KU KANSAS GEOLOGICAL SURVEY
The University of Kansas

Testimony to House Agriculture and Natural Resources Committee
By Rex Buchanan, Interim Director, Kansas Geological Survey
The University of Kansas, Lawrence, KS 66047
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Mr. Chairman, Members of the Committee:

Thank you for the opportunity to appear today. My name is Rex Buchanan. I am the interim director of the Kansas Geological Survey. I am here today to describe the Survey and some of its programs, particularly as they relate to the activities of this committee.

The Survey is a research and service division of the University of Kansas. We are charged, by statute, with studying the state's geologic resources and providing information about them. We have no regulatory responsibility and we do not take positions on natural resource issues.

The issues we study are a direct reflection of the natural resources issues central to Kansas. As you might expect, they are primarily related to water and energy. We also generate new information about the state's geology, and develop tools and techniques for studying the state's surface and subsurface. The primary clients for our information include other state, local, and federal agencies, such as the Division of Water Resources of the Kansas Department of Agriculture, the Kansas Water Office, the state's groundwater management districts, and the Kansas Corporation Commission; private individuals and businesses that explore for oil and natural gas in the state, and drill for groundwater; and engineering companies and consultants who deal with construction and geologic hazard issues in Kansas.

We are located on the west campus of the University of Kansas, and we have a branch office, the Wichita Well Sample Library, in Wichita. The Survey has a twelve-person advisory council that currently includes Representative Williams and Senator Ruth Teichman, and in the past has included Senators Carolyn McGinn, Steve Morris, Derrick Schmidt, and Representative Dennis McKinney.

Water is among the most important natural resource issues facing the state. Brownie Wilson, the Survey's hydrologic data manager, will talk about our work in water, because I know that is of primary interest to you. Before he does that, however, I would like to cover several other areas in which the Survey is active, because they are of concern to the Legislature in general and members of this committee in particular.

Energy is one of the major businesses in the state. Kansas is one of the top 10 leading oil and natural gas producing states in the country, and annual production of those energy commodities in Kansas is valued at more than $6 billion dollars annually. Most of the energy production in

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Kansas is done by independent companies, most of which are too small to carry on their own research in a mature producing area like Kansas, which has long been explored. The Survey studies the state's subsurface geology, and provides Kansas-focused research on techniques that can be applied to exploring for and producing additional oil and gas. In some respects, the Survey provides the same service to the state's energy industry as Kansas State University's Extension program provides to the state's agricultural producers. We disseminate huge volumes of production data, well logs (the records of wells drilled during the search for oil and gas), and other drilling-related data, all publicly available and generally electronically available, through our offices in Lawrence. We also collect, archive, and loan cuttings, the small chips of rock produced during drilling, from our office in Wichita, which houses cuttings from more than 130,000 wells drilled in Kansas.

In the past few years, the Survey has been particularly active in the field of carbon dioxide sequestration, or the potential disposal of carbon dioxide in the Kansas subsurface. While CO_2 sequestration is not currently being undertaken in Kansas, it is a subject of study as a possible method of disposing of this greenhouse gas, or using CO_2 to produce additional oil from mature fields.

Primarily with funding from the U.S. Department of Energy, we have undertaken several projects related to CO_2 sequestration in Kansas. We developed an atlas of CO_2 sources and potential sequestration sites for the country. In 2003, with Murfin Drilling Co., the KU Tertiary Oil Recovery Project, and other partners, we undertook a demonstration project that used CO_2 from an ethanol plant to flood a mature field in Russell County. More recently, we received more than $10 million in stimulus funding to characterize the geology of south-central and southwestern Kansas, with an eye toward learning more about possible reservoir rocks, both in terms of enhanced recovery in producing reservoirs, and deeper disposal of CO_2 in a saline aquifer. This work is being done with a range of industry and university partners, including Kansas State University and Berexco, Inc., of Wichita. This work will not result in the emplacement of any CO_2. But it will provide data that will allow us to better know the subsurface geology, identify faults and fractures that might allow movement of the CO_2, and model the emplacement of CO_2 and how it would move over time.

We are currently drilling a core hole in the Wellington Field, a few miles north of Wellington, and studying those cores to learn more about the subsurface. This information will help guide not only people interested in CO_2 sequestration, but will be useful to those agencies, such as the Kansas Corporation Commission, that are charged with safely regulating sequestration. Should sequestration occur, it would have the potential to benefit the Kansas economy, both in terms of producing additional oil and with the economic activity that results from capturing, moving, and emplacing CO_2 underground. Even if CO_2 sequestration never occurs, the subsurface information we are generating in this project will be of great benefit to people who explore the state for oil and gas.

In addition to our work in energy, the Survey maps the geology of the state's counties, using modern mapping tools to better understand the state's geology, information that is useful in groundwater exploration and construction. The Survey's Data Access and Support Center is an important source of natural resource data for the state. The Survey's shallow seismic reflection program is renowned throughout the country and the world for its ability to provide images of the shallow subsurface, a technique that has been applied to salt-related sinkholes in central Kansas, and abandoned lead and zinc mine subsidence in southeastern Kansas. Just two weeks ago we passed the 10-year anniversary of its use in identifying the movement of natural gas under the city of Hutchinson from the Yaggy natural gas storage facility.

I want to finish by mentioning one outreach program of the Survey that is of particular interest to members of this committee. Each year the Survey, in cooperation with the Kansas Water Office, the Department of Wildlife and Parks, and the Department of Transportation, offers a three-day field conference aimed at providing decision-makers with a first-hand look at the natural resource issues in a given part of the state. The primary audience is legislators, state agency staff, local government staff, business people, and others. Many of you have attended one or more of these over the years. Last year we looked at the intersection between water and energy, and spent time at the John Redmond Reservoir, Wolf Creek, the Coffeyville refinery, and other locations. This year's trip will be June 8-10 along the Kansas River Valley, looking at a variety of water and environmental issues. Shane Lyle at the Survey is the coordinator of the field conference.

Again, I appreciate the opportunity to talk with you today. If we can provide additional information on these or any other geology-related topics, please let me know.

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Public Information Circular 27 December 2008

Geologic Sequestration of Carbon Dioxide in Kansas

Rex Buchanan, Kansas Geological Survey
Timothy R. Carr, Department of Geology and Geography, West Virginia University

> *Worldwide carbon dioxide emissions from human activity have increased from an insignificant level two centuries ago to more than 33 billion tons annually.*

Introduction

Greenhouse gases, particularly carbon dioxide, are of growing international concern. Increased levels of these gases in the atmosphere have been potentially linked to global climate change. Reducing greenhouse gas emissions, while ensuring the availability of energy resources essential to our economy, is a priority and a challenge.

Worldwide carbon dioxide (CO_2) emissions from human activity have increased from an insignificant level two centuries ago to more than 33 billion tons annually. At the same time, CO_2 concentrations in the atmosphere have increased from 280 to 384 parts per million (IPCC, 2007). To curb these trends, scientists are studying the feasibility of capturing and sequestering, or storing, CO_2 (fig. 1).

