concentration of playas in the world. The approximately 23,000 playas in western Kansas occupy more than 81,000 acres in 43 counties (fig. 2). Scott, Thomas, Lane, Cheyenne, Finney, and Sherman counties have the most per county. The largest playa in the state covers 465 acres in Finney County. The vast majority, however, cover less than five acres. Almost all playas in Kansas and the surrounding states are on private property and not accessible without landowner permission. Three in Ford County are on public land managed by the Kansas Department of Wildlife, Parks and Tourism for wildlife and hunting.

Playa Research in Kansas

University of Kansas geography professor Bill Johnson has been studying playas since the early 2000s. Mark Bowen, who completed his dissertation on playas at KU in 2011 and is now at the University of Wisconsin (Oshkosh), works with him. Supported by KU and the Kansas Geological Survey (KGS), their research has been funded in various stages by the U.S. Environmental Protection Agency, the U.S. Fish and Wildlife Service, and ConocoPhillips.

Because the state's playas had never been mapped, the researchers first mapped them in a GIS environment using National Agriculture Imagery Program (NAIP) aerial imagery and LiDAR imagery—three-dimensional aerial imagery of the earth's surface created with laser scanners. A GIS, or geographic information system, is a computer-based method for storing, mapping, analyzing, and

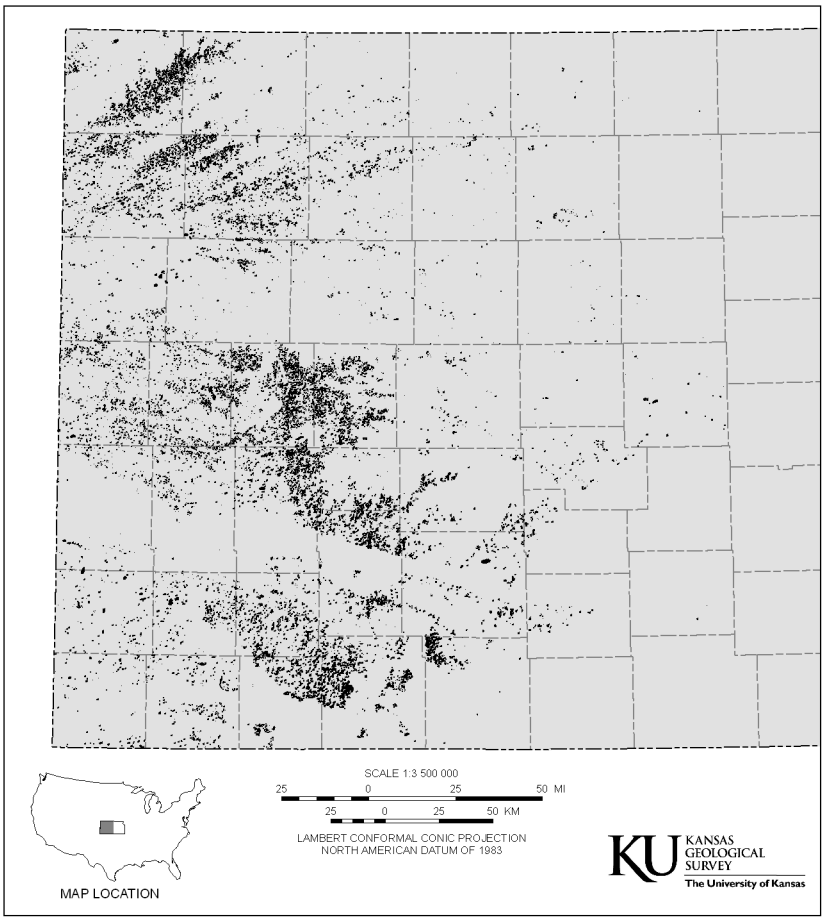

Figure 2. Distribution of the more than 22,000 playas in Kansas (created from data in Johnson et al., 2009; modified from map by John Dunham, Kansas Geological Survey).

interpreting a variety of data and images within a given geographical area. Through this process, they identified many more playas than were previously known. They then verified playas seen on the imagery using ground surveys and low-altitude flights.

Machine coring and trenching were used to characterize the geology and geomorphology (physical features on the surface) of several playas, including a large one in Lane County known as the Ehmke playa. Stratigraphic data (e.g., stable isotopes, radiocarbon dating) collected during the geologic studies were used to reconstruct the playas' environmental histories (Bowen and Johnson, 2015). At least 100,000 years of climate-forced environmental change is recorded in the sediments of the larger playas.

Johnson and Bowen are evaluating the degree to which the function of playa wetlands has decreased due to sedimentation, which often is accelerated by cultivation in adjacent fields. Without adequate vegetation buffer zones, eroded soil washes into the playas, filling in and effectively sealing soil openings. That dramatically alters playa wetland ecology (Bowen and Johnson, 2015).

Another EPA-funded investigation is under way to determine the degree to which playas are a source of recharge for the High Plains aquifer in western Kansas. Above- and below-ground instrumentation will be used to measure how much of the water ponding in a playa infiltrates into the aquifer. The multidisciplinary research by scientists from KU and the KGS will include infiltration studies, deep trenching, and installation of monitoring wells.

The Ehmke Playa and Lunette

The Ehmke playa in Lane County has been the focus of many investigations due to its relatively pristine condition, large size, ease of access, and the presence of a well-developed lunette—a broad and low crescent-shaped dune of sediment formed downwind from the playa. (Landowners Vance and Louise Ehmke have provided continuous access to researchers.) The playa

Figure 3. Wetland vegetation and birds in the Ehmke playa, Lane County, Kansas, during a wet period (photograph by Bill Johnson).

(fig. 3) covers 126 acres and is about 2 meters (6.5 feet) deep (Bowen and Johnson, 2012).

Lunettes, found adjacent to most of the larger playas, are records of climate change and some, including the one at the Ehmke site, contain archeological artifacts. Researchers at the Kansas State Historical Society studied the archaeological deposits at the Ehmke site in 1989. The lunette, southeast of the playa, yielded projectile points, flakes, burned rock, mussel shells, and bone fragments from bison, mammoths, turtles, and birds. Artifacts were found on the southeast side of the lunette, suggesting the hill was used as shelter from northwesterly winds (Campbell et al., 2007). Evidence shows people were using playas in Kansas as a life-sustaining resource at least 10,000 years ago.

Playa Modification and Conservation

Most High Plains playas have been modified in some way since settlement started in the late-nineteenth century. Many have been tilled or filled to prevent occasional flooding. Others have been used for grazing or storage of irrigation water, feedlot runoff, and treated wastewater, or they have been altered by road construction and urban development. Invasive non-native plant species have encroached on wetland vegetation (Haukos and Smith, 2003).

Sedimentation of the playa basins associated with erosion after the removal of protective native plants is the greatest threat to the future of playas and the vital functions they perform. Non-playa soil and other sediments, carried in with runoff, fill the basins and bury the clay soils needed to create wetland environments and recharge the underlying aquifer. Contaminants in the runoff can also lower groundwater quality (Gurdak and Roe, 2009).

Several nonprofit conservation and agricultural organizations, government agencies, and universities in the region explore ways to protect and restore playas in ways that are beneficial to both the environment and landowners. Among them are KU researchers

Figure 4. Ehmke playa, Lane County, Kansas, during a dry period. The lunette, a mound created from windblown sediment, contains archeological artifacts and physical evidence of past climate change (photograph by Bill Johnson).

who inventoried the Kansas playas and are examining the health and geologic structure of the state's playas. The Playa Lakes Joint Venture—a nonprofit partnership of more than 50 federal and state wildlife and natural resources agencies, environmental groups, corporations, and landowners—promotes the conservation of playas and other wildlife habitats in the High Plains (PLJV, 2016).

Adapted from:

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Contact

Bill Johnson
University of Kansas
Department of Geography
785-864-5548
wcj@ku.edu

Animal Agriculture in Western Kansas

Animal agriculture is a vital and growing part of the Kansas economy. Permitted, concentrated animal feeding operations (CAFOs) exist across the state (fig. 1), although the fed cattle industry is predominantly located in western Kansas (fig. 2). According to the most recent available statistics, Kansas ranked third nationally in numbers of cattle and calves on ranches and in feedyards in 2015 with 6 million head and second in the fed cattle market in 2014 (USDA, 2016). Revenue from cattle production grew more than 36% from 2010 to 2014, with cattle providing $7.75 billion in cash receipts in 2013 (KLA, 2016). Nearly half of the state's agricultural cash receipts in 2013 came from the sale of cattle and calves. Kansas ranked 16th nationally in milk production in 2013; in 2015, milk production was valued at $746 million (USDA, 2016).

The transportation industry has benefited from growth in animal agriculture because of the need to transport cattle, dairy cows, swine, feed, milk, and boxed beef. The increase in the number of animals has also enhanced the profitability of corn and other feed grown in the area. The demand for feed is greater than what is produced locally, which helps to push up the price (Guerrero et al., 2013). Even though grain is imported to meet demand, locally grown forage is desired for cattle and needed for dairy cows.

Cattle Ranching and Industries

Kansas has long attracted cattle ranching. **Fairleigh Ranch** in Scott County is a good example of a cow-calf and stocker operation. Roughly 15,000 head move through the 10,000-acre ranch annually (Glunz, 2016). Fed beef operations also moved into western Kansas, a central location with low population pressures, favorable climate, and available feed. The region from west-central Kansas to

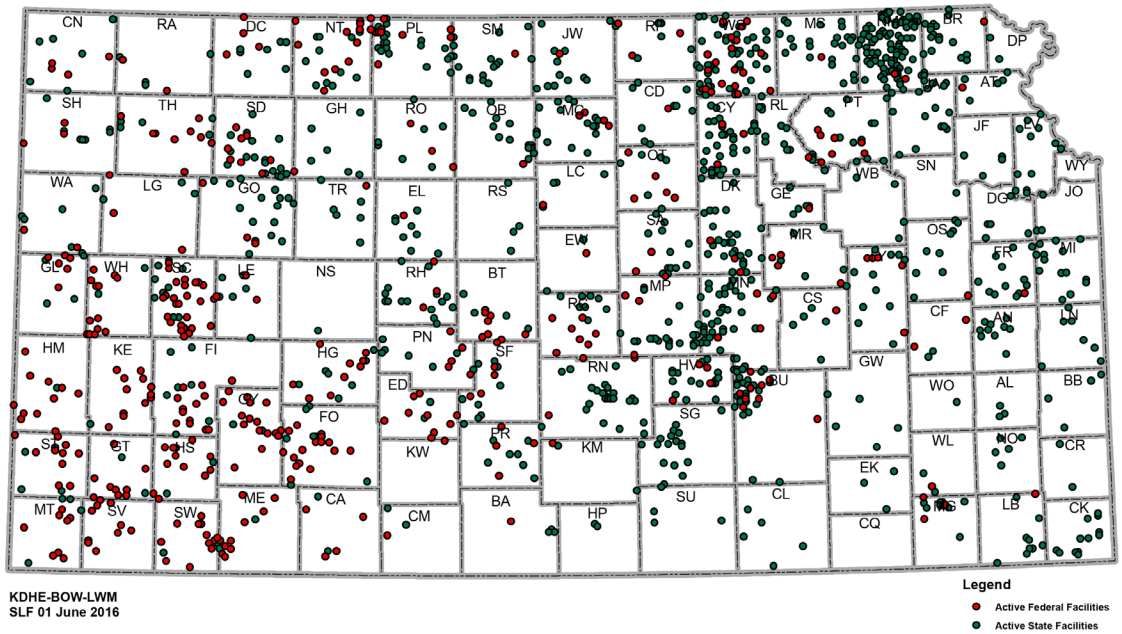

Figure 1. Federal- and state-permitted concentrated animal feeding operations. Federal-permitted CAFO facilities have 1,000 head of cattle or greater. State-permitted operations are typically 300 to 999 cattle head (or animal unit equivalent; for regulatory purposes, 1,000 head of beef cattle, 700 dairy cows, and 2,500 swine weighing more than 55 pounds each would be equivalent). Map by Sarah LaFrenz, KDHE.

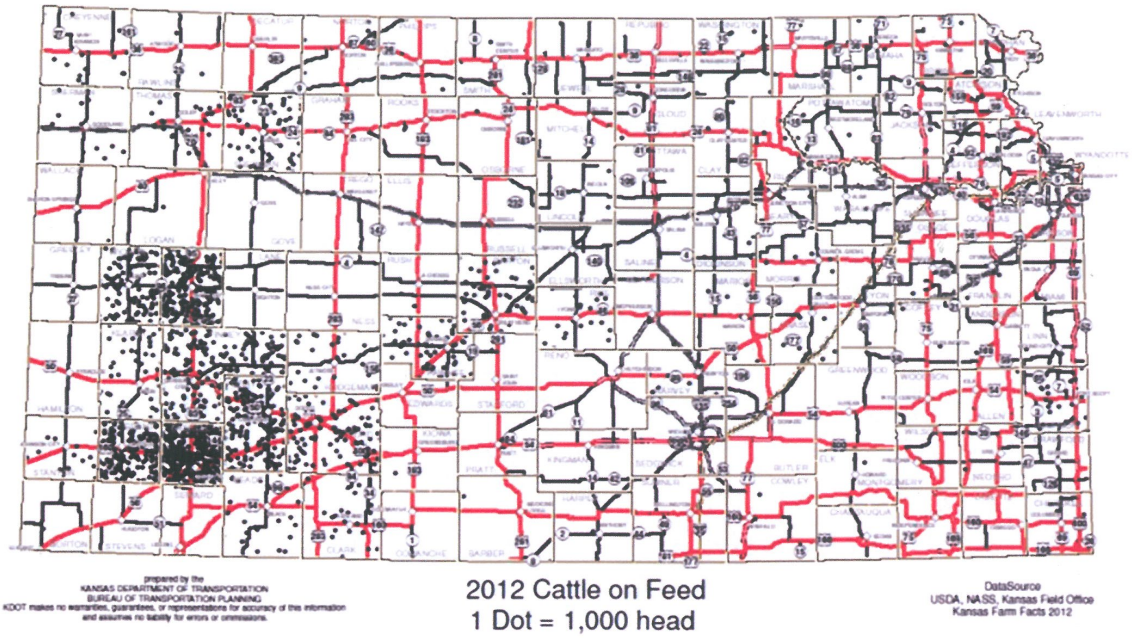

Figure 2: Cattle and transportation in 2012; each dot represents 1,000 head. Source: U.S. Department of Agriculture.

the panhandle of Texas is known as the "Cattle Feeding Capital of the World" (Guerrero et al., 2013). Fed beef inventory in Kansas nearly tripled from 1975 to 2010 (Guerrero et al., 2013). Meat packing plants followed and by the 1980s, southwest Kansas had the largest concentration of beef packing plants in North America (Stull, 2011).

Cargill Feeders is one of the largest cattle feeders in Kansas, with about 230,000 head moving through the feedyard near Leoti annually. It ships about 5,000 head a week and has an annual animal turnover rate of roughly 2.2 times. Cargill produces about 3.5 million pounds of feed daily, most of it flaked corn, high moisture corn, and silage. It buys half of the feed locally. Water management is a priority for the business, which uses about 1 million gallons daily and up to 1.5 million gallons on very hot days (Busch, 2016).

