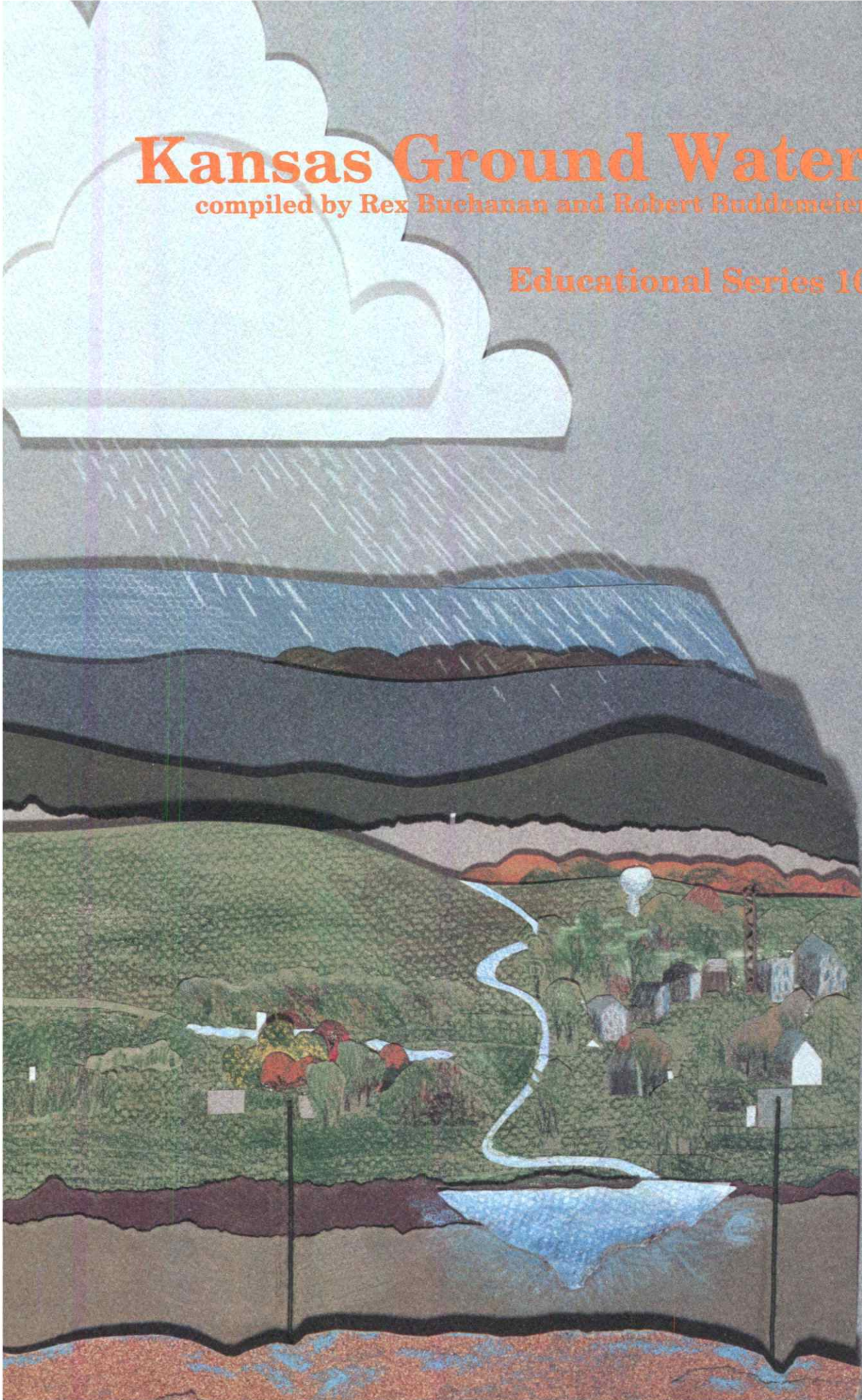


# Kansas Ground Water

compiled by Rex Buchanan and Robert Buddemeier

Educational Series 10



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Kansas geology—an introduction to landscapes, rocks, minerals, and fossils, ed. by *R. C. Buchanan*, 1984, University Press of Kansas, 212 p.

Land of the post rock, its origins, history, and people, by *G. Muilenburg* and *A. Swineford*, 1975, University Press of Kansas, 221 p.

Geologic highway map of Kansas, 1988, Western Geographics, scale 1:1,000,000 (folded only)

# Kansas Ground Water

## An Introduction to the State's Water Quantity, Quality, and Management Issues

compiled by Rex Buchanan and Robert W. Buddemeier

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The Kansas Geological Survey compiled this book according to specific standards, using what is thought to be the most reliable information available. The Kansas Geological Survey does not guarantee freedom from errors or inaccuracies and disclaims any legal responsibility or liability for interpretations made from the book, or decisions based thereon.

# Introduction

**F**rom the earliest times of human occupation of Kansas, water has been a major concern. Native Americans settled near rivers, and the Taos Indians dug irrigation ditches in western Kansas. European pioneers moved across the state on routes that were determined by the availability of water from *springs* and rivers. Late in the 1800s, settlers clung to the belief that the “plow would bring the rain,” that cultivation would increase rainfall. Today, even with the discovery of vast amounts of *ground water* in western Kansas, there is concern about ground-water depletion and the contamination of sources of *freshwater*.