One type of sequestration that may be viable, particularly in Kansas, is storing CO_2 in deep underground rock formations, or geologic sequestration. This Public Information Circular provides background about geologic sequestration, the issues it raises, and potential locations in Kansas that might be amenable to carbon capture and sequestration. Terms shown in bold are defined in the glossary at the end.

Carbon Dioxide

Carbon dioxide (CO_2), a colorless, odorless gas, is a natural and critical component of the atmosphere. It is given off through various natural and human processes. Among the most common sources of CO_2 from human activity are fossil fuels, such as oil, gas, and coal, which are burned for transportation and power generation. CO_2 is one of several greenhouse gases that are essential to maintaining life-sustaining temperatures on earth, but too much CO_2 in the atmosphere could have a detrimental impact on the environment. **Greenhouse gases** allow heat from the sun to penetrate the earth's atmosphere but do not allow it to escape back into outer space. Though some scientists disagree about the nature and degree of

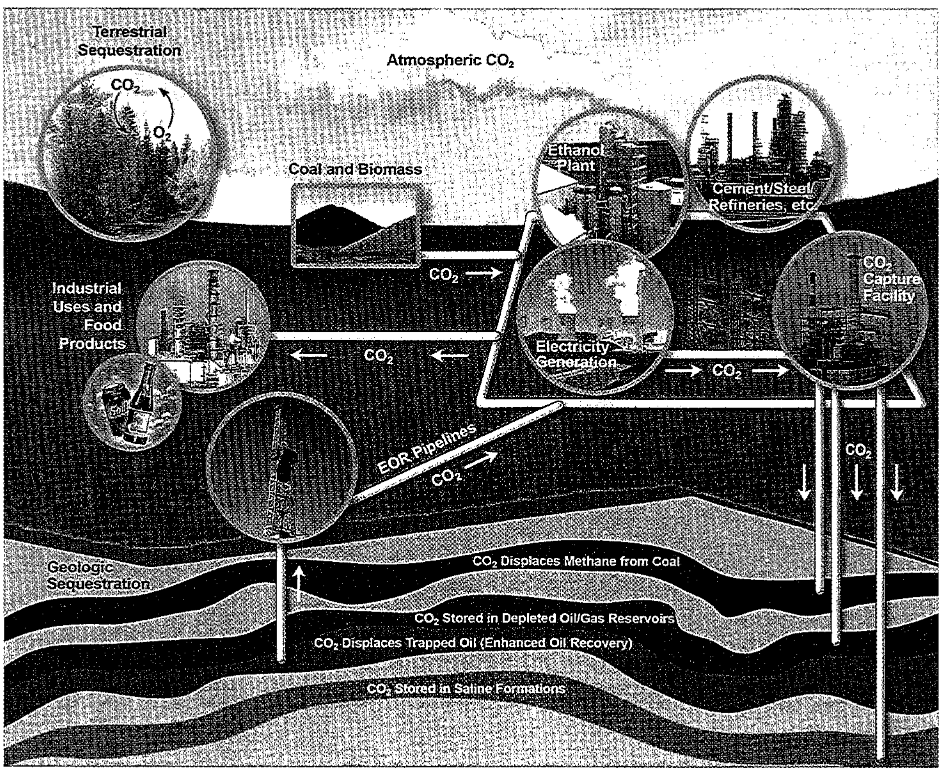

Figure 1—The carbon capture and storage process showing major pathways for geologic and terrestrial storage. Image adapted from U.S. DOE, 2007a.

ate change, there is a general consen[illegible] hat increased greenhouse gases can contribute to increased temperatures and other changes in regional climate patterns. CO_2 is of particular concern because it is increasingly produced through human activities. If current trends continue, the United States will emit 6.8 billion tons of CO_2 by 2030, a 16% increase over 2006; Kansas CO_2 emissions would be 89.5 million tons by 2030 (U.S. DOE, 2008).

In Kansas, coal-fired electrical power plants, refineries, cement plants, and ethanol plants are the most common stationary sources of CO_2 (fig. 2). Unlike emissions from non-stationary sources such as veh[illegible] haust, CO_2 from stationary sourc[illegible] be captured for various uses, such as in food products and as dry ice. CO_2 produced from many Kansas stationary sources, however, is impure—mixed with other gases—making it harder to use. The technology to isolate and capture CO_2 from these sources is expensive, energy intensive, and undeveloped for large-scale applications. Currently, CO_2 is only captured in Kansas at a few facilities that produce high-purity CO_2. However, work is underway to reduce costs and energy requirements to make the isolation of CO_2 from impure sources feasible on a commercial scale.

Managing Carbon Dioxide

Using energy more efficiently to reduce our reliance on fossil fuel combustion is one way to manage CO_2. Promoting low-carbon and carbon-free fuels and technologies, such as geothermal power, hydropower, nuclear power, solar energy, wind power, and biomass fuels, is another. A third strategy is to manage CO_2 through carbon storage sites sometimes referred to as "sinks." Some **carbon dioxide sinks**, such as oceans, plants, trees, and other photosynthetic organisms, are a natural part of the earth's carbon cycle.

Sequestration, the deliberate removal of CO_2 from the atmosphere so that it can be safely contained, involves artificially storing the CO_2 in such sources as water, vegetation, or geologic reservoirs in underground rocks (fig. 1). The entire process of capturing and sequestering CO_2 is sometimes referred to as **carbon capture and storage**, or CCS. Several types of sequestration are being studied. One method under consideration is the injection of liquid-like CO_2 deep into ocean water at depths greater than 3,300 ft (1,000 m). However, this might cause ocean acidification and long-term contamination. Another possibility is terrestrial sequestration. Trees, grasses, and other types of vegetation would be planted to remove CO_2 from the air through photosynthesis. Carbon extracted from the CO_2 would be incorporated into the plant biomass or stored in the soil. Terrestrial sequestration, however, has volume limitations. An estimated 220,000 acres of plants could be required to offset emissions from one average-sized power plant (Newell and Stavins, 2000). Geologic sequestration, described below, is a third option.

Geologic Sequestration of CO_2

Geologic sequestration, injecting CO_2 into underground rocks for secure contaiment, is efficient at depths greater than 2,400 ft (about 800 m). CO_2 increases in density and becomes a **supercritical fluid** under the great pressures that naturally exist at those depths. Supercritical fluids take up less space and diffuse more easily through the pore spaces in rock formations than either gases or ordinary liquids. Five types of geologic formations considered the most likely candidates for geologic sequestration are

- deep saline **aquifers**, underground rock formations whose pore space is saturated with saltwater,
- coal seams, including those that are deep and unmineable and shallower coal beds too thin to be mined economically,
- oil and natural gas **reservoirs**, underground rocks with pore space that holds oil or natural gas,
- oil- and gas-rich organic shales, and
- basalt, a volcanic rock with a chemical makeup that converts the CO_2 to a solid mineral form, thus isolating it from the atmosphere.