Dairy and Swine Operations

The same qualities that attracted the cattle industry to western Kansas have also led to a growth in dairy and swine operations (fig. 3). Seaboard Foods operates a large pork processing plant in Guymon, Oklahoma, that processes about 20,000 pigs a day, which helps support growth of the swine industry in western Kansas. Just under 2 million hogs were raised in Kansas in 2015 (USDA, 2016). In 2016, Seaboard Foods is expected to roughly double its swine production in Greeley County to 260,000 pigs when it opens a second facility (Mahin, 2016). Swine production has moved in a similar direction as cattle production, with larger facilities being built to take advantage of the economy of scale. Of the 1,000 hog farms in Kansas, 150 produce more than 99% of the state's pigs (KLA, 2016). Grain sorghum and corn are the primary feed, with soybean meal and distiller grains also used.

Large dairies began appearing in western Kansas in the 1990s. According to the Kansas Dairy Industry, 2,500–3,000 head dairies are the most popular size of the new facilities in western Kansas (Kansas Dairy, 2016). The 21 federally permitted facilities (those with more than 1,000 head) produced 78% of the state's milk in 2012 (Kansas Dairy, 2016). Dairies are located where there is irrigated cropland available for silage, which due to its bulk and high moisture content needs to be grown locally.

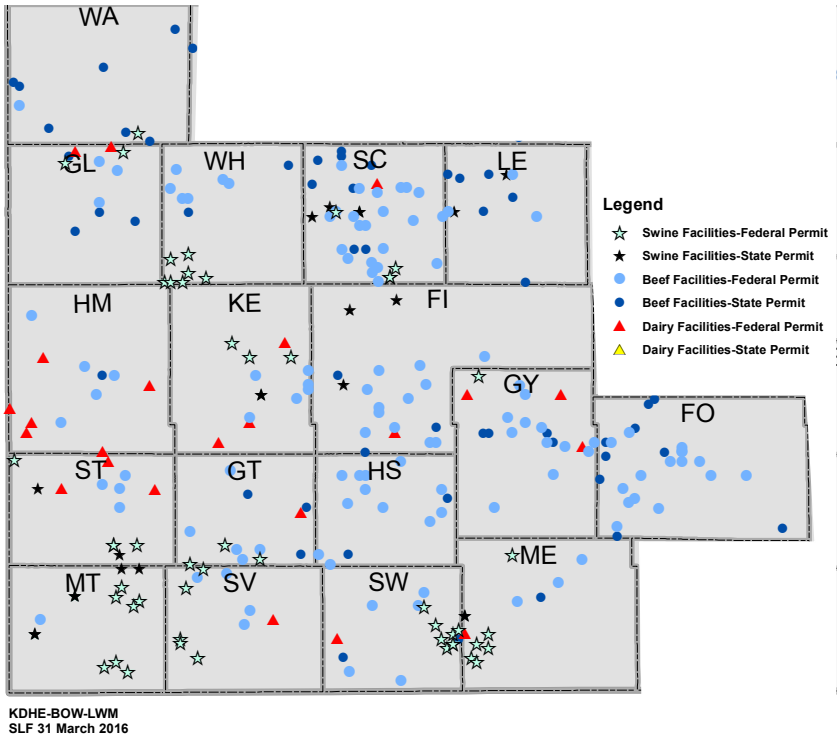

Figure 3. Federal- and state-permitted concentrated animal feeding operations in western Kansas. Federal permits are required for CAFOs with 1,000 or more cattle or equivalent animal units. State permits typically are required for CAFOs with 300 to 999 head or equivalent animal units. Map by Sarah LaFrenz, KDHE.

McCarty Family Farms is an example of a dairy that relocated to Kansas, having moved from Pennsylvania in 2000. The operation now has its own milk processing plant to handle product from its four dairies (Rexford [established in 2000], Bird City [2008], and Scott City [2011] in Kansas and Beaver City [2014] in Nebraska). During processing, the milk goes through an evaporator to remove excess water before the cream is separated, and both the cream and skim milk are condensed. After pasteurization and quality and safety testing, the milk is shipped by truck to the Dannon Company. The water removed from the milk is reused throughout the dairy. An estimated 45,000 gallons of water is reclaimed per day (McCarty Family Farms, 2016).

Land and Water Considerations

Land is a major consideration for a concentrated animal facility, not just for the animals' living area but also for feed and waste management. High-moisture feed, such as silage and alfalfa, comes from local sources. Dairy cows typically consume 120 pounds of feed per animal daily, roughly half of it silage. A general guide for land requirements for a dairy is that it takes 1 acre of 200 bushel corn to produce enough silage to feed two dairy cows for a year (Harner, 2016). Double cropping for silage has become common for dairies and requires more water. Some of the demand is being met by use of effluent water from the dairies (Guerrero and Amosson, 2013).

Nutrient management of animal waste requires lagoons to capture liquid wastes, land to stockpile solid waste, and land to apply or treat waste. The nutrient management plan to control nitrogen and phosphorous is a condition of the CAFO permit from the Kansas Department of Health and Environment. This plan indicates the fields where animal waste may be applied, either through ownership or

by agreement with the landowners. Nutrient management plans are site specific and reflect soil type, the potential for run-off, proximity to streams and depth to groundwater, and the local climate (Mahin, 2016).

Cattle, swine, and dairy industries in western Kansas are dependent on the Ogallala aquifer. Their continued success depends on reliable, high-quality water. Water requirements are both direct and indirect. Direct use is for drinking, washing, and facility maintenance, and indirect use is for growing feed crops.

The guide for direct daily water consumption by beef cattle is 10 gallons of water for every 1,000 pounds in weight (Harner, 2016). Reasonable use under a stockwater water right allows for 15 gallons per beef cattle for an open lot CAFO. Many cattle feed yards are able to manage on 12.5 gallons per head. Use of water tanks that either don't overflow or that capture any overflow water improves water efficiency.

Dairy cows require more water than cattle. The maximum allowed under a water right is 135 gallons per milking cow daily, which allows water for drinking, servicing, flushing, and cooling the animals. Kansas dairies typically are more efficient, using about 60 gallons per day per cow. Half of this is for drinking and the rest is used in the milking parlor, by employees, and for cooling cows in the summer months. Importantly, much of the water consumed is reclaimed when the milk is processed, condensed, or powdered.

Direct water use by swine varies based on its life cycle, but averages about 11 gallons a day (Guerrero and Amosson, 2013). Water is also used for keeping the facilities clean and cooling the animals on hot summer days and nights.

In 2010, if all the cattle industry feed in the southern Ogallala region (Kansas to Texas) had been grown in the area, the indirect water use would have represented 28% of the irrigation water used that year (Guerrero et al., 2013).

Animal agriculture production in the southern Ogallala region has a relatively high economic value per unit of water pumped. The economic impact of cattle in the southern Ogallala in 2010 is an estimated $165,576 per acre foot (AF) when considering direct water use only, or $3,645/AF when factoring in both direct and indirect water use (Guerrero et al., 2013). An acre foot is 325,851 gallons. Dairies' economic contribution from milk production in 2010 was estimated at $93,437/AF (direct water use only) and $1,632/AF (both direct and indirect water use) (Guerrero et al., 2012).

Relatively high economic return per volume of water is also seen in western Kansas. For example, Scott County has a high concentration of cattle feedlots. In 2012, it ranked first in the state in the value of livestock and its products. In 2012, livestock sales in the county represented 93% and crops 7% of the market value of products sold (USDA, 2012). Water use is almost reversed: In 2014, 92% of water used was for irrigation and 6% for stock water (fig. 4). That is, however, only the direct water use. If indirect water use associated with silage production and other animal feed were considered as water for animal production, the stock water percentage would increase. Scott County ranked third in acreage in corn for silage (USDA, 2012).

Discussions about conserving and extending the usable life of the Ogallala water, though driven by irrigation stakeholders, also include those involved in animal agriculture.

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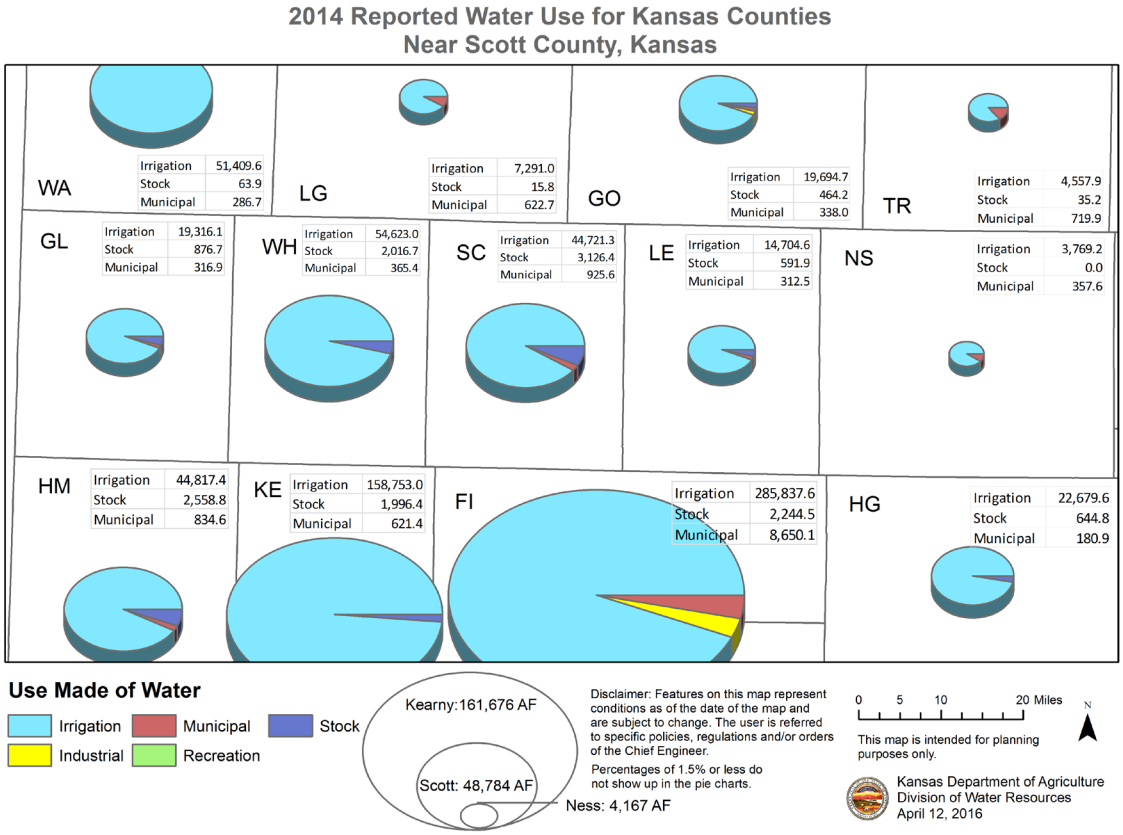

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Contacts

Lonnie Busch
Cargill Feeders
620-874-2137
lonnie_busch@cargill.com

Ken McCarty
McCarty Dairy
785-443-2453
kmmccarty@mccartyfamilyfarms.com

Ogallala–High Plains Aquifer in West-Central Kansas: Conditions, Conservation, and Plans

The High Plains aquifer underlies portions of eight states from South Dakota to Texas and consists of several hydraulically connected aquifers. In Kansas, the Ogallala aquifer lies in the western third of the state, with the Great Bend Prairie and the Equus beds aquifers farther east. Groundwater management districts (GMDs) cover nearly all of the High Plains aquifer that has much saturated thickness in Kansas. GMDs are organized and governed by area landowners and local water users to address water-resource issues. The Ogallala portion of the High Plains aquifer is managed by GMDs 4, 1, and 3 (fig. 1). The saturated thickness and recharge rates vary substantially across the High Plains and even within a single GMD.

Western Kansas Groundwater Management District 1 (GMD1) is in a region where, in general, the underlying Ogallala aquifer holds less water than elsewhere in the state. The aquifer held less water in storage before development, and it holds much less now, with most of the district containing 40 feet or less of saturated thickness. Exceptions are southern Wallace County and a north-south trending trough through Scott County, both of which have more than 100 feet of saturated thickness (fig. 2). Although the decline rate in the Ogallala aquifer is less in absolute feet than in other areas of the High Plains aquifer, a relatively small decline in the Ogallala represents a larger percentage of the remaining saturated thickness.

Depending on the location of their wells, most water producers in GMD1 have long been dealing with water shortages. The first irrigation well in GMD1 was drilled in 1907. This district

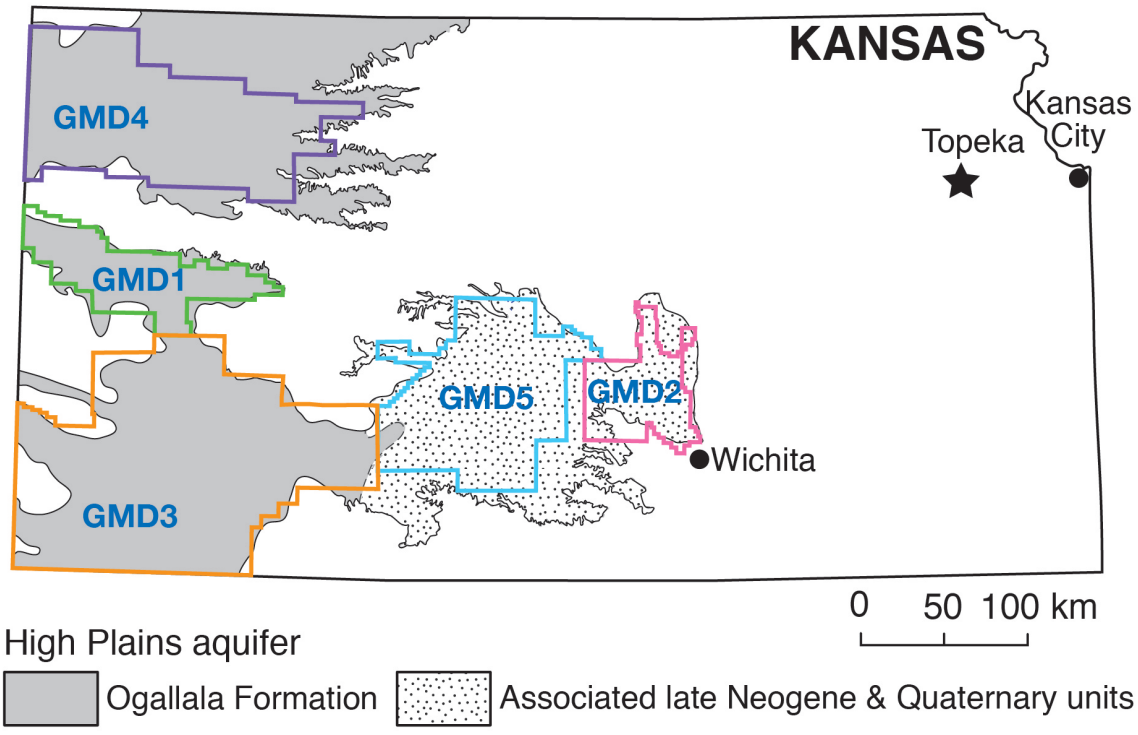

Figure 1. In Kansas, five groundwater management districts cover nearly all of the High Plains aquifer that has much saturated thickness. GMDs 1, 3, and 4 overlie the Ogallala portion of the High Plains aquifer.