The purpose of this book is to help Kansans understand, protect, and manage wisely an important natural resource—the state’s ground water. About half of all Kansans depend on ground water for their domestic supplies, and about 85% of the total water used in the state is ground water. This is an extensive reliance on a diminishing resource; on average, we are removing water from the ground at a rate several times faster than it is being replenished.

Underground water is often viewed as mysterious. Its presence, depth, and quality are often hard for non-scientists (and sometimes professionals) to imagine. It can be maddeningly elusive when we want to get at it, but it often seems as if any hazardous material placed on or in the earth will quickly and unerringly find its way into a ground-water supply. Although much remains to be learned, the general principles that determine the occurrence and characteristics of ground water are well known, and we have a generally good and steadily improving understanding of ground water in Kansas. The material that follows is designed to communicate the essential aspects of that knowledge to interested citizens.

We begin by summarizing the use and importance of ground water in Kansas. We use the simplest possible definition of ground water—any water that can be pumped from a *well*. To expand on this, we then discuss ground-water occurrence and its place in the *hydrologic cycle*, both in general and with specific reference to Kansas. This section concludes with a summary of Kansas ground-water resources and their characteristics. Next, we discuss

the basic issues of water quality—both natural factors and human effects. Well construction and ground-water production are described to provide a view of the procedures and problems involved in making use of this resource. Finally, we discuss the principles of ground-water management and end with an overview of the major problems and issues facing Kansas with respect to water resources in general and ground water in particular. Appendices provide a glossary of technical terms and information, a reading and reference list for those seeking further information, and a list of agencies and organizations in Kansas with responsibilities for ground water.

Before continuing, a note on definitions, disciplines, and objectives. Hydrologists are people who study or manage water resources; they come from a variety of disciplines, although geology and civil engineering are two of the most common backgrounds. This book is mostly about what some people call *hydrogeology* and others, *geohydrology* (similarly, there is controversy about whether ground water is one word or two, but as far as we know the water doesn’t care). Because water is central to life and must be studied on an interdisciplinary basis if we are to understand all of the implications and complications, water scientists have training or research experience in various fields of the earth sciences, engineering, computer technology, chemistry, and biology. Water is enormously important in a political, economic, and social sense. Our objective is to provide factual background information so that readers can better draw their own conclusions about the water-resource issues facing the state, the nation, and the world.

English units of measure are strongly entrenched in applied water-resource fields in the United States, although some U.S. researchers and the rest of the world use the metric system. We present our information in English units for the convenience of our readers; but wherever it is not awkward, we place the metric equivalents in parentheses. The glossary appendix contains a summary of the two systems and conversion factors. The unit *acre-foot* may be unfamiliar to some; it is the volume of water that would cover an area of 1 acre to a depth of 1 ft (43,560 cubic feet, or 325,851 gallons).

## Use and importance of ground water

**G**round water constitutes most of the earth’s usable water resources. The total amount of water on the earth is estimated at 326 million cubic miles. Of this total, more than 97% is sea water. An appreciable part of the world’s

total water, 2%, is frozen in ice caps and glaciers. Virtually all of the remaining water is ground water. The water in rivers and lakes (which scientists call *surface water*), in the atmosphere, and in unsaturated soils and rocks

amounts to only about one-fiftieth of 1% of the total world water supply at any given moment. Ground water accounts for about 2 million cubic miles, or about 0.6% of the earth's total water. If we exclude ice, ground water represents about 97% of the non-ocean water. About half of the ground water occurs within the upper half mile of the earth's crust, and the remainder below this depth. Not all of it is usable; some is saline, and some can be regarded as inaccessible because of the great depths at which it occurs. Nor is it uniformly distributed over the land areas of the world. In many places, ground water cannot be obtained in sufficient quantities to justify the expense of installing wells.

In some areas, including parts of Kansas, ground water is the only reliable source of large volumes of water. Kansans rely on ground water for 85% of their water needs, including municipal, industrial, agricultural, and rural domestic water supplies. In fact, Kansas relies on ground water to supply a higher percentage of its water needs than almost any other state in the U.S. Eastern and western Kansas differ dramatically in their reliance on ground water. In the western two-thirds of the state, where precipitation amounts are usually small, relatively abundant ground-water resources provide most of the water. Ground-water resources are limited in the eastern third of the state, but precipitation is more abundant and surface water provides most of the water supplies. Ground water supplies approximately 4.8 billion gallons per day. Municipal and rural-water supply systems provide ground water to approximately 51% of the state's population (1.2 million people). Approximately 94% of the ground water withdrawn (4.5 billion gallons per day) is used for irriga-

tion, 2% for industry, 3% for public municipal supplies, 0.5% for livestock use, and 0.4% for rural domestic use. Water-use figures in this paragraph are from C. H. Baker, Jr., and J. F. Kenny, "Kansas: Water Supply and Use;" in, U.S. Geological Survey, National Water Summary 1987, Water-Supply Paper 2350, 1990.

These numbers provide perspective on water use. Domestic use (municipal plus rural) amounts to about 160 gallons per day (or gpd) per person, fairly typical for the U.S. We know that adequate life support requires less than a tenth of that amount; experience in areas of water shortage has shown that conservation measures can reduce that 160 gpd by about half without health or serious economic consequences. On the other hand, if we divide total water use (including agricultural and industrial as well as domestic) by total population, the state's total use rate is about 2,800 gpd per person. This very large difference between individual use and collective use represents water used in economic activities, of which irrigated agriculture is by far the largest consumer. Figure 1 shows a breakdown of water use by source and type of use.