Geologic storage of CO_2 has been underway for more than a decade with projects in Norway and Algeria and a joint U.S.-Canadian effort at the Dakota Gasification facility in North Dakota and the Weyburn field in Saskatchewan. These enterprises have provided significant data and experience with a variety of natural reservoirs. Numerous field projects in the U.S. and Canada are being developed in saline aquifers, oil reservoirs, and coal seams through the U.S. Department of Energy's Regional Carbon Sequestration Partnerships (U.S. DOE, 2007b), regional partnerships between private companies, universities, and governmental agencies. Thus far, no evidence suggests significant volumes of CO_2 have migrated out of the confining reservoirs, indicating that long-term storage is feasible.

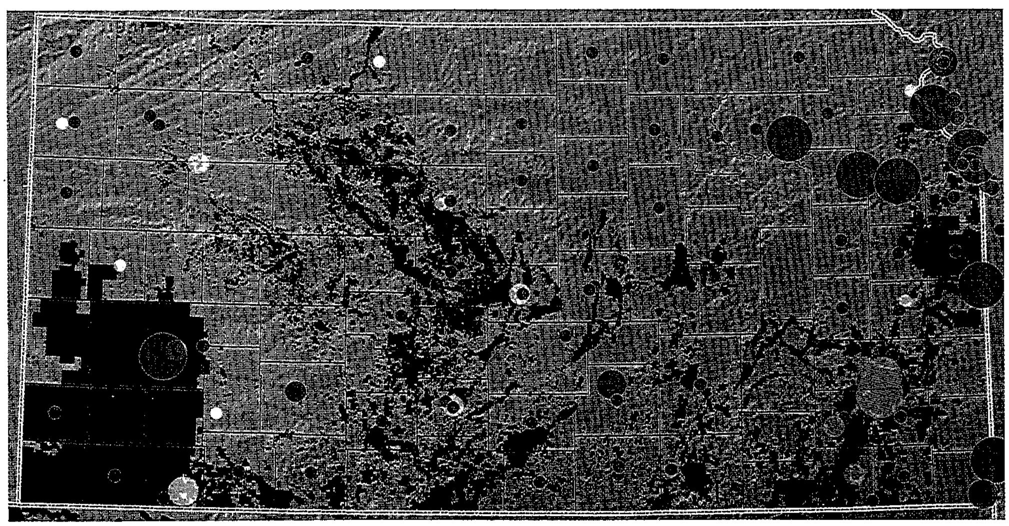

Figure 2—Documented stationary sources of CO_2 and evaluated potential geological storage sites. Stationary sources include power-generation facilities, refineries, cement kilns, and ethanol plants.

Geologic Sequestration of CO_2 in Kansas

In Kansas, geologic sequestration of CO_2 may be possible in all five of the geologic formations: deep saline aquifers, coal seams, oil and natural gas reservoirs, oil- and gas-rich organic shales, and basalt (the most problematic because no one knows how much CO_2 the ancient rock—deeply buried in parts of Kansas—can hold). Altogether, researchers estimate Kansas has at least 2.7 to 5.4 billion tons of potential geologic sequestration space, enough to hold almost 70 years worth of the state's stationary CO_2 production.

Saline aquifers could potentially store large amounts of CO_2 in Kansas. The highly saline water is not usable for other purposes and would dissolve the CO_2. The Arbuckle Group, a series of rock layers found only in the subsurface in Kansas, is a prospective environment for CO_2 sequestration. Consisting mainly of dolomite, the sedimentary strata of the Arbuckle Group were deposited about 480 million years ago during the Cambrian and Ordovician periods of geologic history. They are found at depths ranging from less than 250 ft (75 m) in southeast Kansas to 8,000 ft (2,500 m) in southwest Kansas. In parts of the state, large amounts of oil have been produced from rocks in the Arbuckle Group. Brine from thousands of oil wells has already been successfully placed in the Arbuckle and other aquifers, indicating the aquifers might safely contain CO_2 as well (Carr et al., 2005).

Sequestering CO_2 in unmineable coal beds would remove it from the atmosphere and might also aid in the recovery of natural gas from Kansas coal beds, an important source of the gas (Sawin and Brady, 2001). In 2007 Kansas produced 41 billion cubic feet of coal-related gas, much of it from the Cherokee basin in the southeast. Although this gas is sometimes referred to as **coalbed methane**, it includes constituents other than methane.

Scientists at the Kansas Geological Survey (KGS) are studying ways to use gas high in CO_2 emitted from cement plants and commercial landfills to enhance natural gas production from coal. They are investigating the practicality of injecting CO_2 into subsurface coal beds to displace coalbed methane, which could then be processed and used. Such studies are in the preliminary stages, and the feasibility of using CO_2 to produce natural gas from coal will be determined only after taking many geologic and economic factors into account. Whether or not CO_2 sequestration in coal seams could be used to successfully produce more natural gas, the coal could still be used to sequester CO_2.

Another way to manage CO_2, at least in the near term, would be to use it in the production of hard-to-recover oil from older fields. In the process known as **enhanced oil recovery** (EOR), CO_2 could be injected to force out additional oil, a procedure that would also sequester much of the CO_2. Even in Kansas fields that are declining after decades of production, significant amounts of oil remain trapped in the pore space of underground rocks. CO_2 pumped into these reservoirs would dissolve into the oil and reduce the oil's viscosity, making it easier to recover (fig. 3). Small amounts of CO_2 coming back to the surface with the oil could be captured and reinjected to help produce more oil. Much of the CO_2, however, would remain trapped below ground. CO_2 is already being used commercially and experimentally to enhance oil recovery in a number of locations in the country, most notably in west Texas.

To better understand the use of CO_2 in enhanced oil recovery, a mature oil field in Russell County, Kansas, was flooded with CO_2 starting in 2003. The KGS monitored the movement of the CO_2 underground using a geophysical technique called seismic reflection. Oil production increased as a result, though the complexity of the subsurface formations made it difficult to predict the exact movement of the CO_2 flood.

In Kansas, the suitability of CO_2 for enhanced recovery will depend on oil prices, the nature of the state's oil and gas reservoirs, and the ready availability of CO_2. Because the state has had a long history of oil production, a great deal is known about its subsurface geology and incredible amounts of geologic data are available. Many known oil reservoirs appear to be candidates for CO_2 flooding. KGS scientists estimate that oil reservoirs in Kansas could produce between 400 and 900 million additional barrels of oil with the use of CO_2 flooding (Byrnes, 2000). At the same time, the process would sequester significant quantities of CO_2. However, concerns have been raised in the state about regulating CO_2 enhanced oil recovery and whether the CO_2 would be trapped in these reservoirs or move back to the surface over time. Because Kansas has long been drilled for oil and gas and some areas have been very densely drilled, concerns also exist that CO_2 could move back to the surface through poorly plugged or long-forgotten wells.