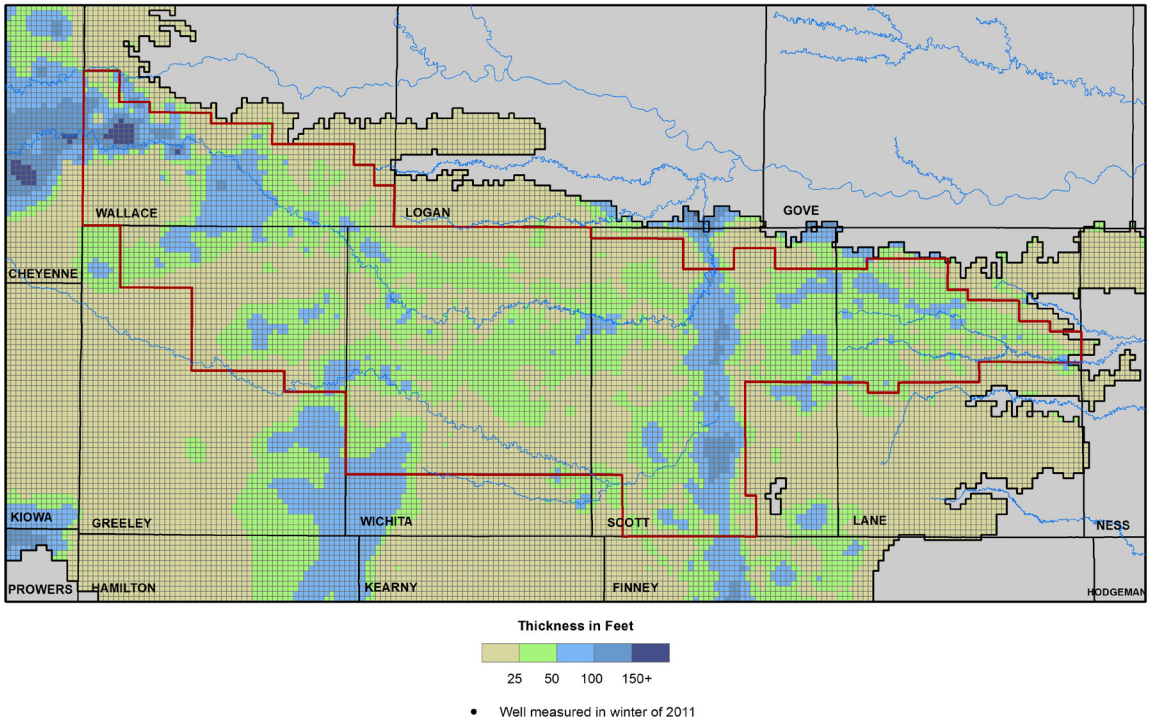

Figure 2. Saturated thickness in GMD1, 2011 (Wilson et al., 2015).

has one of the greatest densities of vested water rights, those established before 1945 when the Kansas Water Appropriation Act was enacted. In GMD1, a large number of irrigation water rights overlap in place of use (a senior water right and junior water right may be associated with the same field, for example), and many water rights for irrigation and stock water uses also overlap. West-central Kansas has a high concentration of animal agriculture operations.

The Kansas Geological Survey completed a groundwater model of west-central Kansas in 2015 with support from the Kansas Water Office (KWO) and GMD1. The model allows for future water conditions to be projected based on various management or climatic scenarios. The GMD1 board and KWO requested three scenarios: 1) no change in current pumping patterns except as limited by the aquifer, 2) turn off all irrigation wells, and 3) a 20% reduction from the historic irrigation pumping rate. In the 20% reduction scenario compared to the no reduced use scenario, the water left in storage doesn't change dramatically initially but water savings increase significantly several years out. However, a reduction greater than 20% would be needed to hold water levels close to 2013 quantities (fig. 3).

Approaches to Water Conservation

GMDs can propose *Local Enhanced Management Areas* (LEMAs) to establish corrective measures to address a groundwater concern, such as declines, within GMD boundaries. LEMAs were adopted into state law in 2012 as part of the Groundwater Management Act. LEMAs assure that corrective measures that are adopted have been proposed at the local level. A GMD sends a proposal to the chief engineer of the Kansas Department of Agriculture's Division of Water Resources (DWR) for review, approval, or dismissal. If the chief engineer suggests modifications, the GMD decides whether to modify and resubmit the proposal. LEMAs allow producers flexibility to manage their crop water while using less water overall. Such flexibility may include establishing a multiyear rather than annual water quantity

allocation and the ability to expand irrigation beyond the fields originally authorized on the water right permit. Once approved and ordered by the chief engineer, the corrective measures have the force and function of law on all prior appropriation water rights identified within the LEMA boundary. Vested water rights are not subject to the LEMA conditions, but owners of vested water rights may voluntarily join and receive the increased water use flexibility.

One active LEMA has been established in a 99 square mile area of Sheridan and Thomas counties in Northwest Kansas GMD4. The LEMA, known as SD-6, is in its fourth of five years.

In 2014, GMD1 held a vote by private ballot in each of its member counties to establish a districtwide LEMA. The GMD1 board sought a supermajority to approve a six-year LEMA with a goal of reducing water use by 20% over recent historical use. The proposal did not pass, although in three of the five counties a simple majority voted to support it and a fourth county recorded a near tie vote. In Wallace County, the vote was three to one against the proposed LEMA.

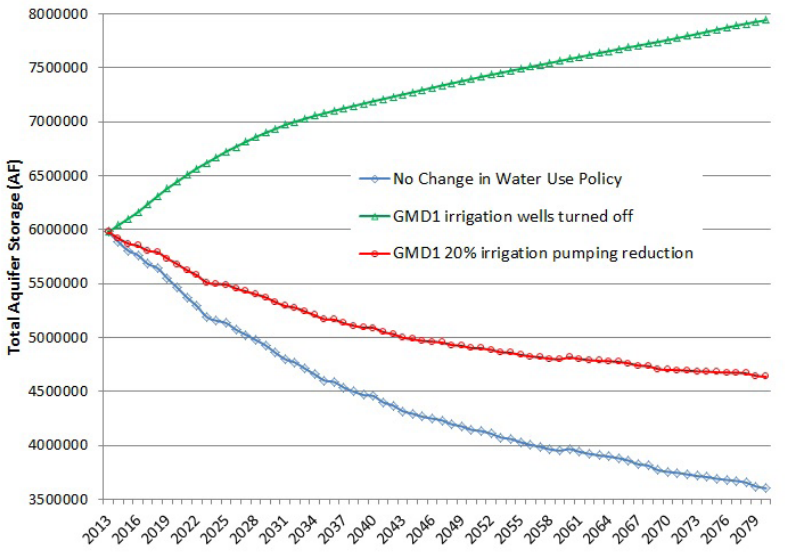

Figure 3. Projected future groundwater in storage in west-central Kansas under different assumptions (Wilson et al., 2015).

Figure 4. Cloud seeding in western Kansas. Photo by Kyle Spencer, GMD1.

Water Conservation Areas (WCAs) provide another High Plains aquifer conservation option with flexibility for the producer. Signed into state law in 2015, WCAs allow water-right owners or groups of owners to voluntarily enter into a multiyear agreement with the DWR for the purpose of conserving groundwater. Once signed, a WCA becomes enforceable. Flexible options available within WCAs include multiyear allocations, movement of allocations between water rights, and allowing for new uses of water. If water producers can document that they have already implemented

water conservation measures, the measures can become part of the WCA plan, making the WCA flexible water use options available to those producers (KDA, 2016).

Weather Modification

For 42 years, GMD1 has operated a weather modification program to seed rain clouds (fig. 4). During that time, an average of 12 counties participated in the program annually. Current participation is very low, reflecting stretched county budgets. The early goal was to increase precipitation during the growing season. Although studies have not detected a statistically significant increase in rainfall, there has been a statistically significant reduction in hail. Reduced loss of irrigated crops has indicated a 37:1 benefit/cost ratio of this program.

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Contacts

Kyle Spencer, Manager
Western Kansas GMD1
620-872-5563
gmd1@wbsnet.org

Brownie Wilson
Kansas Geological Survey
785-864-2118
bwilson@kgs.ku.edu

Lake Scott State Park

Lake Scott State Park (fig. 1) provides a unique mix of scenery, recreation, history, geology, archeology, water resources, and wildlife. Besides bluff-and-canyon scenery uncommon to Kansas, the park incorporates a 100-acre lake (fig. 2); the only Native American pueblo in the state; numerous other archeological sites from prehistory through the 19th century; an early homestead; and a species of beetle found nowhere else in the world.

In the area, streams carved canyons into the Ogallala Formation (fig. 3), an expansive wedge of sand, gravel, silt, and clay that eroded off the Rocky Mountains. Some of the formation was cemented into a highly porous and permeable rock, locally called mortarbed, that helped define the High Plains millions of years ago. The Ogallala aquifer—the saturated portion of the formation—underlies portions of eight states and holds most of the groundwater used to sustain towns, agriculture, and industry in western Kansas. Near Lake Scott, water seeps out through springs at the contact between the outcropping Ogallala and underlying, less-permeable Niobrara Chalk that forms the canyon floors. Besides Ladder Creek, Big Spring (fig. 4) and a series of smaller springs continuously replenish the lake with freshwater (Buchanan and McCauley, 2010).

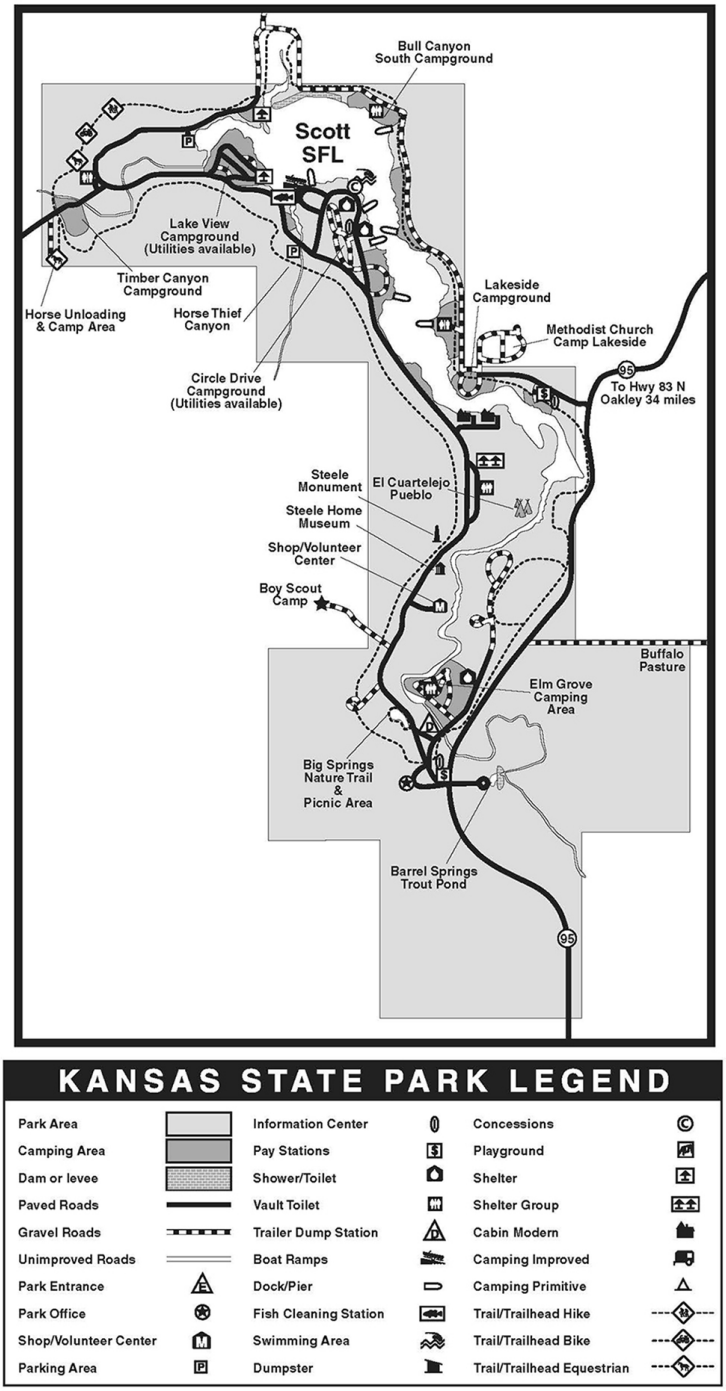

Figure 1. Lake Scott State Park (illustration from Kansas Department of Wildlife, Parks and Tourism).

The state of Kansas acquired 1,280 acres of land for the park in 1928 and dammed Ladder Creek, also called Beaver Creek, to create Lake McBride, now called Lake Scott, as a

Figure 2. Lake Scott. Photo from Friends of Lake Scott State Park.

recreational oasis. After damage to the dam by a 1933 flood nearly drained the lake, the Civilian Conservation Corps (CCC) repaired the dam, planted 4,000 evergreen trees, and made additional improvements (KDWPT, 2016a).

Recreational opportunities today at the park and nearby 160-acre wildlife area include boating, swimming, hiking, horseback riding, fishing, hunting, and wildlife observation. Common wildlife includes wild turkeys, deer, bobcats, and beavers (KDWPT, 2016c). Rare wildlife includes the Scott optioservus riffle beetle, which has not been found anywhere except at Big Spring in Lake Scott State Park (KDWPT, 2016b). Battle Canyon south of the lake is the site of the 1878 Battle of Punished Woman's Fork—the last engagement of the Plains Indian Wars in Kansas—between the U.S. Army and Northern Cheyenne.

Long before the lake was built, the abundant water supply from the springs and creek in the otherwise semi-arid environment lured inhabitants and travelers. Evidence

Figure 3. Ogallala Formation bluff.

Figure 4. Big Spring.

found in the park of pre-historic and historic occupations include fragments of pottery, turquoise, pipes, knives, and needles; glass and bone beads; a bone whistle; roasting pits; and burial sites (KSHS, 1983). A dart point found during the Kansas Archeology Training Program (KATP) field school in 2009 may date back thousands of years (Hoard, 2009).

El Cuartelejo

The most notable archeological site at Lake Scott State Park encompasses the ruins of a Southwestern-style pueblo (fig. 5). University of Kansas paleontologists S. W. Williston and H. T. Martin were first to excavate the site, in the late 1890s, after landowner Herbert Steele alerted them to an unusual small mound near his home. Williston, Martin, and later investigators proposed that the ruins were the remains of a pueblo built by Taos Indians within a Plains Apache settlement known in historical documents as El Cuartelejo (KDWPT, 2016a)

A common hypothesis is that a Taos band escaping Spanish suppression in the U.S. Southwest fled to El Cuartelejo (also spelled Quartelejo) in the mid-17th century and settled in for a number of years with the Plains Apache. Later, a band of Picuries also fleeing Spanish rule were thought to have arrived there (Martin, 1909). Exactly when, why, how often, and how long the Taos and Picuries were at El Cuartelejo, as well as the size and chronology of the Plains Apache settlement, are still being investigated and debated, but evidence shows the Pueblo and Plains cultures overlapped and the site was well used.