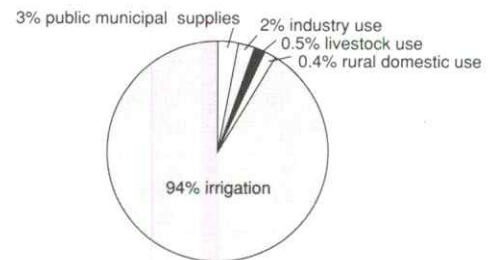
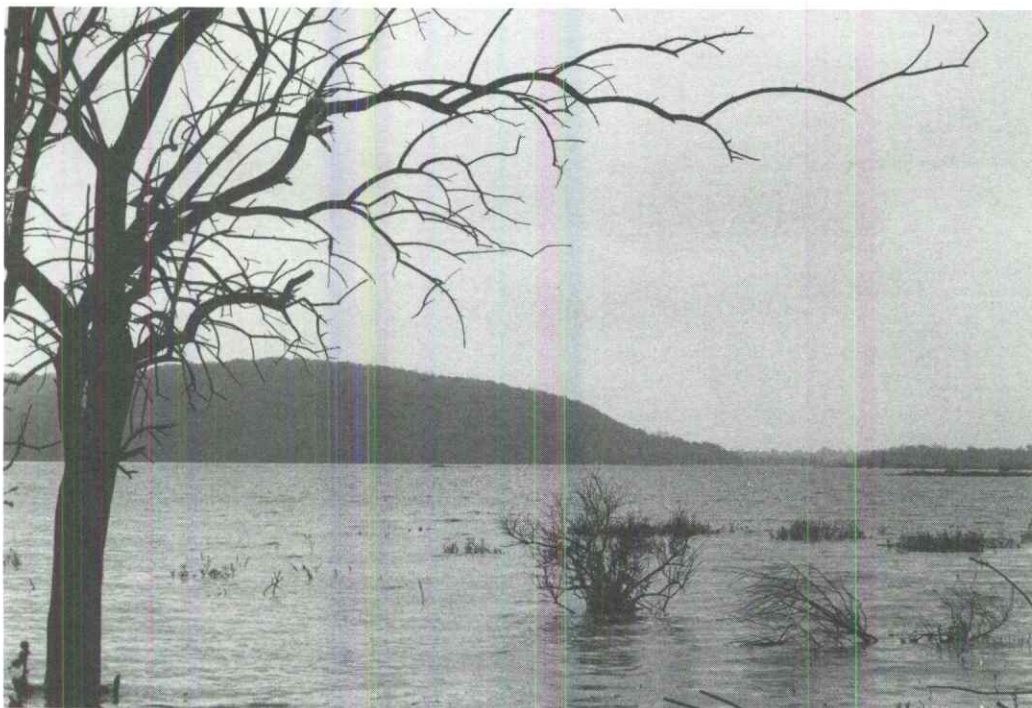


Figure 1—Percent of total ground-water use in Kansas going to various applications in 1987 (USGS, Water-Supply Paper 2350, 1990).



Surface water is generally much more plentiful in eastern Kansas than in western Kansas. This is the Marais des Cygnes waterfowl area in Linn County.

# Ground-water occurrence

## General

Nearly all rocks and sediments contain openings called pores or voids, which come in all shapes and sizes. Some of them are too small to be seen with the unaided eye, and the smallest range in size down to the dimensions of molecules. In exceptional cases, they may be many feet across, like the limestone caverns in the Ozarks. The fraction of total volume occupied by pores or voids is called *porosity*. Materials containing a relatively large proportion of void space are described as porous or said to possess “high porosity.” That fraction of the pores through which water can flow is called effective porosity. Total porosity may range from near zero to over 50%, depending on the material, while effective porosities are typically somewhat smaller. Figure 2 shows examples of different types of porosity.

Soil also is porous. On hot summer days, the surface soil may appear quite dry, but if we dig down a little way the soil feels damp; if we could dig far enough to reach rock, this too would feel damp. This is because the pores are not empty; some are filled, or partly filled, with water. In general the smaller pores are more likely to contain water and the larger ones are more nearly empty. At a still greater depth, we would find that all the pores are completely filled with water, and we would then describe the rock or soil as “saturated.” In scientific terms, we would have passed from the surface through the vadose or *unsaturated zone* to the *saturated zone*.

If we dig or drill a hole from the ground surface down into the saturated zone, water will flow from the surrounding material into our hole until it reaches a constant level. This is the depth at which all of the pores are filled with water—in other words, the upper limit of the saturated zone. We call this level the *water table*. The thickness of the layer of rock or loose sediment that is saturated with water is called the *saturated thickness*.

The distance we need to drill or dig to reach the water table varies from place to place; it may be less than 3 feet (1 m), or more than 300 feet (90 m). It may even coincide with the ground surface. If so, the ground will be wet and marshy, or there will be a pond, spring, or river. Where the water table is below the ground, as is usual, its depth can be measured in a well.