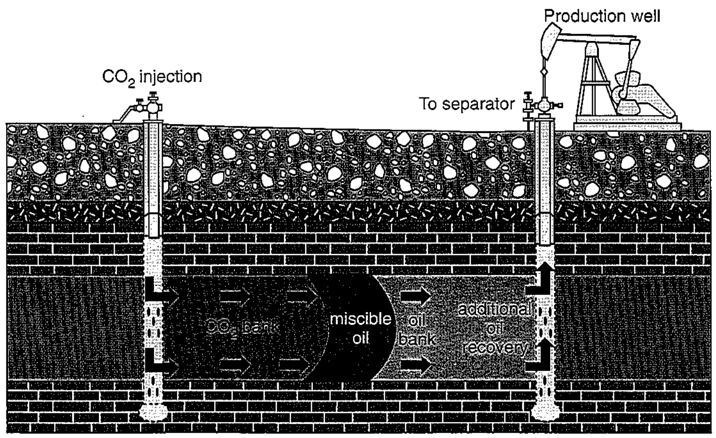

Figure 3—Carbon dioxide flooding.

Sequestration Concerns and Information Resources

A number of issues must be resolved before geologic sequestration can play a major role in CO_2 management. The capture of CO_2 from waste streams, such as smokestacks, requires considerable cost and energy and has only been tested on a small scale. Even if it could be efficiently captured, much CO_2 would have to be transported to storage locations. This would likely require construction of an extensive pipeline network. To be pumped underground, the gas would have to be compressed and perhaps turned into liquid CO_2. This would require additional energy, although it would also significantly reduce the volume of the gas, which would make less storage space necessary. Finally, a regulatory environment would have to be created to protect health, safety, and the environment for long periods. Storage locations, for example, would need to be regularly monitored for leaks.

In Kansas, sequestration needs to be studied in more detail to determine if oil and natural gas reservoirs and coal beds have the

5-6

KANSAS GEOLOGICAL SURVEY

The University of Kansas

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

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

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capacity to t[illegible]nd hold CO_2. This is especially true in locations with long histories of oil and gas exploration where older, poorly plugged wells could provide avenues for CO_2 to return to the surface. In addition, a variety of legal issues, such as ownership of the underground pore space used for sequestration, would need to be resolved, and a workforce would have to be developed. Ultimately, regulatory decisions, economics, and a well-defined environment for greenhouse gas management will highly influence any decisions concerning the feasibility of geologic sequestration. Determining its future will require much data collecting and analysis.

The success of geologic sequestration depends on the availability of information about the location of CO_2 sources, such as power plants, cement plants, refineries, and fertilizer plants, and th[illegible]unt of CO_2 they produce. Informa[illegible] about potential sequestration sites and transportation needs, such as pipelines, also is necessary. With funding from the U.S. Department of Energy, the KGS worked with geologic institutions in other states across the U.S. and Canada to develop a database of available information (http://www.natcarb.org) (Natcarb, 2008). A Carbon Sequestration Atlas of the United States and Canada was produced as a result of that project (U.S. DOE, 2007a) and allows users to most efficiently match the sources, transportation methods, and potential sequestration locations for CO_2.

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Glossary

Aquifer: Rock formation capable of holding and yielding large amounts of ground water, usually held in pore spaces between rock particles. Aquifers of saline water are potential locations for sequestering CO_2.

Carbon capture and storage (CCS): Process of capturing CO_2 from large stationary sources such as power plants and isolating it from the atmosphere.

Carbon dioxide (CO_2): Compound composed of one atom of carbon bonded with two atoms of oxygen that is a gas at standard temperatures and pressures.

Carbon dioxide sink: A reservoir that takes CO_2 in, as opposed to a source, which produces CO_2. Natural sinks are oceans, plants, and other organisms. Artificial sinks include geologic reservoirs.

Coalbed methane (CBM): Methane produced from coal layers. Because gas from the coal contains other components besides methane, the more general term is coalbed natural gas.

Enhanced oil recovery (EOR): Methods of producing oil after primary and secondary methods of production have been used. Primary production involves using natural underground pressures or pumping; in Kansas, secondary production generally refers to flooding underground oil reservoirs with water to produce more oil. Flooding with CO_2 is a form of EOR.

Greenhouse gases: Gases that trap heat in the atmosphere and thus are often blamed for higher temperatures. The most abundant are water vapor, carbon dioxide, methane, nitrous oxide, and ozone.

Reservoir: As used herein, a natural underground formation that holds a liquid, such as oil or water. In Kansas, reservoirs generally hold oil or water in the pore space between rock particles.

Supercritical fluids: Highly compressed gases that take on many of the properties of both gases and liquids.

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5-7

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Kansas Geological Survey

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The High Plains Aquifer

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Kansas Geological Survey

Introduction

The High Plains aquifer, which includes the well-known Ogallala aquifer, is the most important water source for much of western and central Kansas (fig. 1), supplying 70% of the water used by Kansans each day. Water from the High Plains aquifer supports the region's cities, industry, and much of its agriculture.

However, large-volume pumping from this aquifer has led to steadily declining water levels in the western portion of the region, and the area faces several critical water-related issues. This Public Information Circular describes the High Plains aquifer, the effect of decades of large-volume pumping, and some responses to water issues in central and western Kansas.

The High Plains Aquifer Defined

Aquifers are underground deposits containing permeable rock or sediments (silts, sands, and gravels) from which water can be pumped in usable quantities. The High Plains aquifer is a regional aquifer system composed of several smaller units that are geologically similar and hydrologically connected—that is, water can move from one aquifer to the other. The High Plains aquifer system lies beneath parts of eight states in the Great Plains, including about 30,500 square miles of western and central Kansas (fig. 1).

Aquifer characteristics are determined in large part by geology. The High Plains aquifer is composed mainly of silt, sand, gravel, and clay—rock debris that washed off the face of the Rocky Mountains and other more local sources over the past several million years. The aquifer varies greatly from place to place: thick in some places, thin in others; permeable (able to transmit water easily) in some places, less so in others. Where the deposits are thick and permeable, water is easily removed and the aquifer can support large volumes of pumping for long periods. In most areas, this water is of good quality.

The most important component of the High Plains aquifer is the Ogallala aquifer, generally the western half of the High Plains aquifer in Kansas. In some locations (such as Lake Scott State Park in Scott County), the Ogallala Formation crops out at the surface, forming a naturally cemented rock layer called mortarbeds. In the subsurface, the Ogallala largely consists of silt and clay beds that are interlayered with sand and gravel that is mostly unconsolidated, or not naturally cemented together.