When Williston and Martin excavated the seven-room pueblo (fig. 6), they found the remains of thick, mud-plastered stone walls—by then just 2½-feet high—rectangular fireplaces lined with stone, a grinding stone, and post holes, as well as evidence of a destructive fire. Although most of the artifacts found during subsequent excavations are representative of Plains Indian cultures, several pottery fragments appeared to be of Southwestern origin (KSHS, 1983). And in 2014, researchers analyzing pottery fragments

Figure 5. El Cuartelejo ruins.

from various excavations at the site determined Pueblo potters likely made bowls and Southwestern-style vessels on site out of local materials (Beck and Trabert, 2014).

In the early 1970s, the Kansas State Historical Society and Kansas Archeological Association conducted extensive re-excavations at and around the pueblo. By that time, amateur collectors had removed artifacts and damaged the site. Erosion had also taken a toll. The pueblo ruins were reconstructed in the 1970s to the condition described by Williston and Martin (KSHS, 1983), and the number of known archeological sites in the park more than doubled to 58 following discoveries during the 2009 KATP Field School (Hoard, 2009).

The El Cuartelejo archeological district, including the pueblo and nearby sites, is a National Historic Landmark and listed on the National Register of Historic Places (KSHS, 1983). Kansas Department of Wildlife, Parks and Tourism maintains the pueblo site, which was deeded by Steele to the Kansas Society Daughters of the American Revolution (DAR)

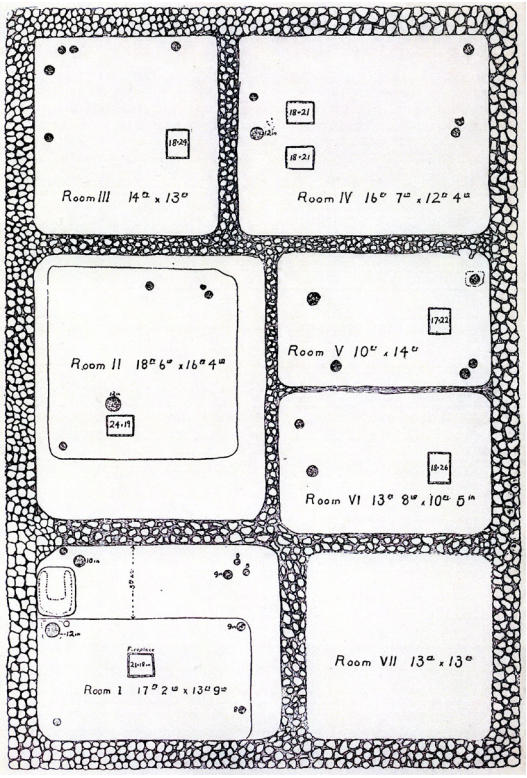

Figure 6. Drawing of the El Cuartelejo ruins from an 1899 excavation report by S. W. Williston and H. T. Martin (Martin, 1909).

in 1922 (KDWPT, 2016a) and is now owned by the state. In October 2015, KDWPT announced the formation of the Scott State Park Historic Preservation and Development Committee, a private group of citizens that is partnering with KDWPT to seek funding to enclose the ruins and build an interpretive museum (Pettengill, 2016).

Herbert and Eliza Steele Homestead

Herbert and Eliza Steele homesteaded land that is now in Lake Scott State Park. The seven-room stone house they built in about 1894 has been renovated over the years but still retains its original character and architecture (fig. 7). It is now a museum maintained by volunteers with visitor donations.

Half of the land now in the park belonged to the Steeles, who were interested in protecting and promoting it as a recreational resource. Besides deeding two acres of the El Cuartelejo site to the DAR, they invited members of the newly formed Kansas Forestry, Fish and Game Commission (KFFGC; predecessor of KDWPT) to tour their farm and Ladder Creek Canyon in 1925 in hopes the state would want to develop the area into a lake and park. The 1,280 acres the KFFGC eventually bought included 640 acres of Steele property, for which the couple was paid $18 per acre. The Steeles, who had outlived all three of their children, were allowed to stay in their home rent-free for the rest of their lives (KDWPT, 2016a).

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Figure 7. Herbert and Eliza Steele homestead (KDWPT, 2016c)

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Contacts

Greg Mills, Park Superintendent
Lake Scott State Park
620-872-2061
Greg.Mills@ksoutdoors.com

Jerry Thomas
Artist, Manhattan
785-565-1914
ljjms@cox.net

Thursday, August 18, 2016

6 a.m.	Buffet breakfast Poky Room, Clarion Inn (start time is informal)
	(Check out of hotel, load luggage in your car or store with hotel manager)
7:45 a.m.	**Bus leaves hotel**
	Bus session—Water Technology Farms *Tracy Streeter*, Director, Kansas Water Office *Tom Willis,* Owner, T&O Farms LLC
8:15 a.m.	**Site 7:** T&O Farms LLC *Loren Seaman*, Crop Consultant *Monty Teeter,* Dragon-Line Drip Irrigation *Jonathan Aquilar and Isaya Kisekka,* Kansas State University Research and Extension *Mike Meyer,* Kansas Department of Agriculture, Division of Water Resources Other partners
9:10 a.m.	Bus to Site 8
	Bus Session—Water Conservation and Planning in GMD3 *Mark Rude,* Executive Director, Southwest Kansas GMD3
9:50 a.m.	Kearny County Fairgrounds Restroom Break
10:10 a.m.	**Site 8:** Amazon Ditch Flume *Randy Hayzlett*, Arkansas River Compact Commissioner *Hal Scheuerman,* Arkansas River Compact Commissioner
10:45 a.m.	Bus to Site 9
11 a.m.	**Site 9:** Lakin Public Water Supply Treatment Plant *Mike Heinitz*, City Administrator, Lakin *Fred Jones*, Water Resource Manager, City of Garden City
11:40 a.m.	Bus to Site 10
	Bus Session—Energy Planning and Environmental Oversight in Kansas *John Mitchell,* Director, Division of Environment, Kansas Department of Health and Environment (KDHE) *Gary Mason,* Deputy Secretary for Environment, KDHE

12:10 p.m. **Site 10:** Finnup Center for Conservation Education, Garden City
Restroom Break
Lunch—sponsored by Sunflower Electric Power Corporation

12:45 p.m. **Panel:** Transmission Line Planning for Kansas Energy Development
Moderator: *Rex Buchanan,* KGS
Antoine Lucas, Director of Transmission Planning, Southwest Power Pool
John Olsen, Executive Director, Systems Operations & Transmission Development, Westar Energy
Al Tamimi, Ph.D., Vice President, Transmission Policy, Sunflower Electric Power Corporation

1:50 p.m. Bus to Site 11

Bus Session—Drive by Wind Turbine Staging Area, Trans-Load Site
Matt Allen, City Manager, Garden City
Jennifer Cunningham, Assistant City Manager, Garden City

2:20 p.m. **Site 11:** Milk Processing Plant Construction Site
Matt Allen, City Manager, Garden City
Larry Thompson, KDOT

2:50 p.m. Bus back to Clarion Inn

Ogallala–High Plains Aquifer in Southwest Kansas: Conditions, Conservation, and Plans

Southwest Kansas Groundwater Management District 3 (GMD3) manages the largest portion of the High Plains aquifer in Kansas. It not only has the largest areal extent but also the most water in storage as indicated by saturated thickness (fig. 1). Intensive development of this groundwater in southwest Kansas has led to the greatest amount of water use in the state (fig. 2). Water has been key to the large, integrated agricultural economy of the region with high-yield irrigated crops, animal feeding operations, meat packing plants, dairies, milk processing, and ethanol plants.

An irrigated field has higher crop yields than dryland production. Over the past 10 years in southwest Kansas, irrigated corn averaged 149 bushels per acre more than dryland corn yields (Roe, 2016). Irrigation also provides a buffer from drought, with farmers limited by their water right quantities and the physical ability of the aquifer and irrigation system to keep up with crop water demands.

The ability to withdraw large quantities of water in southwest Kansas has also led to the greatest water-level declines in the state. Cumulative declines in GMD3 from 2010 to 2014 were nearly 15 feet, or about 3 feet per year. 2015 was a relatively wet year with favorably timed rainfall during the growing season, so irrigation demands were less and the districtwide decline averaged just 0.84 foot.

The Kansas Geological Survey (KGS) developed a hydrologic model for southwest Kansas that simulates groundwater flow and stream-aquifer interactions from 1947 to 2007 and projects future groundwater conditions based on different water management

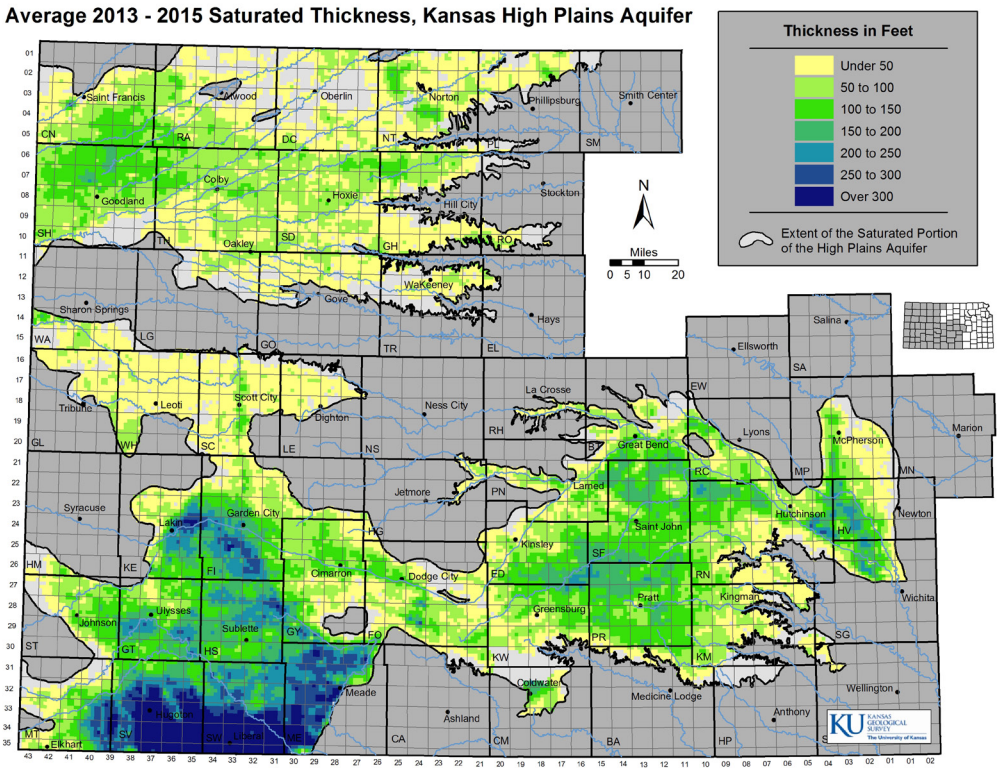

Figure 1. Average saturated thickness of the Kansas High Plains aquifer, 2013–2015.

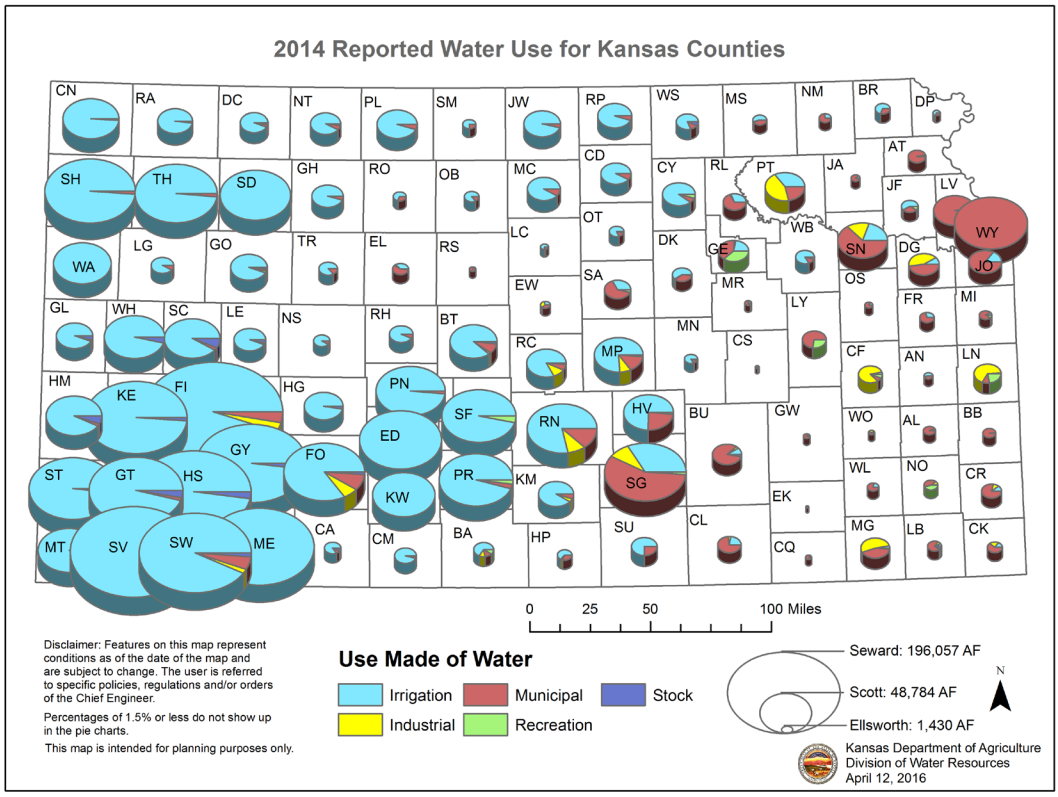

Figure 2. Average reported water use in 2014, by county and type of use.

scenarios. The model shows a nearly 30% loss in aquifer storage between 1947 and 2007 (Liu et al., 2011). Model results indicate that unless there is a significant reduction in water use, groundwater declines (fig. 3) will force an increasing number of wells to reduce pumping by 75% or more or to be shut off completely. By 2068, only Stevens, Seward, and Meade counties are projected to have significant aquifer storage left (fig. 4).

The decline of the Ogallala aquifer has been known for decades. When more is taken out than replaced, it is an unsustainable system. Annual water-level measurements, index wells, water modeling, and studies have improved our understanding of the aquifer characteristics and the demand for water in relation to the region's climate. To slow the decline, many efforts have been made and programs developed to conserve and extend the Ogallala aquifer. The GMD3 staff, board, and members have led the discussion on obtaining alternate, sustainable sources of water for the future.

Water Conservation Programs

Local Enhanced Management Areas (LEMAs) and Water Conservation Areas (WCAs) are conservation programs available to water producers in GMD3. (See pages 32–33 for a description of the LEMA and WCA programs.)