Once we drill to the water table, several factors control how much water we can extract from the saturated zone. One is the porosity. If it is small (a few percent or less), then the amount of water contained in a given volume of rock will be small. The second factor is the

ease with which fluids can move through the porous rock or loose sediment. It is directly related to a combination of the size of the pores and the degree to which the pores are interconnected. We call this second factor *permeability* or hydraulic conductivity. Materials that allow water to pass through them easily are said to be permeable; those that permit water to pass only with difficulty or not at all are impermeable. A rock may be porous but relatively impermeable, either because the pores are not connected or because they are so small that water can be forced through them only with difficulty. Conversely, a rock that has no voids except for one or two open cracks will have a low porosity and will be a poor storer of water, but because water will be able to pass easily through the cracks, the permeability will be high. Layers of rock sufficiently porous to store water and permeable enough to allow water to flow through them at useful rates are called *aquifers*. Related terms are applied to low-permeability layers (*aquitards*) and impermeable zones (*aquicludes*). Aquifer materials may be either consolidated (that is, solid but

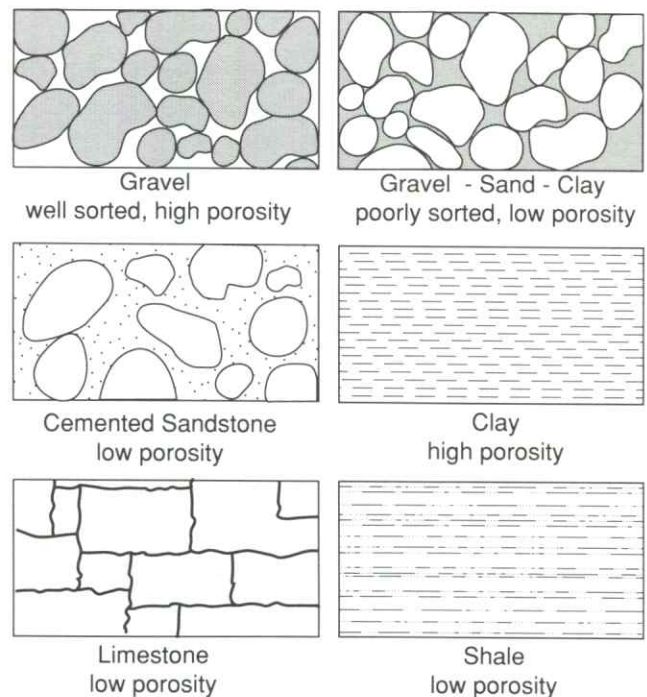


Figure 2—Different rock types have different levels of porosity.

porous rock) or unconsolidated (sands and gravels with little or no attachment of the mineral grains).

When an aquifer is covered by an extensive layer of low-permeability material, the aquifer is said to be *confined*. Water in an *unconfined aquifer* is free to flow and establish an equilibrium level with respect to gravity and atmospheric pressure. However, water in a confined aquifer may be under pressure from being confined. If a well penetrates that confined aquifer and the water is allowed to seek a natural level, the *hydraulic head* or equilibrium elevation of the water may be very different from the confined elevation. In *artesian wells*, pressure in the aquifer causes water in the well to rise above the top of the aquifer. If the pressure in the confined aquifer is high enough, a well that penetrates the confining layer may produce water that flows freely at or above the ground surface; this is known as a flowing well. Kansas has flowing wells in many locations, particularly where the water table is close to the earth's surface. Southwestern Kansas and central Kansas were once the site of numerous flowing wells. The artesian valley of Meade County had a number of flowing wells, and water in one Meade County well rose as much as 17 feet (5 m) above the land surface. Because of lowered ground-water levels, most of those wells no longer flow at the surface. However, a flowing well still exists at Meade County State Lake. There also are flowing wells in other parts of the state, such as northeastern Stafford County and western Marion County.

Impermeable layers also play a role in another hydrologic phenomenon known as perched water bodies. In this case locally occurring aquitards (rock or clay layers) may collect and support water that infiltrates through the soil to form the underground equivalent of a

puddle. To the dismay of those who try to develop them into water supplies, perched water bodies are not connected with any larger aquifer system and are often very limited in extent. If the perching layer is leaky, it may fluctuate greatly with variations in rainfall. Figure 3 illustrates several of the terms and aquifer types discussed above.

In the preceding paragraphs we have focused on characteristics that determine how much water an aquifer holds (or can hold) and how easily the water may be extracted. The question of how easily water may be extracted from an aquifer on an instantaneous basis relates to a property called the *specific yield*, which will be discussed more in the section on well construction and ground-water production. However, an aquifer is a container of finite size and it can be effectively emptied if water removal exceeds water replenishment. The factor that determines the amount of ground water available from an aquifer over the long term is the rate of replenishment or ground-water *recharge*—the degree to which water removed from the aquifer is replaced over time—minus the natural discharge such as flow into rivers. The sustainable yield (also known as the *safe yield*) of an aquifer is often defined as the long-term average recharge rate minus the average natural discharge. However, it is important to recognize that withdrawals equal to long-term recharge can result in reduction of streamflow and wetlands, as ground-water discharge is replaced by ground-water pumpage as the means of balancing the inflow of water to the aquifer.

Withdrawals in excess of the sustainable-yield rate will result in aquifer depletion (also referred to as loss of saturated thickness, *drawdown*, water-level decline, etc.).



Ground water, moving along an underground layer of rock, leaves the subsurface and freezes at this Johnson County roadcut.