The south-central extension of the High Plains aquifer is composed of younger sediments that are similar to the Ogallala. These younger sediments,

The High Plains aquifer system lies beneath parts of eight states in the Great Plains, including about 30,500 square miles of western and central Kansas

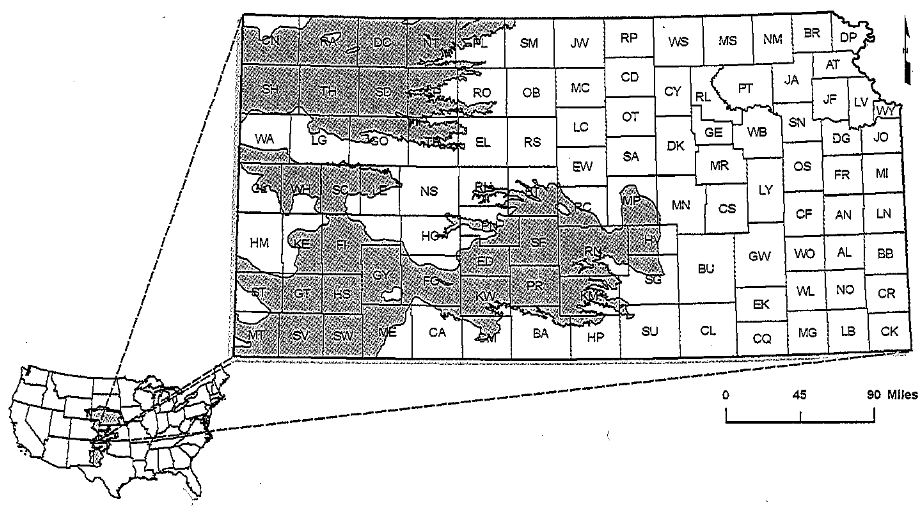

Figure 1—*Saturated extent of High Plains aquifer in Kansas.*

In the year 2000, about 21 million acre-feet of ground water was removed from the High Plains aquifer across the eight-state region

deposited du[illegible] the Pleistocene Epoch, or Ice Ages, include the "Equus beds" aquifer (in McPherson, Reno, Harvey, and Sedgwick counties) and the "Great Bend Prairie aquifer" (in Stafford, Edwards, Pratt, Kiowa, and other counties). Also lying above the Ogallala Formation are other Pleistocene deposits and other younger deposits in the valleys of modern streams. Where these stream deposits (known as alluvium) are connected to the Ogallala or Pleistocene aquifers, the alluvial aquifers are considered part of the High Plains aquifer (fig. 2).

[illegible]ath the High Plains aquifer is mu[illegible]r, consolidated bedrock, usually limestone, sandstone, or shale (fig. 3). In some places this bedrock holds enough water to be called an aquifer, and it may be connected to the overlying aquifer. Layers of permeable sandstone in the Dakota Formation, for example, are connected to the High Plains aquifer in parts of southwestern or south-central Kansas. Some layers of the underlying bedrock contain saltwater; where these are directly connected to the High Plains aquifer, they pose a threat to water quality.

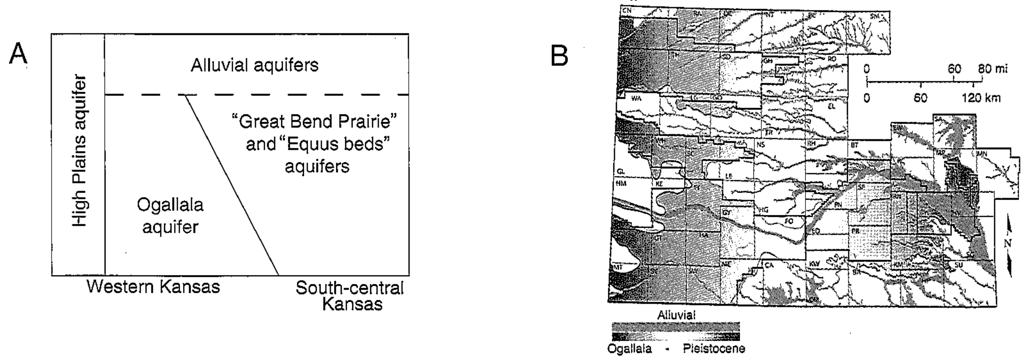

Figure 2—*Schematic (A) and map (B) showing aquifers that make up the High Plains aquifer.*

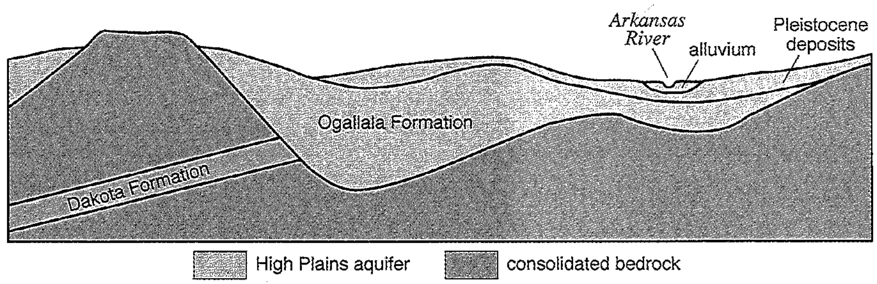

Figure 3—*Generalized cross section showing the High Plains aquifer and underlying bedrock. The Ogallala Formation, Pleistocene deposits, and alluvium combine to form the High Plains aquifer.*

Water Resources in the High Plains Aquifer

Usable water in the High Plains aquifer is in the pore spaces between particles of sand and gravel. This water (called ground water) accumulated slowly—in some of the deeper parts of the aquifer, over tens of thousands of years. In the subsurface, water in the aquifer generally moves slowly from west to east, usually at the rate of tens of feet per year.

Recharge is the natural movement of water into an aquifer, usually from precipitation. Natural recharge to the High Plains aquifer from precipitation is low, in part because much of the rain falls during the growing season, when plant roots intercept the soil moisture. In western Kansas, where precipitation is scant and the water table is relatively deep (several hundred feet) in many places, recharge occurs infrequently and the long-term average is less than an inch per year. In central Kansas, where the aquifer is closer to the land surface, where soils are sandier, and precipitation amounts greater, recharge can be significant, as much as 4 to 6 inches per year.

Water volumes and use are measured in various ways. One measure is an acre-foot, or the amount of water necessary to cover an acre of ground (a parcel about the size of a football field) with a foot of water. An acre-foot equals 325,851 gallons of water. In the year 2000, about 21 million acre-feet of ground water was removed from the High Plains aquifer eight-state region (McGuire, 2009). In Kansas, the High Plains aquifer yielded 4.4 million acre-feet, of which 2.4 million acre-feet came from the Ogallala aquifer in 2007. Estimated average annual natural recharge to the Ogallala in Kansas is 0.72 million acre-feet.

Another measure of ground water is saturated thickness—the thickness of the sands, gravels, and other materials that are saturated with water. Saturated thickness is commonly measured in feet, but "feet of saturated thickness" is not the same as feet of actual water. Only about 10 to 25% of the aquifer volume is pore space that can yield extractable water. Therefore, in an aquifer with 17% pore space, removing 1 acre-foot of water causes the water table to drop by about 6 feet. In Kansas, saturated thickness in the High Plains aquifer is generally greatest in the southwestern part of the state (see fig. 4). There, saturated thicknesses of 300 feet and greater were common before the onset of large-scale irrigation, a time that is often called "pre-development."