Water Technology Farms

Water Technology Farming is a strategy that reduces water consumption using technologies infrastructure, alternative crops, and enhanced water management. It's an approach that tests the economic and water-conservation impact of implementing the latest technologies and methods on an irrigated farm. The Kansas Water Office (KWO) and others partner on equipment and technical assistance, including crop consultants, to enable producers to incorporate these innovative methods into their farming operations. Producers agree to allow evaluation of their farming operation details to determine the success of various strategies and decisions.

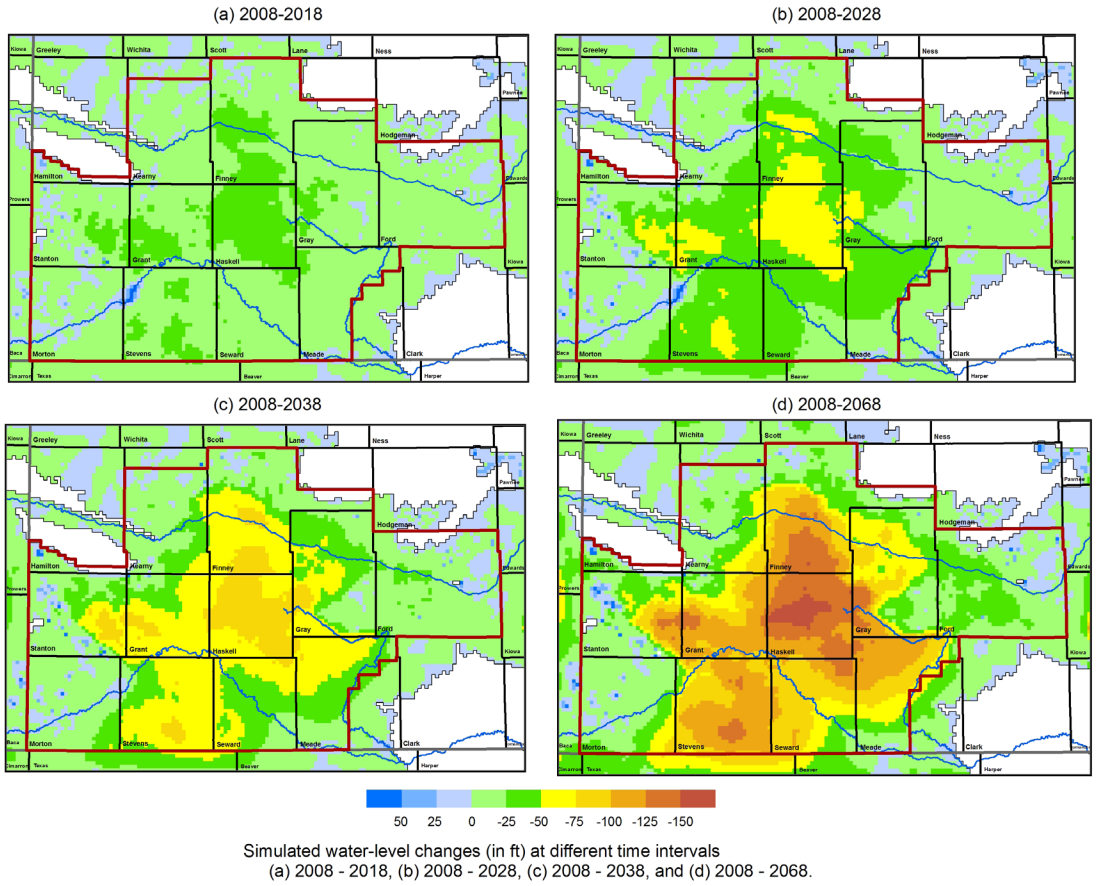

Figure 3. Water-level changes (in feet) projected in southwest Kansas under current pumping conditions for four different time spans (Liu et al., 2012).

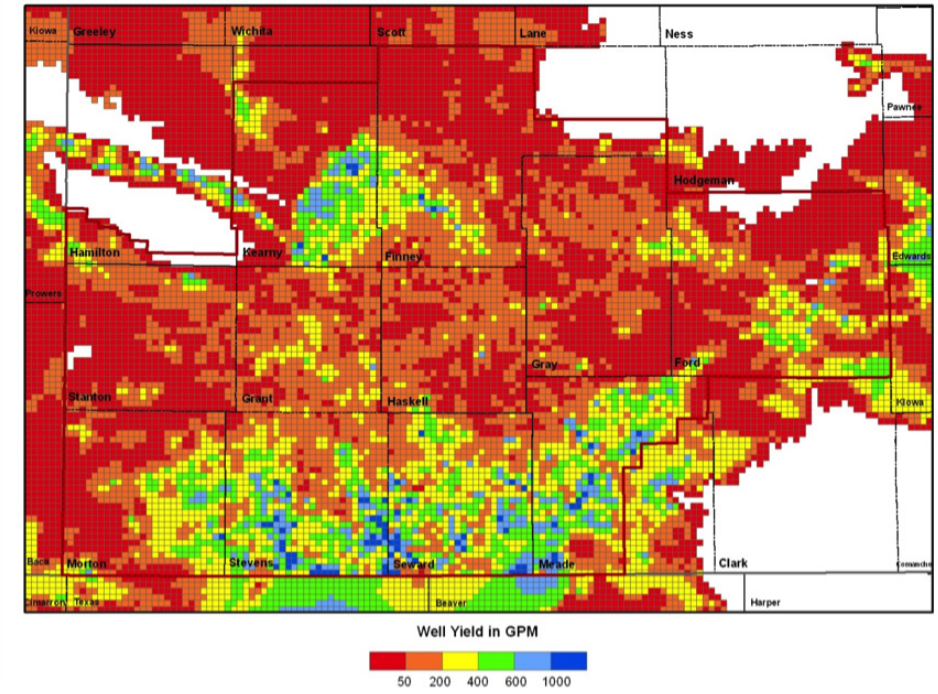

Figure 4. Projected well yields (in gallons per minute) available in year 2068 under the current pumping scenario (Liu et al., 2012).

Although water technology farming does not require reduced total water use, farmers are strongly encouraged to operate within a framework that conserves and extends the life of the Ogallala aquifer. To be eligible for cost share on equipment from the KWO, participating farmers must be enrolled in a WCA or LEMA. More efficient irrigation technology without a water conservation commitment would have benefits for crop production but could also allow pumping of a low-yield irrigation well beyond what was possible under older technology and could actually accelerate aquifer depletion.

A three-year pilot began in the spring of 2016 on T&O Farms LLC in Finney County, using new technology and frequent crop consulting for close management of water application and crop conditions. The objective is to keep the farm operation profitable while enrolled in a WCA that commits to using 40% less irrigation water than authorized. Ten fields planted to corn, soybeans, alfalfa, and sorghum (milo) are part of the pilot study, which will compare fields irrigated with mobile drip irrigation systems ("Dragon-Lines") with nearby fields irrigated with traditional center pivot spray nozzles (fig. 5). The farm manager will be offered advice on how to maximize yields and returns on investments with reduced irrigation water. Kansas State University (KSU) is managing the research and providing technical support with input by local crop consultants. This pilot project has support from the following partners and programs: T&O Farms LLC, Kansas Farm Bureau, KWO, KSU, KGS, Kansas Corn Commission, National Sorghum Check-off Program, Netafim, Seaman Crop Consulting, Aquaspy, Aquachek, Helena Corporation, Arkansas River Projects Fund, Ogallala Aquifer Initiative, and Purpose Unlimited.

Regional Conservation Partnership Program (RCPP), GMD3, NRCS-USDA

This grant program provides assistance to producers to purchase and link soil moisture probes, water flow meter sensors, and other

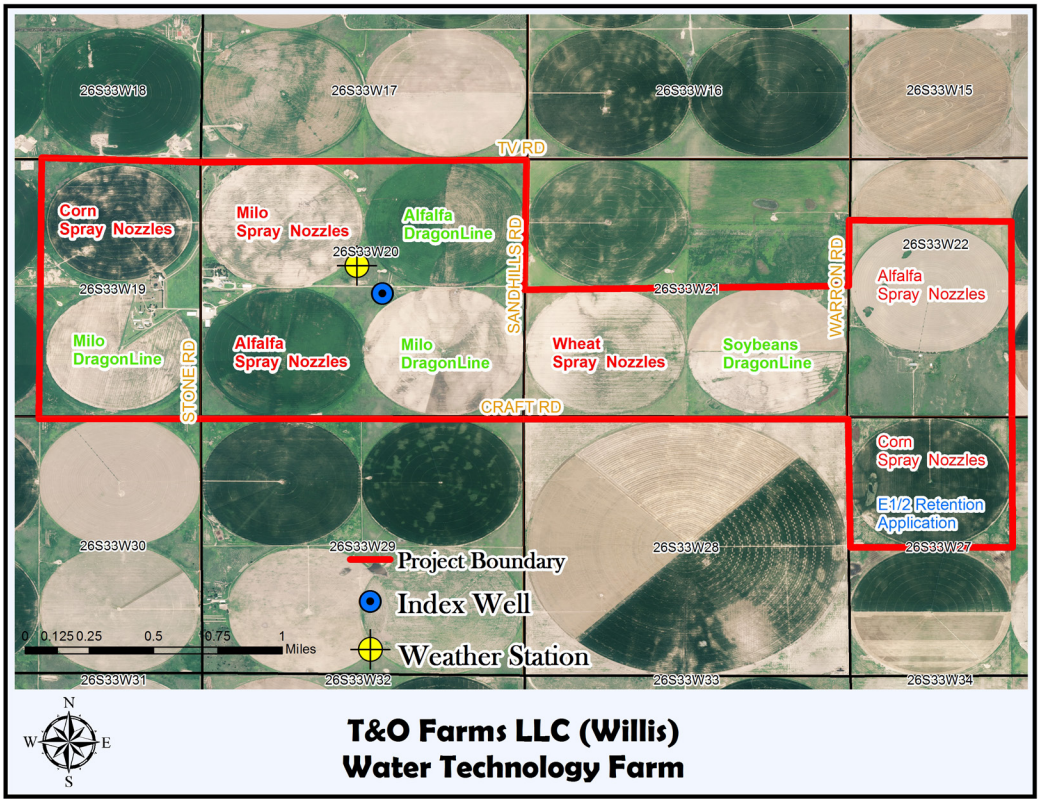

Figure 5. Proposed planting arrangement for year 1 of pilot study at T&O Farms LLC.

field and irrigation system level sensors that provide near-real-time water information to a smart device dashboard. The USDA pays for the implementation of advanced irrigation-water management technologies if a producer agrees to contract with a crop consultant on their use in a 120-acre field for at least three years. The goals are to reduce Ogallala water use by 20% from historical rates and to provide a cost savings for the producer.

Upper Arkansas River Corridor Conservation Reserve Enhancement Program (CREP)

A federal-state-local partnership, this program provides annual payments to irrigators in an eligible area along the upper Arkansas River corridor who voluntarily enroll their acreage, dismiss the associated water right, and keep the acreage in a conservation planting for 14 to 15 years. Groundwater conservation along the river is a primary goal. However, establishing a permanent cover on highly erodible land has been of equal merit. The soils are sandy and fragile; windblown erosion will be hard to manage once there is insufficient groundwater to establish a cover crop. As of September 2015, 17,176 acres have been enrolled and water rights permitted for 34,500 acre feet have been permanently retired.

Alternate Water Sources

Dakota Aquifer

The Dakota aquifer extends beneath the western two-thirds of Kansas and has been developed as a water supply where it is fresh or only slightly saline. It underlies the High Plains aquifer in areas where both aquifers are present. Although the Dakota is geographically extensive, it contains less water than the High Plains aquifer and much of it is saline. Southwest Kansas has the most wells in the Dakota aquifer and pumps the most water out of it, primarily for irrigation. The increasing number of wells completed in both the High Plains and Dakota aquifers indicate that the Dakota is providing supplemental water to offset declines in the High Plains aquifer (Whittemore et al., 2014).

Other groundwater sources

Searches for alternate sources of water have led to drilling test holes into Permian-aged formations. Recently, test holes were drilled 800 to 1,000 feet below the ground surface in Haskell County at a cost of nearly $30,000 per test well to explore for alternate sources of water. Water quantity, water quality, and protection of the upper, freshwater aquifers are all factors in determining suitability of alternate sources.

The highly mineralized brine water that is produced with oil and gas development is also being evaluated for possible treatment and reuse. Typically, this formation water, known as "produced water," is treated as waste and injected into saltwater disposal wells into another deep formation. The high volumes of saltwater disposal in some areas have triggered small earthquakes, particularly in Harper, Barber, and Sumner counties. At this time, there is no economic way to transport and treat the brine to a level that is suitable for irrigation.

Kansas Aqueduct Proposal

Interbasin transfer of water for use on land overlying the Ogallala aquifer was evaluated by the U.S. Army Corps of Engineers as part of a 1982 federal report, *Six State High Plains: Ogallala Aquifer Area Regional Study*. One transfer discussed in the report would bring Missouri River water through a 360-mile canal to western Kansas (fig. 6). The study was updated in 2015 to re-examine municipal and irrigation demands, water availability, and the technical feasibility of diverting high flows. Based on the storage capacity of a proposed reservoir near the river and the frequency of flows above those needed for navigation and water-supply requirements, the report determined a 6,000 cubic feet per second transfer along a route following a ridge line would be the most efficient. The preliminary estimate projects an $18 billion construction

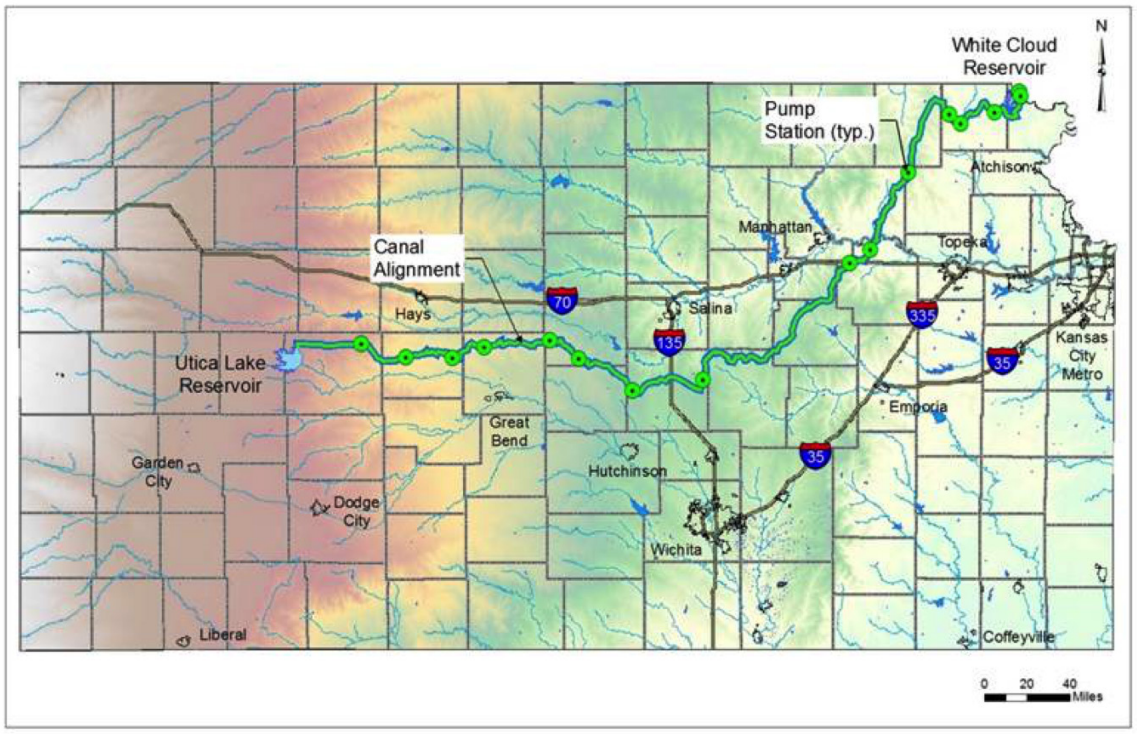

Figure 6. Proposed interbasin aqueduct route for transferring Missouri River water to western Kansas. Map by HDR for U.S. Army Corps of Engineer's study (2015).

cost over a 20-year period. The operation and maintenance, interest, amortization, and energy costs were projected at $1.08 billion annually. Environmental review and mitigation costs were not included.