The replenishment factor or recharge depends not only on the nature of the rocks but on the soil and vegetation that cover them and on the climate of the region. It is part of the *water balance* (or budget) of the area—the average balance between the water that enters the area and the water that is used and leaves it. Hydrologists use water-budget calculations in much the same way that homeowners balance their checkbooks or businesses

monitor cash flow and assets. In assessing the groundwater resources of any region, knowledge of the water balance is as vital as knowledge of the porosity and permeability of the rocks. This is because groundwater is not isolated from other water; as we have seen, it is part of the earth's total amount of water. As such, it is in more or less continuous interchange with all other water in a system of circulation called the water cycle or hydrologic cycle.

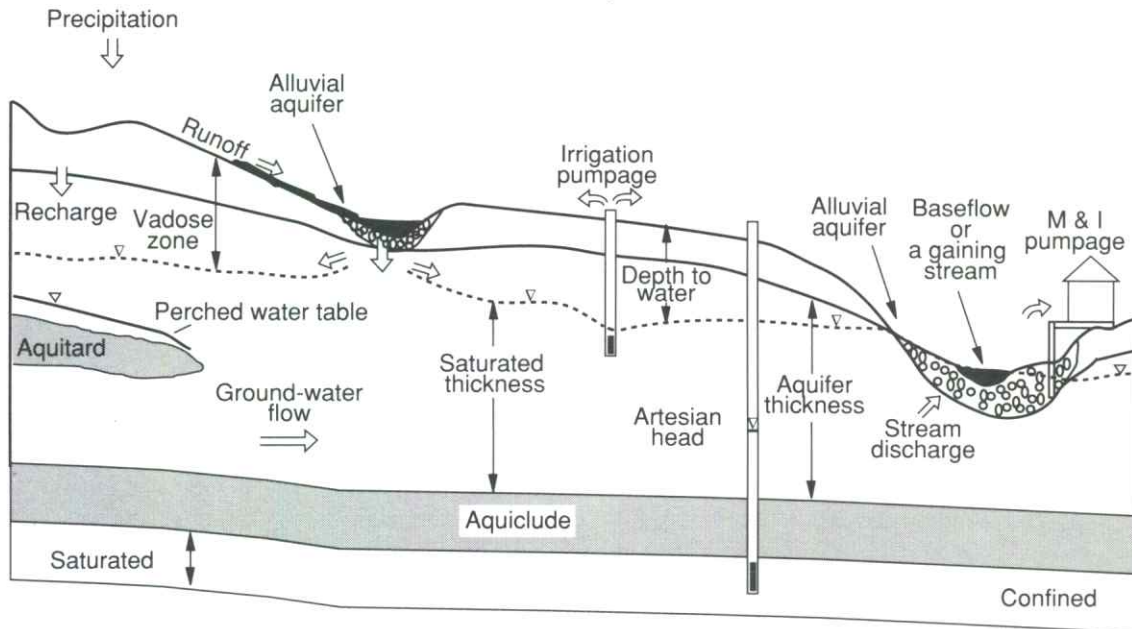


Figure 3—A cross section of the subsurface, depicting several hydrologic situations.



*A flowing well in Meade County.*

## Hydrologic cycle

The hydrologic cycle is a vast and complex system that circulates water over the whole planet. Figure 4 illustrates the various parts of this cycle, which starts and ends with the oceans. Energy from the sun powers the system, causing water to evaporate from the surface of the world's oceans. This water then condenses to form large cloud masses. These clouds are moved by the global wind system and, when conditions are right, the water precipitates, falling back to the surface again as rain, snow, or hail. Most precipitation returns to the atmosphere as evaporation from water bodies or from the ground surface, and as transpiration from plants. Transpiration is very similar to respiration (breathing) in animals, and releases water vapor to the atmosphere. The processes of evaporation and transpiration are usually lumped together as *evapotranspiration*. Some of the water that falls onto the land generates surface runoff that collects to form streams and rivers that eventually flow back into the sea, where the process starts all over again. A final portion of precipitation—generally the smallest fraction—percolates through the soil to reach the water table and become ground water. Unless ground water is removed by pumping from wells, it flows through the aquifer towards natural discharge points, such as springs, streams and rivers, lakes, or the ocean coastline. Figure 5 illustrates these processes and provides

a picture of a local part of the hydrologic cycle and the effects of ground-water withdrawal.

A ground-water system, therefore, consists of recharge from precipitation percolating into the ground, reaching the water table, and flowing through rocks of varying permeabilities towards natural discharge points. The rate at which water flows through the system depends upon the precipitation, evaporation, transpiration (respiration by plants), the geological conditions, and many other factors. Hydrogeology encompasses many fields of study because it is impossible to isolate completely one portion of the hydrologic cycle from the others, and because water in its natural cycle takes different forms in different realms—ice in glaciers, liquid and vapor in the sea, rivers, aquifers, and vapor in the atmosphere.

People have trouble visualizing and understanding ground water because it is out of sight and operates on unfamiliar scales. When we look at a river, lake, or ocean, we can see and measure its area and its depth, and we know that the water is relatively uniform throughout (homogeneous). If water is flowing, particularly in a flash flood or a summer stream, we can see and measure that process, and we have an intuitive grasp of how quickly water moves on the earth's surface. For ground water, our surface-oriented intuition does not serve us well.