5-9

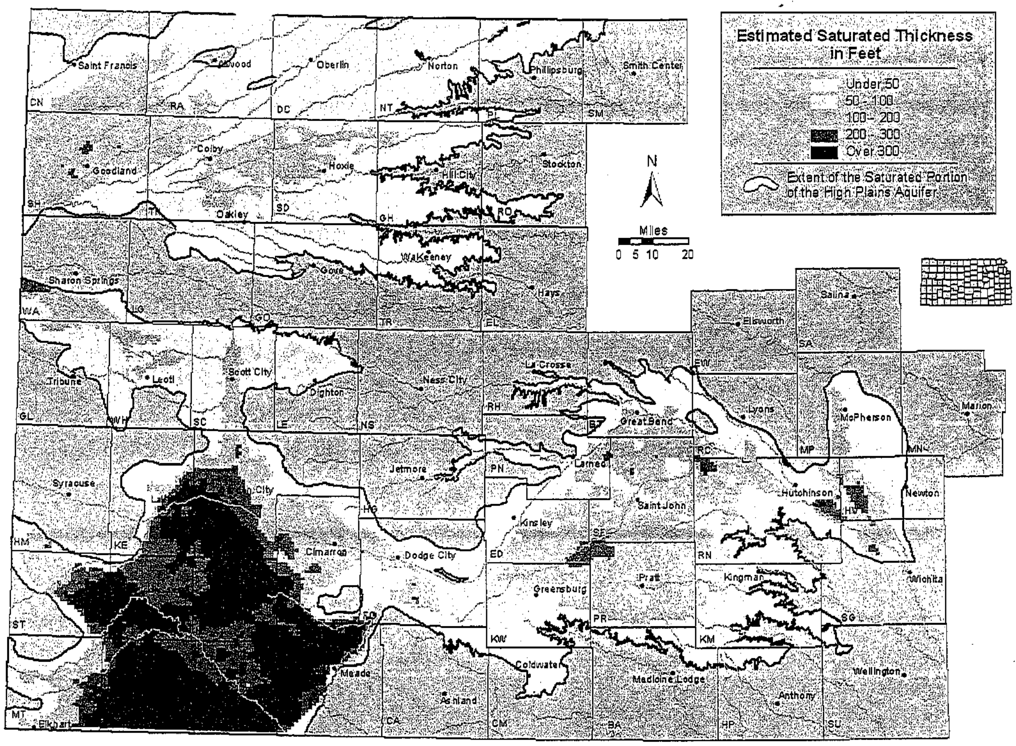

Figure 4—*Predevelopment saturated thickness for the High Plains aquifer in Kansas.*

Ground water can also be measured in terms of its availability: how much water can be removed by a well over short periods. Large volumes of water can be pumped rapidly (1,000 gallons or more per minute) from the High Plains aquifer in many locations. This contrasts with much of the rest of the state, where wells generally produce smaller amounts (less than 100 gallons per minute). By way of comparison, a good household well produces 5 to 10 gallons per minute, although many household wells produce less.

Water-level Declines in the Aquifer

Large-scale irrigation began in western Kansas in the late 1800's, with the use of ditches to divert water from the Arkansas River. As technology improved, ground water became the major irrigation source because surface water (lakes, rivers, and streams) is relatively scarce in western Kansas. With the advent of large-capacity pumps that were capable of drawing several hundred gallons of water per minute, people began to develop that ground water. Using a technique called flood irrigation, water was pumped through long pipes or ditches along the edges of a field, then out onto rows of crops (fig. 5A).

In the 1950's and 1960's, technological developments led to a dramatic increase in large-scale pumping. In particular, center-pivot irrigation systems—large sprinklers that roll across the land on wheels—allowed people to irrigate uneven terrain, thus opening up large new areas for irrigation (fig. 5B). These irrigation methods led to the cultivation of crops, such as corn, that could not previously be grown reliably in the area. That grain production led, in turn, to large feedlots and packing plants and a boom in the economy of much of western Kansas, all largely dependent on ground water. One study in 2001 estimated that the economic

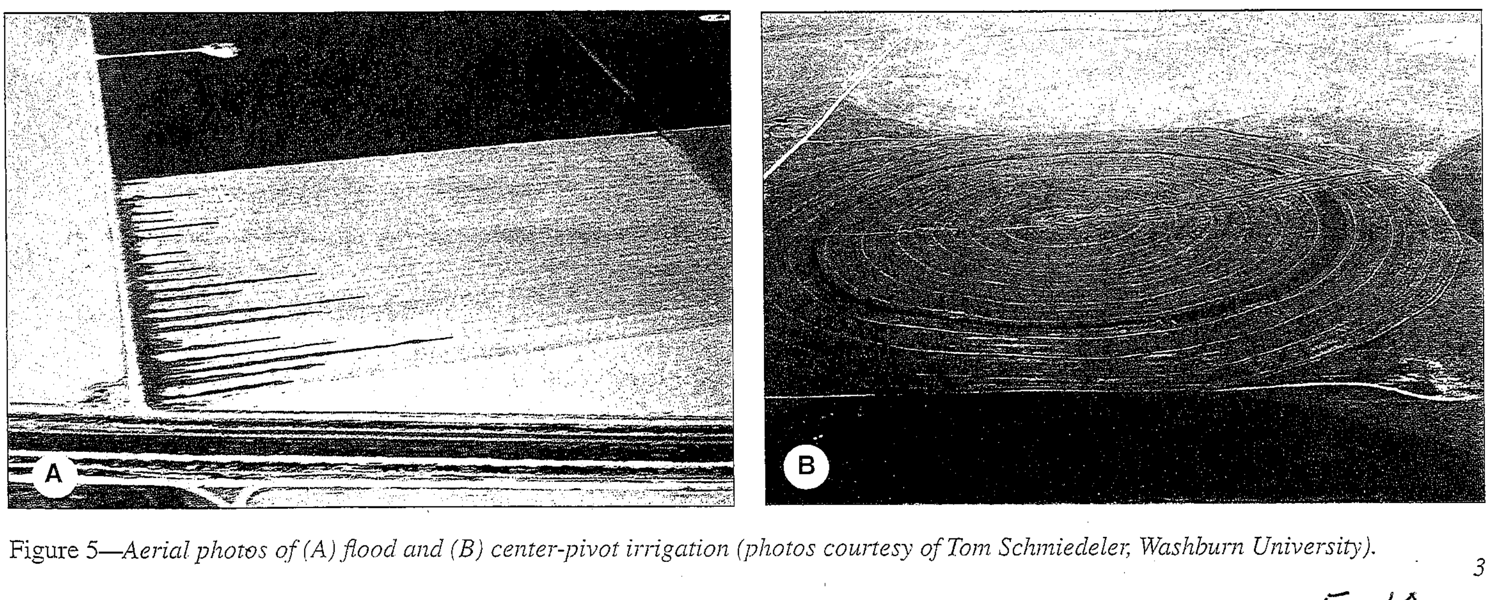

Figure 5—*Aerial photos of (A) flood and (B) center-pivot irrigation (photos courtesy of Tom Schmiedeler, Washburn University).*

impact of irrigation in southwestern Kansas alone amounts to more than $188 million annually (Gilson et al., 2001).