The GMD3 board is moving forward to keep the Kansas aqueduct project an option for future water supplies. GMD3 was a proponent of recent proposed legislation to lower the filing fee to apply to appropriate water that otherwise leaves the state. Under current law, the filing fee for an application to appropriate 4 million acre feet of water would be about $900,000. The GMD3 board is discussing raising the fee it assesses its members from the current $0.12 per acre foot (the maximum allowed is $1.00 per acre foot) to help fund water transfer related activities. GMD3 contracted a study that projected a 10% statewide economic shrinkage with a depleted aquifer if no alternate water supply were available and producers and consumers did not adapt to the water loss (Apparet Analytics LLC, 2015).

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Contacts

Mark Rude, Executive Director
Southwest Kansas Groundwater Management District 3
620-275-7147
mrude@gmd3.org

Tracy Streeter, Director
Kansas Water Office
785-296-3185
tracy.streeter@kwo.ks.gov

Upper Arkansas River Compact, Use, and Quality

Arkansas River flows are highly dependent on snowmelt in the Colorado Rocky Mountains, rain events, and use by Colorado. In Kansas, no major tributaries contribute to the flow before Mulberry Creek in Ford County. Releases from Colorado's John Martin Reservoir often determine when the river is flowing.

The Kansas-Colorado Arkansas River Compact was ratified in 1948 to protect each state's access to the river flows and to allocate the benefits of John Martin Reservoir, built for irrigation and flood control. The compact requires that Colorado's post-compact development not further reduce flows that otherwise would be available to Kansas. The compact also specified the maximum withdrawal rate each state could call for water from John Martin Reservoir but had no specific allocations. It was a first come, first served call for water, which became very inefficient. An operating plan agreement in 1980 set up a system of storage accounts in John Martin Reservoir that allocates 40% of the water from the compact conservation storage to Kansas and 60% to Colorado.

When the compact was ratified, an Arkansas River Compact Administration was established. Current Kansas representatives are David Barfield, the Kansas Department of Agriculture's Division of Water Resources (DWR) chief engineer; Hal Scheuerman of Deerfield; and Randy Hayzlett of Lakin.

Six active irrigation districts in Kansas divert water from the Arkansas River between the state line and Garden City (fig. 1). Under the current amended compact, the ditch companies can call for releases from John Martin at times and rates that benefit their growing season. Peak demand for crop water is usually in July.

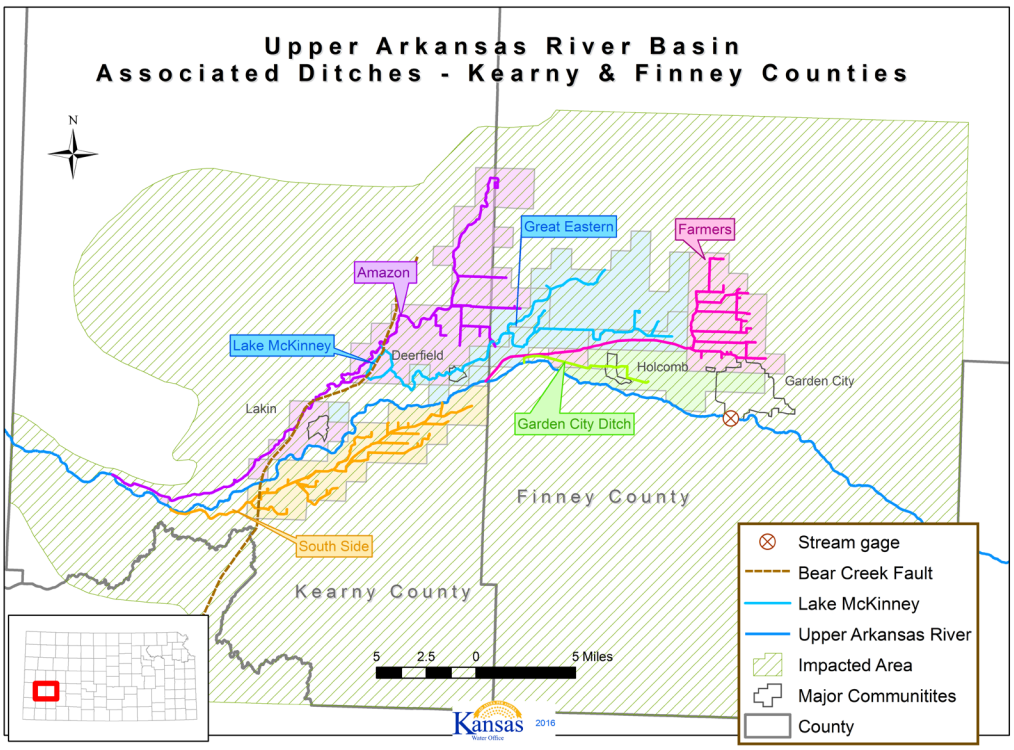

Figure 1. Irrigation ditches and their service areas. Map by Diane Knowles, Kansas Water Office.

In 1985, Kansas filed a lawsuit to enforce the terms of the compact. As a result, in 2005 Colorado paid Kansas more than $34 million in damages for compact violations. Of that amount, $9.7 million went to a fund for water conservation projects in the area damaged by non-compliance. Projects supported from the fund include Lake McKinney bypass and renovation, South Side Ditch alternative ditch system and ditch lining, Frontier Ditch west bridge creek flume replacement, and an Amazon ditch gate replacement. The fund (Western Water Conservation Projects Fund) is administered by GMD3, and recommended projects are reviewed and approved by the Kansas Water Office director in consultation with the DWR chief engineer.

One project completed in 2016 was replacement of the Amazon flume near Lakin. The original flume was a wood structure built in 1954 to convey water diverted from the Arkansas River across the Sand Creek drainage into an irrigation ditch system. The new flume is reinforced concrete U-tub with new substructure supports. The flume's integrity is essential because it conveys all of the water delivered to the Great Eastern Ditch and nearly all of the water delivered to the Amazon Ditch (fig. 2). The new flume also provides greater operational efficiency.

Water Quality

The Arkansas River is one of the most saline rivers in the United States when it enters Kansas. Salinity in the river derives from irrigation practices in Colorado that, as a result of evaporation and transpiration, leave a large quantity of residual salts dissolved in a small volume of water. Sulfate is the major dissolved solid contributing to the high salinity, with sulfate concentrations ranging to more than 2,000 milligrams per liter (mg/L) in the river water. Total dissolved solids can exceed 4,000 mg/L where the river enters Kansas (Whittemore, 2000a). Freshwater by definition has less than 1,000 mg/L total dissolved solids. In addition, concentrated selenium usually exceeds the chronic toxicity level for aquatic life, and uranium typically exceeds the allowable level for public supplies of drinking water. In general, selenium and uranium increase with increasing salinity of

Figure 2. Amazon irrigation ditch, Kearny County. Photo by Bill Johnson.

the river water (Whittemore, 2000a). The Kansas Department of Health and Environment established TMDLs (total maximum daily load) for several contaminants in the river. A TMDL, developed where action is needed to restore water quality, is the calculated maximum amount of a pollutant that a body of water can receive from all sources and still meet water-quality standards.

Poor-quality river water is contaminating the groundwater along the upper Arkansas River corridor in Kansas (Whittemore, 2000b). Saline water from the river and from fields irrigated with river water is seeping into the alluvial aquifer and Ogallala–High Plains aquifer (fig. 3). Municipalities, rural homes, and businesses along the river corridor have been affected by poor-quality water. Between 2006 and 2011, Syracuse, Hamilton RWD1, Lakin, Deerfield, and Holcomb all experienced water-quality impairments. Additional challenges for these water users include inadequate resources to build new treatment plants, insufficient expertise and funding to operate and maintain existing treatment facilities, and the need for adequate disposal of the waste stream generated from water treatment.

Water Quality and the City of Lakin

National drinking water standards for public supplies, developed by the U.S. Environmental Protection Agency (EPA), specify maximum contaminant levels (MCLs) for a list of contaminants. The EPA also established secondary drinking water recommendations for contaminants that cause cosmetic or taste and odor problems but don't pose a major health risk. Several communities along the upper Arkansas River (fig. 4) have had at least periodic increases in contaminants above the maximum level deemed safe for drinking water.

In 2003, the EPA set an MCL of 30 micrograms per liter (same as parts per billion) for uranium in drinking water supplies. Long-term exposure to high levels of uranium can result in kidney damage and increase the risk of cancer. Though uranium occurs naturally in rocks and soil, leached uranium has become concentrated in Arkansas River water through evaporation and transpiration, primarily as the result of irrigation practices in Colorado. As river water reached the aquifer from which Lakin draws its drinking water, the salinity and uranium concentration in the groundwater increased. Informed that its public water supply exceeded the MCL for uranium, the City of Lakin monitored the city's wells for four years and determined that the levels were persistent and required action.

In 2015, the City of Lakin began operating a new nanofiltration plant. Nanofiltration is a physical and chemical filtration process that

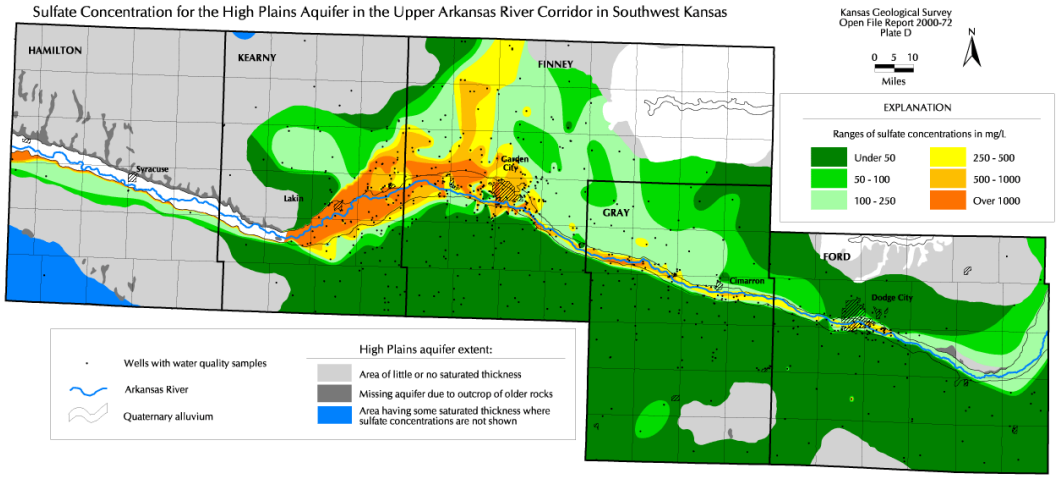

Figure 3. Sulfate concentrations in the Ogallala–High Plains aquifer in the Arkansas River corridor (Whittemore, 2000b).

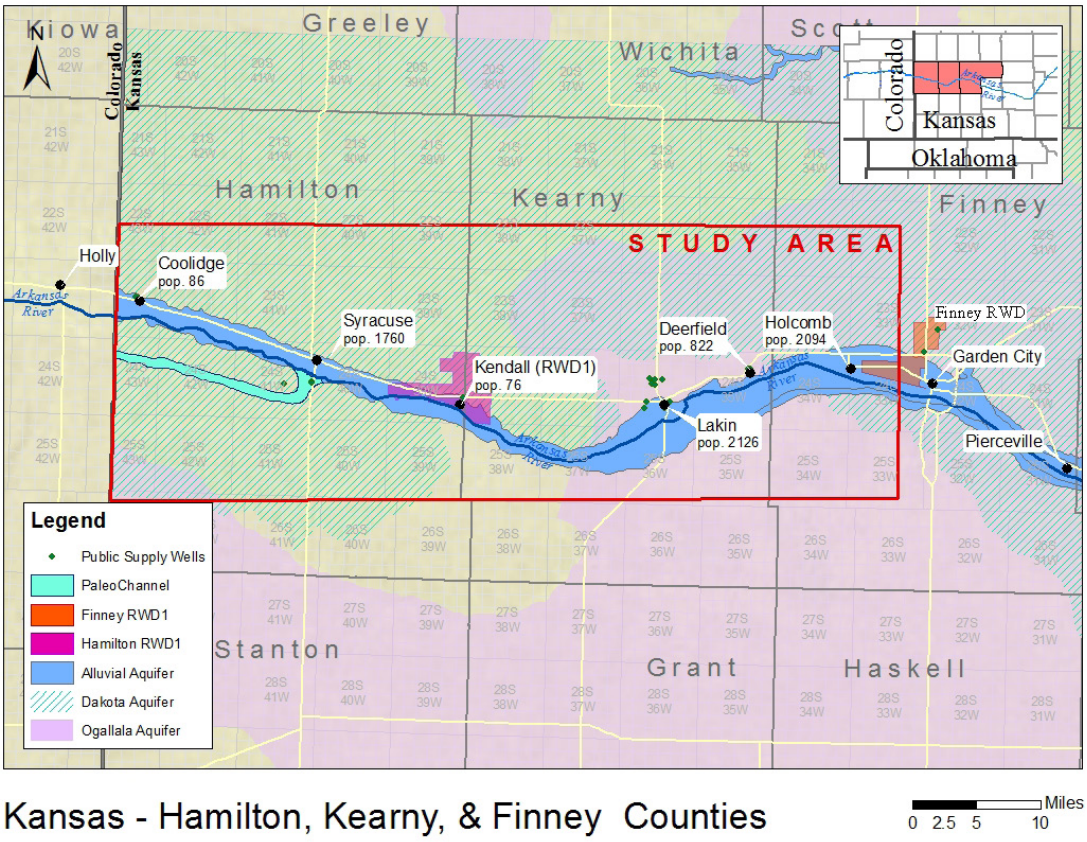

Figure 4. Communities along the upper Arkansas River (Bureau of Reclamation et al., 2014).

can remove contaminants down to 0.0001 micrometers in size. Although reducing uranium was the driving force behind the water-quality treatment process, the city selected an upgrade option that also alleviated water hardness and that would be able to address more-restrictive drinking water standards in the future.