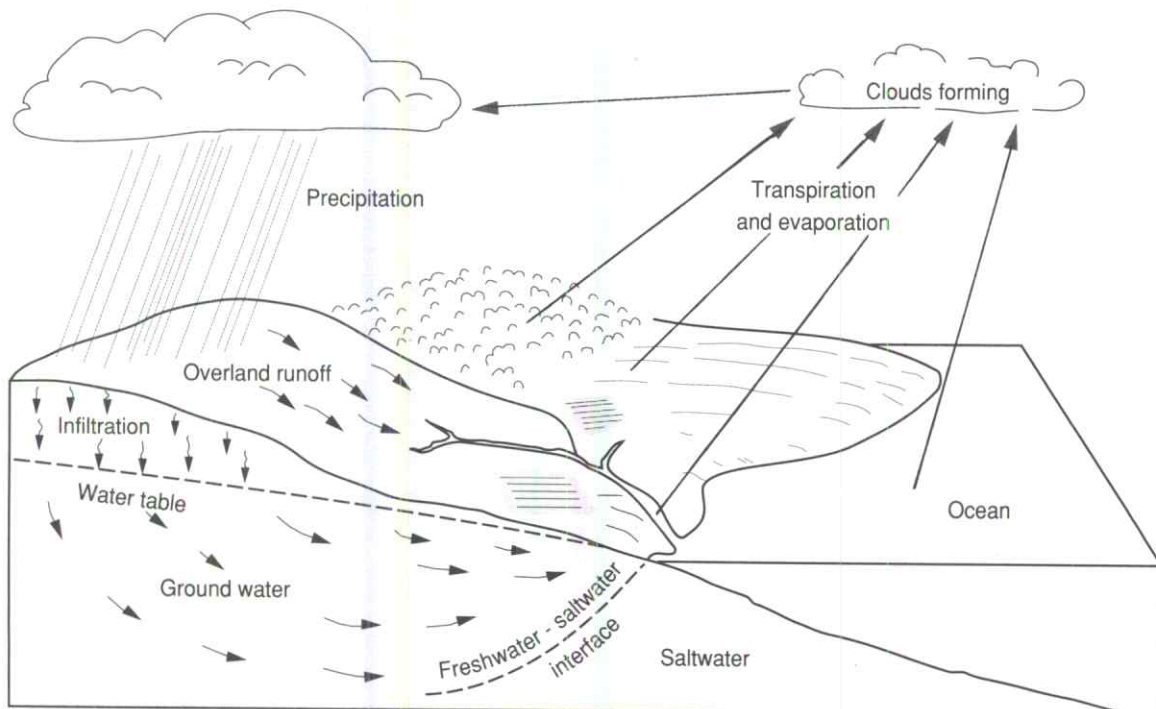


Figure 4—The hydrologic cycle. Precipitation falls to the earth's surface, runs off or infiltrates into the ground, then moves back into the atmosphere through transpiration or evaporation.

Aquifers are out of sight, often difficult to identify and measure, and they are far from uniform in thickness, shape, and such important properties as porosity and permeability. When an aquifer is deep underground or extremely variable in its characteristics, obtaining a precise estimate of its extent, characteristics, or water content can be impractical. Because of the inability to

accurately characterize these complex and highly variable systems, ground-water scientists and managers must accept and deal with various types and levels of uncertainty.

Although we haven't specifically said so, most of the descriptions so far assume that we are concerned primarily with aquifers containing freshwater. This is generally