For many years, people believed that the High Plains aquifer contained an inexhaustible amount of water. However, large-volume pumping (mostly for irrigation) eventually led to substantial declines in the water table, and people realized that the amount of water in the aquifer was finite and could be exhausted. Much of the Ogallala portion of the High Plains aquifer has declined since predevelopment, with some areas having declines of more than 60% (fig. 6).

Nonetheless, in much of the aquifer, considerable amounts of water remain. For example, declines of 100 feet or more may have occurred in parts of southwestern Kansas, but that represents less than half of the original saturated thickness, and 100 to 200 feet (or more) of saturated thickness may remain. On the other hand, in parts of west-central Kansas—such as Greeley, Wichita, Scott, and northern Finney counties—the original saturated thickness was much less, often less than 100 feet. In these places, where early flood-irrigation systems were prevalent, less than 50 feet of saturated thickness remains.

When Will the Aquifer Run Dry?

Perhaps the most common and important question about the High Plains aquifer is: How much longer can it support large-scale pumping? It's a simple question with a complicated answer. First, the aquifer will probably be able to support small, domestic wells far into the future. With proper planning, most cities and towns should be able to provide for their water needs. Second, the future of agricultural use of the aquifer depends on a variety of factors, including the price of irrigated crops, the price and availability of energy (the deeper the water table, the more energy it takes to pump water), climate, and how the water is managed. Third, it is important to remember that the aquifer is not one consistent, homogeneous unit. Rather, it varies considerably from place to place. In places, the aquifer consists of less than 50 feet of saturated thickness and receives little recharge. In other places, the aquifer is far thicker or receives considerably more recharge.

With those qualifications in mind, researchers at the Kansas Geological Survey have made projections about the aquifer, based on past trends in water-level declines. Obviously, the actual future use of water will be affected by commodity prices, energy prices, climate, and management policies. Relatively little data are available for some parts of the aquifer, and projections are not practical in those areas. Assuming saturated thickness sufficient to support pumping of at least 400 gallons per minute, researchers concluded that parts of the aquifer are effectively exhausted in Greeley, Wichita, and Scott counties (fig. 7). Other parts of the aquifer, in areas such as southwestern Thomas County, are projected to have a lifespan of less than 25 years, based on past decline trends. However, the biggest share of the aquifer in southwest Kansas would not be depleted for 50 to 200 years. It is important to remember that these projections are based solely on past water-level trends, and future changes could alter the actual depletion rate.

Much of the Ogallala portion of the High Plains aquifer has declined since predevelopment, with some areas having declines of more than 60%

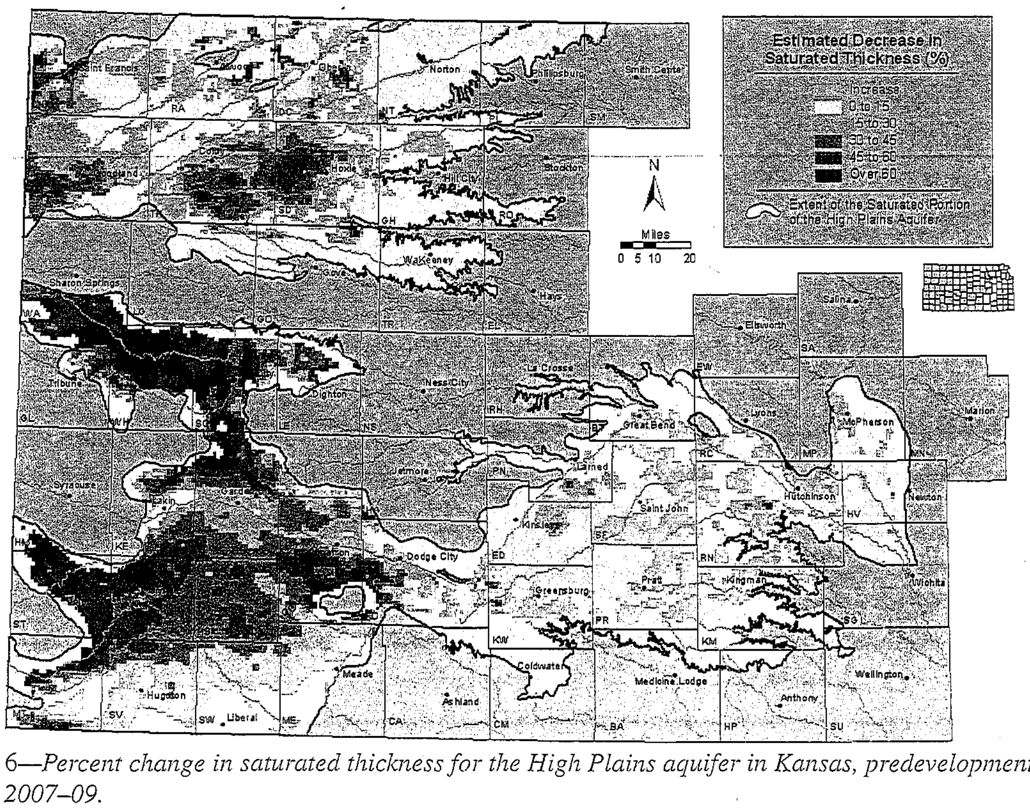

Figure 6—*Percent change in saturated thickness for the High Plains aquifer in Kansas, predevelopment to 2007–09.*

By Kansas law, water is a public resource that is dedicated to the people of the state