An especially expensive component of the treatment process is disposal of waste that contains radioactive materials. Lakin's wastewater is disposed of in a Class V underground injection well normally designated for non-hazardous fluids. However, because the plant's water contains higher than acceptable levels of uranium, the city's disposal well is required to have many of the same protective criteria of a hazardous-waste underground injection well. The city received federal assistance with a grant and a loan through USDA Rural Development, although the majority of the treatment plant's $7.4 million cost was financed through the State Revolving Loan Fund. These loans are being paid off through increases in customers' water bills. The base rate went from $17/month to $40.16/month for the first 5,000 gallons, and water use has dropped off dramatically due to customers' price sensitivity. The treatment plant has the capacity to sell treated water to other entities.

Potential Effect of Uranium in Irrigation Water

In addition to the effect of uranium on public water supplies, a question has arisen about the repercussions of using water with high uranium content for irrigation. The Kansas Geological Survey is completing a study that measures the concentration of uranium in soils and crops in the river corridor where uranium is high. The results to date indicate that most of the uranium

in affected plants is concentrated in the roots; the grain has low uranium concentration (Whittemore et al., 2015).

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Contacts

David Barfield
Division of Water Resources
Kansas Department of Agriculture
785-564-6640
David.Barfield@kda.ks.gov

Mike Heinitz
City of Lakin
620-290-4032
mheinitz@pld.com

Don Whittemore
Kansas Geological Survey
785-864-2182
Donwhitt@kgs.ku.edu

Energy in Western Kansas: Transmission Line Planning Process

Coal-fired power plants generate nearly two-thirds of the state's electricity, but wind energy development has been growing over the past decade, particularly in western Kansas, and is gradually replacing some of that net generation (EIA, 2016). Kansas has some of the nation's greatest wind energy potential and is one of the leading states in wind power development (fig. 1). In 2014, wind provided more than 20% of the state's net electricity generation (EIA, 2016). Westar Energy is on track to provide more than 30% of its retail customers' and more than 50% of its residential customers' electricity needs with wind energy by the end of 2017 (Loveless, 2016). By 2017, Kansas is projected to produce more than 4,000 megawatt hours (MWh) of wind energy in 30 counties. The extension through 2019 of federal tax credits for wind production is helping support development. However, for continued growth in wind energy sales, new or upgraded transmission lines are necessary.

A critical component to increasing the electrical energy production in western Kansas is the ability to reliably transport electricity from where it is generated to where it's in demand. The rapid growth in wind energy in western Kansas has congested the current transmission infrastructure. Much of the wind energy is going to markets that are outside of western Kansas, requiring new or upgraded lines to transmit the electricity. Additionally, transmission lines are aging; nationally, the bulk of lines are more than 30 years old (Barnett, 2016).

Southwest Power Pool (SPP) is one of seven regional transmission organizations (RTOs) in the United States. RTOs are not-for-profit organizations authorized by the Federal Energy Regulatory Commission (FERC). They do not own transmission lines or any part of the power grid but are instrumental in planning and running the grid. RTOs identify the needs and limitations of the electric grid, develop plans for transmission line upgrades, track the progress for timely completion of system improvements, and manage the wholesale energy market.

The SPP serves all or part of 14 states in the central United States (fig. 2). It has a responsibility to ensure reliable supplies, adequate transmission organization, and competitive, least-expensive, wholesale electricity prices. FERC Order 1000, issued in 2011, requires transmission planning at the regional level to evaluate possible alternatives and create a regional transmission plan. With input from members, regulators, and stakeholders, the SPP creates regional transmission plans to meet long- and near-term electricity needs. The plan is to select solutions that are more efficient or cost-effective and meet the region's needs.

The SPP and stakeholders developed a transmission owner selection process to promote competition in regional transmission line planning and development. An industry expert panel was created to review and prioritize competitive proposals. Once a project is selected, the SPP gives a directive for a new line to a utility provider. Who pays for a new or upgraded line depends on the project. Local lines may be paid for by local users, but large projects that benefit a wide area may be paid for by all SPP customers. Fixed costs are built into the energy usage costs. The regional transmission plans are to ensure the costs of transmission solutions are allocated fairly to the beneficiaries and are roughly commensurate with estimated benefits.

For example, the ITC Great Plains 345 kV transmission line (also known as the KETA line) that runs from Spearville through Hays and up into Nebraska was completed in

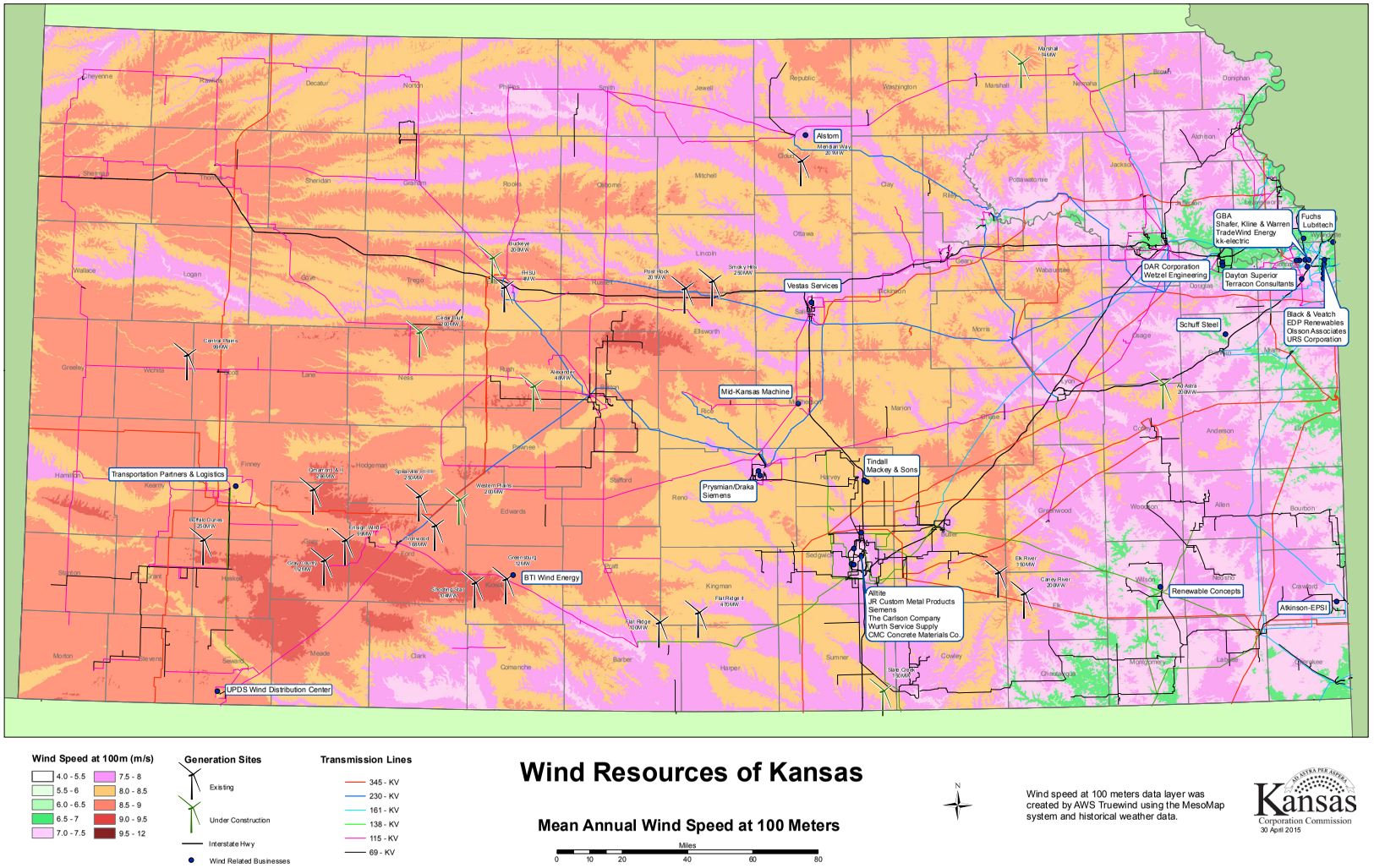

Figure 1. Wind generation and transmission lines in Kansas. From Kansas Corporation Commission, 2015.

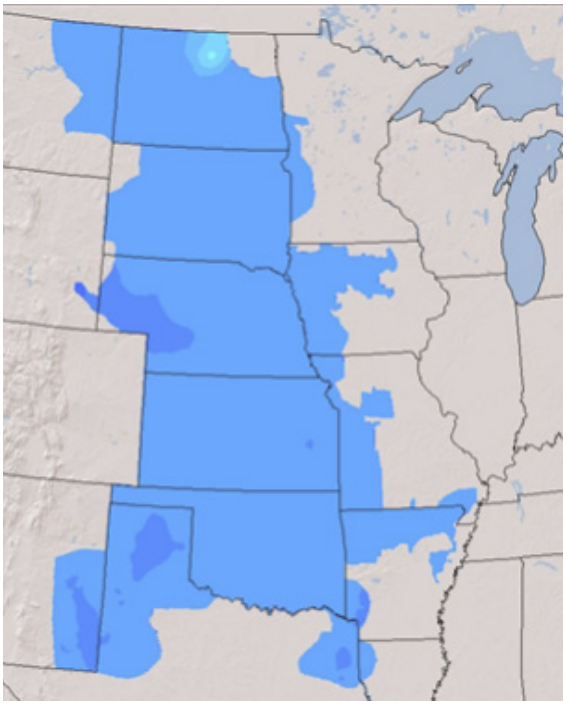

Figure 2. Southwest Power Pool coverage includes all of Kansas (Southwest Power Pool, 2016).

December 2012. It was one of five projects in a nine-state region for which the SPP approved the costs to be spread on a pro-rated basis to all customers in the pool, not just to those in the region where the line was built. The SPP took this approach because the projects created a more reliable power grid (Green, 2009).

The SPP has a 10- to 20-year planning horizon for considering new energy resources and determining which existing energy resources will be retired. The following is a typical timeline for new infrastructure development: planning (12–18 months), selection of builder (3–12 months), and design, right-of-way acquisition, and construction (2–6 years) (Nickell, 2016).

The Grain Belt Express Clean Line (fig. 3) is a proposed private merchant line that would be used to transport wind energy from western Kansas to eastern markets. The proposed 780-mile route would begin southeast of Dodge City, travel through Kansas, Missouri, Illinois,

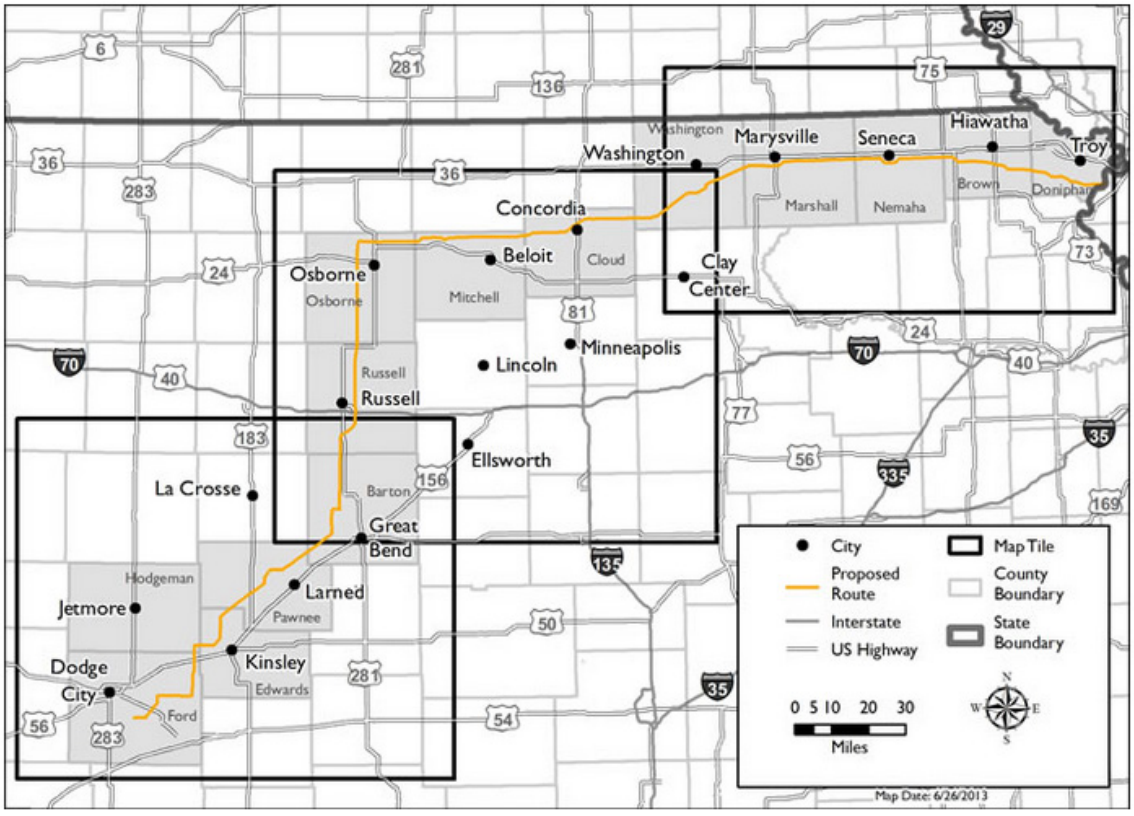

Figure 3. The 370-mile proposed route of the Grain Belt Express Clean Line through Kansas (Grain Belt Express Clean Line, 2016).

and Indiana, and have the capacity to deliver up to 4,000 megawatts. This could double wind energy production in Kansas. The plan is projected to provide an economic boost by way of land leases for wind farms and jobs to build and maintain the infrastructure (Grain Belt Express Clean Line, 2016). However, it would be a private line for private use and would require additional regulatory approvals before it could proceed. This private line would not be under the SPP's direction or part of the SPP's power grid planning and management (Nickell, 2016). The Kansas Corporation Commission approved Grain Belt Express's permission request to build the new high capacity transmission line in Kansas.

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Contacts

Antoine Lucas
Director of Transmission Planning
Southwest Power Pool
alucas@spp.org

John Olsen, Executive Director, Systems Operations and Transmission Development
Westar Energy
john.olsen@westarenergy.com

Al Tamimi, Vice President
of Transmission Policy
Sunflower Electric Power Corporation
atamimi@sunflower.netatamimi@sunflower.net

Garden City's Economic Development: Truck-Train Transloading and Dairy Processing

Two new economic development projects are under way in Garden City. Construction for the first, a $235 million dairy ingredients plant, began in October 2015. Plans for the second, a transload shipping facility, are in the works after Garden City was selected by the Kansas Department of Transportation (KDOT) as one of two towns to serve as a transloading hub for trucks and trains.

Dairy Ingredient Plant

The decision to build a sizable milk processing plant in Garden City is a reflection of the growth of the dairy industry in western Kansas, which had no large dairies 20 years ago but now produces about 70% of the state's milk (Kansas Dairy, 2016). Although the eastern half of the state has significantly more licensed dairies (fig. 1), those operations are, on the whole, much smaller. Due to the growth in western Kansas, the state rose from 30th in the country in milk production in 1996 to 16th in 2014, when 3.18 billion pounds—or about 370 million gallons—of milk were produced in the state (USDA, 2015).