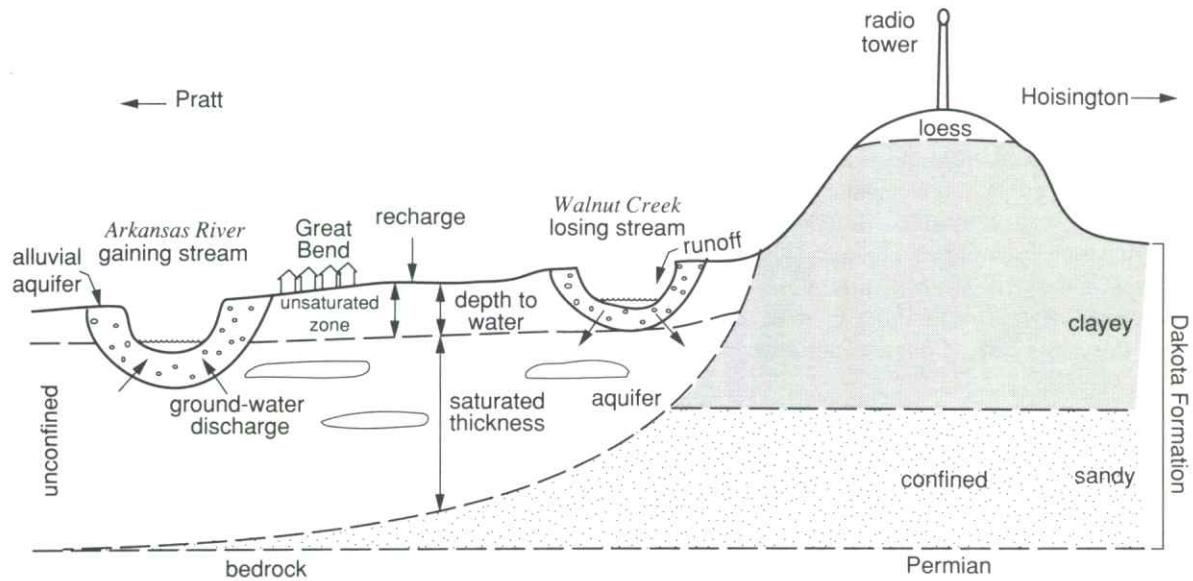
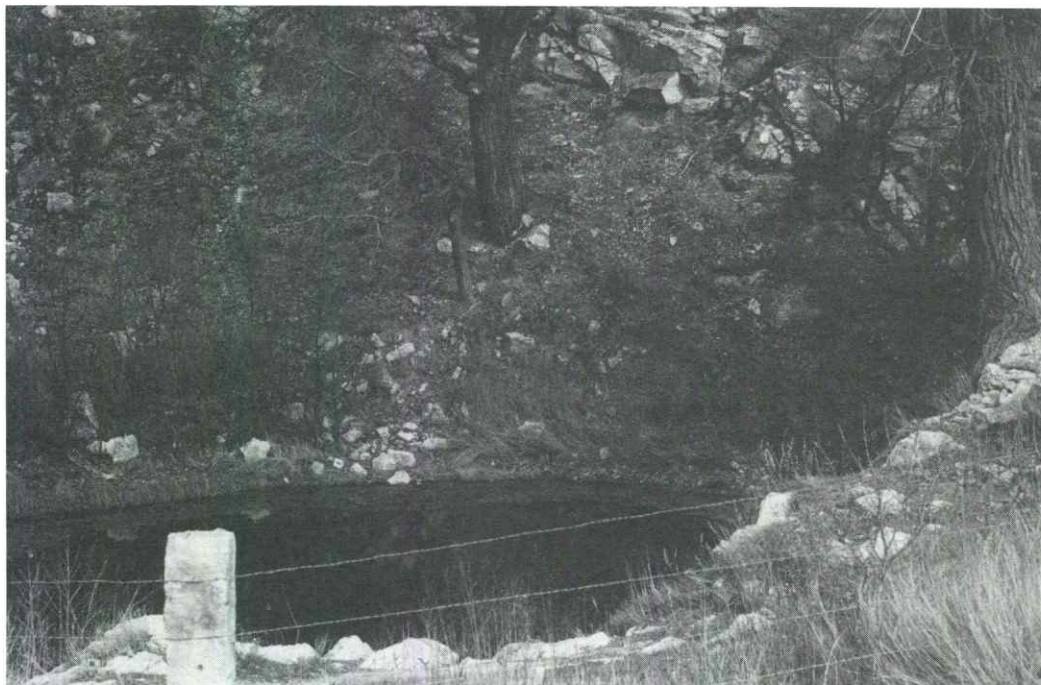


Figure 5—A schematic cross section of hydrogeology in the Great Bend area.



St. Jacob's Well, a spring at the bottom of Little Basin in Clark County.

true, but aquifers can (and many Kansas aquifers do) contain and transport *brines* or other poor-quality water. Although not usable for human water supplies, these aquifers can't be ignored. Where aquifers with poor water quality are near the surface or are hydraulically connected with usable aquifers, water-quality problems may occur in freshwater supplies—this is common in much of central and southeast Kansas. In addition, deep saltwater-bearing aquifers (most notably the Arbuckle Group) are economically important because they contain hydrocarbons and are used for the injection and disposal of liquid wastes from both industry and oil-field operations. Kansas ground-water issues therefore can not be fully addressed without considering these aquifers, and we will mention them in the course of discussing freshwater supplies.

Time scales of ground-water processes also are difficult for many people to understand. Although ground water in very shallow, permeable aquifers may recharge and drain on a time scale of years to decades, deeper ground water may be thousands to millions of years old (thus, this ground water is sometimes referred to as “fossil water”). If this is the case, climatic conditions under

which it was recharged may bear little resemblance to those of today, and we may not be able to define the safe yield of such an aquifer with any real confidence. Figure 6 illustrates some of these time-scale points. Recharge in the Ogallala aquifer of western Kansas, for example, is slight, and it may take many years for precipitation at the earth's surface to reach a deep aquifer.

In much of western and central Kansas, aquifers slope or dip down slightly to the east, resulting in a west-to-east flow of the water. The flow velocities, however, are only about a foot per day—much slower than free water would flow on the earth's surface. (To gain a practical appreciation of this difference, observe how long it takes for water to flow out of a full bottle when it is tipped over with the cap off—and then repeat the experiment with a wet sponge tied firmly over the mouth of the bottle.) This means that it will take about 15 years for ground water to move a mile, almost 500 years to cross a typical county in Kansas. As we have learned to our distress, depletion and contamination may seem like local problems in the short run, but they have a way of involving all of us eventually.

## Kansas aquifers

We have discussed some of the characteristics of aquifers, but when we come to identifying and describing specific aquifers, the terminology can be a bit untidy. Part of the aquifer definition problem stems from the use to which a water-bearing formation may be put. Rocks in which wells can produce a few gallons per minute (gpm) may be a perfectly adequate aquifer for domestic or livestock water supplies, but they would be completely inadequate for irrigation or municipal supply use where well yields of thousands of gpm may be required. Likewise, rocks that may transmit water over significantly long periods of time may not produce water for wells during

short time periods. Still, such a formation is an aquifer in either case.