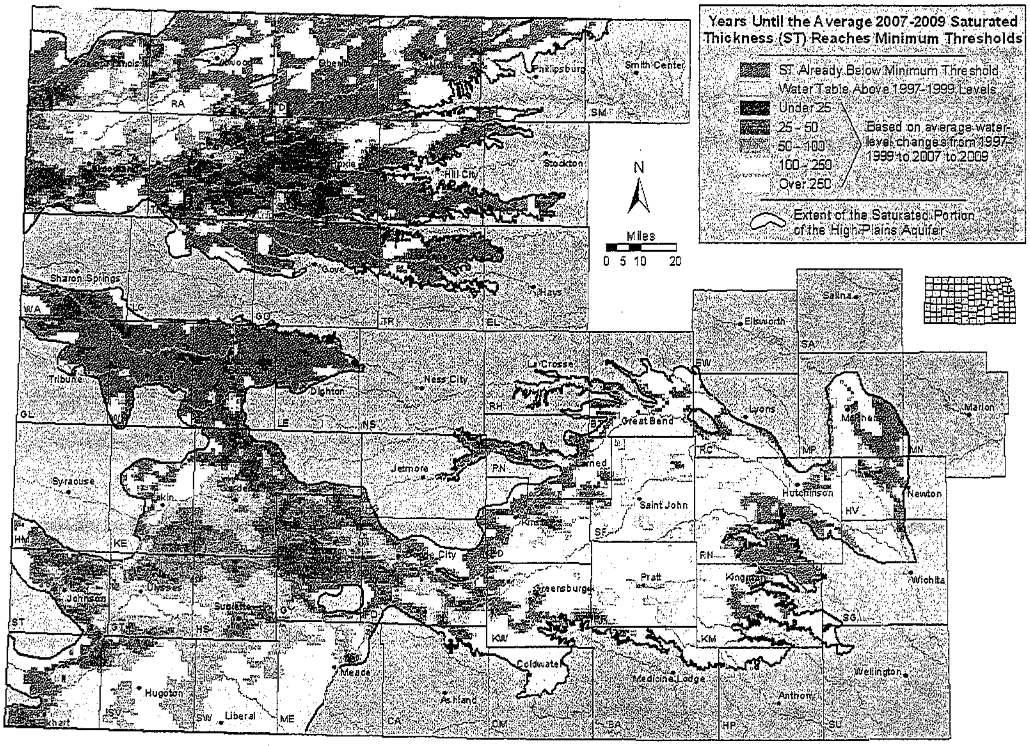

Figure 7—*Estimated usable lifetime (1998–2008) trend for the High Plains aquifer in Kansas.*

Managing Water in the Aquifer

By Kansas law, water is a public resource that is dedicated to the use of the people of the state. Individuals, companies, municipalities, and other entities can obtain permission to use water for beneficial purposes by obtaining a water right, either new or existing. In general, all beneficial uses of water, except most domestic use, require a water right. Kansas water law is based on the doctrine of prior appropriation. That is, when there is insufficient water to meet all water rights, the date of the water right determines who has the right to use the water. This doctrine is commonly expressed as "First in time, first in right."

Responsibility for managing water use in Kansas is spread over several agencies. The Division of Water Resources of the Kansas Department of Agriculture is responsible for administering water rights, and thus is primarily responsible for regulation related to the quantity of water used. Water issues also are subject to local control and management. Five groundwater management districts have been created in Kansas to provide local management of the resource within the framework of the State's water laws. Together, they cover nearly all of the state underlain by the High Plains aquifer (fig. 8). Groundwater management districts, through staff and an elected board, develop and implement policies and rules and regulations to manage and protect the quality of water, undertake educational activities,

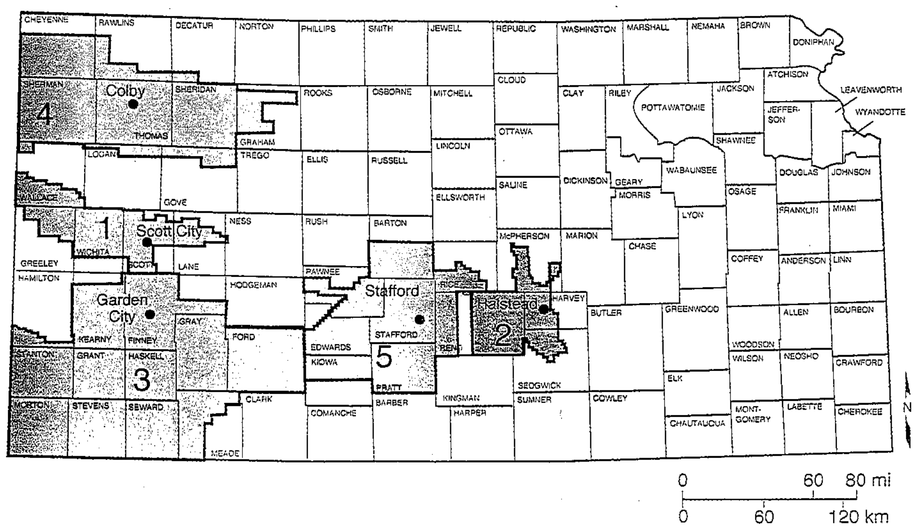

Figure 8—*Groundwater management district boundaries in Kansas.*

5-12

and work with State and Federal water-related agencies to regulate and manage the High Plains aquifer.

A variety of other agencies deal with other aspects of water in the state. The Kansas Geological Survey, for example, a research and service division of the University of Kansas, undertakes a variety of water-related activities, but has no regulatory responsibility. The Kansas Department of Health and Environment monitors water-quality issues. The Kansas Water Office, working with the Kansas Water Authority, is responsible for water planning. That planning is according to drainage basins, or areas that are drained by a common stream, such as the Cimarron River or Neosho River. Each of those basins is represented by a volunteer basin-advisory committee. The Kansas Department of Wildlife and Parks, Kansas State University's Extension program, the Kansas Biological Survey, the U.S. Geological Survey, and other State and Federal agencies have various responsibilities for water.

Where Do We Go From Here?

Individuals, governmental agencies, and private organizations are all attempting to address issues related to the High Plains aquifer. In addition, several new institutions have recently been proposed to deal with issues concerning the aquifer on a regional basis. Irrigators have implemented a number of techniques that have improved the efficiency with which they use water—using low-pressure application methods on center-pivot systems, for example, instead of spraying water high into the air.

Among the more far-reaching proposals for extending the life of the aquifer is the idea of sustainable development. This is the concept of limiting the amount of water taken from the aquifer to no more than the amount of recharge, and perhaps less, depending on the impact on water quality and minimum streamflows. This level of use is the target of the safe-yield management policies currently in effect in the Big Bend and Equus Beds Groundwater Management Districts in the eastern part of the High Plains aquifer. Adoption of a similar policy in other areas of the High Plains aquifer would require a substantial decrease in the amount of water currently used. This would have an impact on the type and amount of crops grown in western Kansas and, in turn, on a variety of economic activities. Because many of the water rights in the High Plains aquifer were established long ago and thus have priority, the implementation of sustainable-development approaches to water resources has serious legal implications. Other methods for dealing with the High Plains aquifer are being proposed, discussed, and implemented. All are aimed at extending the life of this crucial resource.

[*The authors thank Dave Young, formerly of the Kansas Geological Survey, and Bob Sawin, Kansas Geological Survey, for their help in the preparation of this circular.*]

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Web Sites

Kansas Geological Survey — **http://www.kgs.ku.edu/**
Information about water-levels in specific wells is available at **http://www.kgs.ku.edu/Magellan/WaterLevels/** and can be searched by legal description or county.
More information on the High Plains Aquifer is available at **http://www.kgs.ku.edu/HighPlains/index.shtml**

Kansas Department of Agriculture, Division of Water Resources — **http://www.ksda.gov/dwr/**

Kansas Water Office — **http://www.kwo.org/**

U.S. Geological Survey's Water Resources Division Office, Lawrence — **http://ks.water.usgs.gov/**
This site includes current streamflow information.

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

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

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5-13