The milk processing plant project is a partnership between Dairy Farmers of America (DFA)—a dairy-food processor and milk-marketing cooperative with 14,000 members in 48 states—and 12 of its member farms in southwest Kansas. DFA-subsidiary Meadowlark Dairy Nutrition will manage the plant (DFA, 2016; Haflich, 2015a).

Many large dairies in western Kansas are now shipping their milk to other states for processing. The Garden City plant will be able

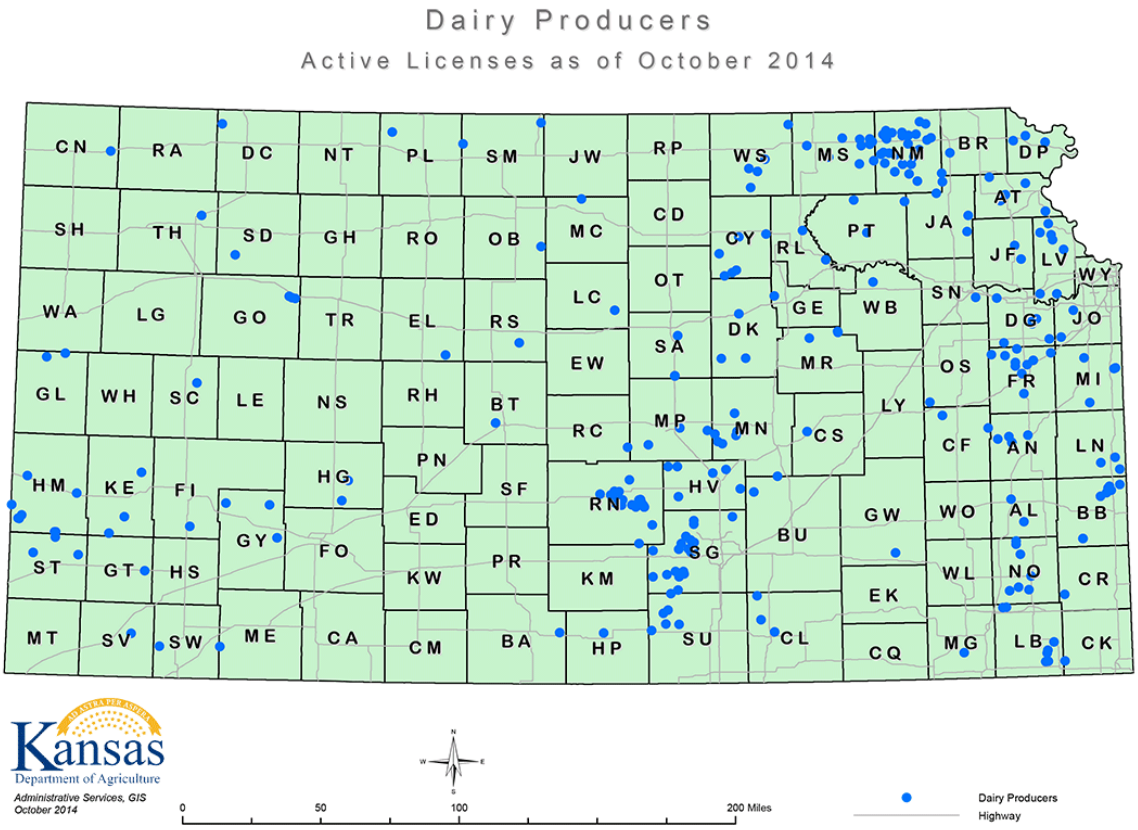

Figure 1. Kansas dairy producers with active licenses as of October 2014 (KDA, 2016).

to process 4 million pounds of milk a day from regional farms, cutting down transportation costs for area producers. The plant will produce whole, skim, and nonfat dry milk powder as well as cream (DFA, 2015).

The 214,000-square-foot plant is expected to open by the end of 2017 and bring 55–60 full-time jobs to the area. It is being built on 156-acres of city-owned land, which Meadowlark is leasing from the city with an option to purchase. In September 2015, the Garden City Commission approved a resolution of intent to issue industrial revenue bonds not to exceed $240 million to buy the land and to build and equip the plant. Meadowlark will be responsible for repaying the bonds (Haflich, 2015a).

As part of the development agreement, the city will purchase the treated wastewater generated by the plant over the first 20 years of operation and use it to water landscapes in city parks and for other non-potable purposes. The water will be used in place of treated municipal water (Haflich, 2015a).

Transload Shipping Facilities

Transloading is the process of moving goods from one mode of transportation to another, such as truck to rail or rail to ship. In 2014, the Kansas Freight Advisory Committee recommended that KDOT investigate the potential for intermodal or transload facilities outside the Kansas City area. The committee also noted that Kansas has well-maintained roads and a state-of-the-art intermodal facility near Kansas City but that western Kansas needed additional investments, including transload options.

To select transload sites, KDOT requested that cities and other entities submit proposals. A Transload Facility Site Analysis Selection Committee was appointed and the engineering consulting firm HDR Inc. was selected to help with the process. The committee included Kansans from industry, finance, transportation, technology, agriculture, banking, development, and energy (KDOT, 2015).

Of the 111 proposals submitted (some cities submitted more than one site), seven finalists were named: Abilene, Concordia, Great Bend, Norton, El Dorado's Refinery Road site, Garden City's U.S. 50 Industrial Park site, and Great Plains Industrial Park near Parsons.

In September 2015, Garden City and Great Bend were chosen from the finalists to be transload shipping centers. Garden City's proposal included expansion of an existing transload facility operated by Transportation Partners and Logistics LLC (TP&L) that was established primarily to serve the wind industry. The existing site will be expanded in phase one of the proposed project. In phase two, Garden City and the Finney County Economic Development Corporation will develop additional land at the site of the former ConAgra meat packing plant, which has been vacant since a fire in 2000. The city approved purchase of the ConAgra site in November. That property comes with nearly 1,900 acre-feet of water rights (Haflich, 2015b). In total, 900 acres are available for the facility.

The Garden City and Great Bend sites have access to federal and state highways and existing rail lines. BNSF Railway Co. will serve the Garden City facility, and Watco Company's K&O Railroad will serve the Great Bend facility. The Great Bend site covers 18 acres and is located at the Airport Industrial Park (Green, 2015). At both hubs, shipments will be transferred from train to truck and truck to train. Unlike at the BNSF Intermodal–Logistics Park Kansas City near Gardner, where whole shipping containers are loaded off rail cars onto trucks, the cargo at the Garden City and Great Bend facilities will be transferred manually.

The objective of the transload system is to combine shipping by rail and local/short-haul trucking to provide railroad access and expanded warehousing for local businesses and to decrease long-haul truck traffic. According to the Federal Highway Administration, long-haul truck traffic is expected to increase

dramatically on the national highway system by 2040, with truck traffic on high-volume federal highways expected to rise more than 175% over 2011 levels (FHWA, 2015).

As of August 2016, Garden City was awaiting final approval of its plan before preliminary engineering could begin. Great Bend received approval in February. KDOT will contribute $3 million for the $6.8 million Great Bend project. The amount for Garden City will be determined after approval (KDOT, 2016).

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Contacts

Matt Allen
City of Garden City
620-276-1160
matt.allen@gardencityks.us

Larry Thompson
Kansas Department of Transportation
620-276-3241
larry.thompson@ksdot.org

OPTIONAL (on your own)
Monument Rocks and Niobrara Chalk

In a region not known for excess moisture, the chunky pillars at Monument Rocks National Landmark (fig. 1) in Gove County are reminders of a time when water there was abundant. The towering rocks are composed of chalk formed from an enormous amount of ooze that settled on the floor of a Cretaceous inland sea about 80 million years ago (Buchanan, 2010). Deposited at a rate of about 0.036 mm, or 0.0014 inches, per year, the mud accumulated to a height of several hundred feet over millions of years (Hattin, 1982). In subsequent periods, it was buried under layers of sediment, compressed into rock, and eventually exposed at the surface after water and wind eroded away overlying rocks. Through further erosion, the thick chalk beds started to thin. The remnants at Monument Rocks (fig. 2), however, were spared when more resistant beds helped shield the softer layers below.

In Kansas, the Niobrara Chalk that constitutes Monument Rocks also crops out in other places west of a line running diagonally from north-central Finney County through Jewell County to the Nebraska state line (Buchanan, 2010). Found in 23 counties, the chalk outcrops include the freestanding Monument Rocks and Castle Rock in Gove County as well as a variety of badlands, cliffs, and bluffs. These are especially prominent along the Smoky Hill River and its tributaries in Logan, Gove, and Trego counties. Water and wind continue to slowly erode the chalk and occasionally bring about swift and dramatic change, as when the head of a chalk outlier near Monument Rock called the Sphinx crashed to the ground in 1986 (fig. 3).

Despite its name, the Niobrara Chalk is a geologic formation made up mainly but not entirely of chalk. Formations are divided into

Figure 1. Monument Rocks.

Figure 2. Monument Rocks.

members, and the Niobrara Chalk has two—the chalky Fort Hays Limestone Member and the Smoky Hill Chalk Member (fig. 4). Primarily chalk with thin layers of shale, bentonite, chert, and other minor components, the Smoky Hill Chalk Member holds most of the fossils that make the Niobrara prime collecting territory (Hattin, 1982). The chalk beds became famous in the 19th century for largely complete fossils of giant swimming and flying reptiles known as mosasaurs, plesiosaurs, and pterosaurs as well as fossils of aquatic birds with teeth, 20-foot-long fish, and clams up to six feet in diameter. Renowned paleontologists and their crews scoured the beds and the intense competition, for some, led to wrangling over fossil finds and naming rights.

In 1867, Captain Theophilus Turner, an army surgeon stationed at Fort Wallace, was the first to excavate a massive vertebrate—a 40-foot-long swimming reptile—from Cretaceous chalk in Kansas (Almy, 1987). He shipped it to Edward D. Cope at the Academy of National Science in Philadelphia,

Figure 3. The Sphinx formation before (top) and after (bottom) it collapsed in 1986.

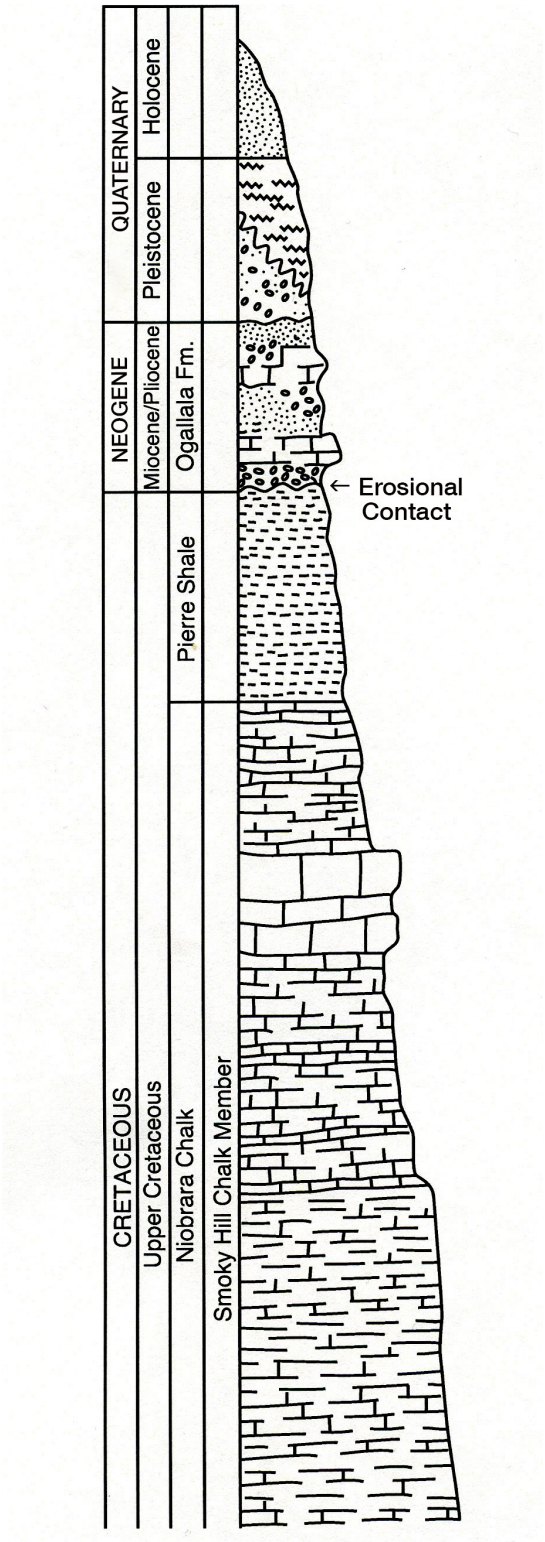

Figure 4. Column showing stratigraphic position of the Smoky Hill Chalk Member of the Niobrara Chalk. The Fort Hays Limestone Member (not shown) underlies the Smoky Hill Chalk Member. At Monument Rocks, the overlying Pierre Shale and Ogallala Formation have been eroded away.

heightening the curiosity of the scientific community. Many spectacular vertebrates were eventually recovered by and for Cope, Benjamin Franklin Mudge, Othniel C. Marsh, Charles Sternberg, Samuel W. Williston, and other scientists. Local collector and Leoti native Marion Bonner gained considerable recognition in the 20th century as a Niobrara fossil expert, and his family has carried on the tradition. As a result of their work, such species as the squid *Niobrarateuthis bonneri* bear the Bonner name (Everhart, 2005).

The Smoky Hill Chalk Member is a soft, fine-textured limestone composed mainly of calcium carbonate accumulated from the calcite-rich remains of marine organisms. Iron oxide and other impurities give the naturally white chalk its orange-ish color (Brosius et al., 2003). The calcium carbonate was largely derived from coccoliths (skeletal plates shed from living algae), skeletal remains of those algae, the fecal pellets from organisms that ate the algae, one-celled organisms called foraminifera, and other organic matter that settled on the sea floor (Hattin, 1982). Remains of large vertebrates and other marine life that died and sank into the muck are particularly well preserved in Kansas.

The thickness of the Niobrara Chalk varies widely, with a maximum reported thickness of about 700 feet (Hattin, 1982). Because of its low permeability, it is not a good source of groundwater. Where the Niobrara is exposed at the surface, the overlying Ogallala Formation—the main source of water for western Kansas—is missing due to erosion. That leaves areas of the region with limited water resources. In northwestern Kansas and neighboring states where the Niobrara is found in the subsurface, natural gas is produced from the Smoky Hill Chalk Member.

Although Monument Rocks National Landmark is on private property, the landowners do allow visitors. Fossils are not as common at Monument Rocks as they are in the less-visited badlands and outcrops along the Smoky Hill, Saline, and Solomon

river drainage systems. Specimens found over the last 150 years in the Niobrara Chalk are in museum collections around the world. In Kansas, museums with Niobrara collections include the Sternberg Museum at Fort Hays State University and the Museum of Natural History at the University of Kansas. The Keystone Gallery, operated by the Bonner family about five miles southwest of the landmark, also displays specimens.

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Contact

Chuck Bonner
Keystone Gallery
620-872-2762
keystone@keystonegallery.com