Other distinctions may arise from the background of the person defining the feature (like mountain peaks, underground features tend to be named by the person who first discovers them). Geologists often define rock layers according to their nature and origin. They usually define rock layers according to a unit called a formation, the smallest possible layer of rock that can be mapped and described over a wide area. For example, the Dakota Formation is a layer of sandstone and shale that crops out in central Kansas. However, hydrologists view aquifers in

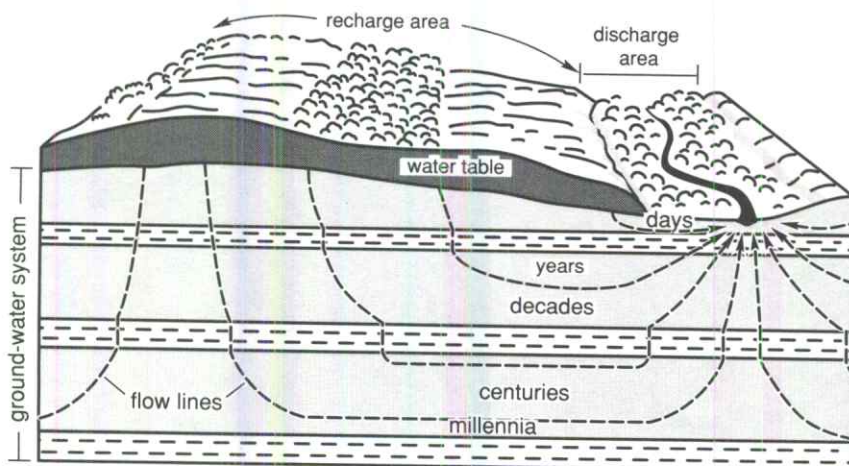


Figure 6—Ground water moves, though slowly. Movement from the surface to a point of discharge may take years, decades, or much longer.

a functional sense, and may include in a single named unit a wide variety of rocks and sediments as long as they are all hydraulically interconnected. Hydrologists, therefore, talk about the Dakota aquifer, and use the term to include several geologic formations that are hydraulically connected and were deposited at about the same time in geologic history.

Both approaches have merit; the hydrologic definition is simple and practical, but an understanding of the geology can often yield important knowledge about aquifer extent or characteristics. In the description of Kansas aquifers that follows, all types occur. For example, the High Plains aquifer in western and central Kansas is a hydrologic feature that includes geologically defined units like the Ogallala Formation and various other units that can be defined either geographically or geologically (the Equus Beds, the Great Bend Prairie aquifer,

etc.). Figure 7 gives the ages and geologic context of the major aquifer formations in Kansas.

### Unconsolidated aquifers

In Kansas, the shallowest, largest, and most productive aquifers are usually unconsolidated deposits of sand, gravel, silt, and clay that were deposited by water, wind, or ice. The majority of these aquifers were formed from the sediment (or *alluvium*) deposited by streams in *bedrock* valleys. Stream and river deposits of this sort are termed *alluvial* materials, although in today's hydrologic terminology, the alluvium associated with existing streambeds is referred to as an alluvial aquifer. Older material of alluvial origin is typically designated by some other name, such as *terraces*, a geologic term for broad benches of land that formed the banks of ancient rivers.

ERAS	PERIODS	EPOCHS	EST.LENGTH (YEARS)*	DESCRIPTION	MILLION YEARS PAST
CENOZOIC	QUATERNARY	Holocene	10,000+	Glaciers moved into northeast at least twice, forming glacial till aquifers. Sand dunes formed by wind in west. Equus Beds and Great Bend Prairie aquifers, as well as present-day stream-channel alluvial aquifers, formed by stream and river action.	1.6
		Pleistocene	1,590,000		
	TERTIARY	Pliocene	3,700,000	Rocks found are part of Ogallala Formation (sand, gravel, and porous rock), which contains a large quantity of ground water and occurs only in western third of state. No rocks were formed in eastern Kansas.	66.4
		Miocene	18,400,000		
Oligocene		12,900,000			
Eocene		21,200,000			
		Paleocene	8,600,000		
MESOZOIC	CRETACEOUS		77,600,000	Much of western half of Kansas was covered by seas. Limestone, sandstone, and chalk formed from sea deposits, and Dakota aquifer formations were deposited by stream channels and deltas.	144
	JURASSIC		64,000,000	Most rock in Kansas is underground in west. A few small outcrops found in southwest corner, where Jurassic Morrison formation acts as an aquifer.	208
	TRIASSIC		37,000,000	No rocks have been found in Kansas.	245
PALEOZOIC	PERMIAN		41,000,000	Much of Kansas was covered by several seas, which deposited limestone, shale, and chert as they rose and fell. When seas dried up, they left behind salt and gypsum in bedded deposits and "red beds" of central Kansas, which are sources of natural saltwater discharge.	286
	PENNSYLVANIAN		34,000,000	Seas and swamps came and went, leaving behind coal as well as shale, limestone, sandstone, chert, and conglomerate. Pennsylvanian rocks are found at surface in eastern Kansas, and include the Tonganoxie and Ireland sandstones that serve as locally important aquifers.	320
	MISSISSIPPIAN		40,000,000	Repeated layers of limestone, shale, and sandstone indicate that seas rose and fell. Mississippian rocks are oldest found at the surface and are used locally as source of ground water in extreme southeastern part of state.	360
	DEVONIAN		48,000,000	Seas covered Kansas during much of period. Limestone, shale, and sandstone deposits are only underground.	408
	SILURIAN		30,000,000	Land was uplifted and seas disappeared. Limestone deposits found only underground.	438
	ORDOVICIAN		67,000,000	Seas covered parts of Kansas during much of period. Dolomite and sandstone are underground, and in combination with Cambrian formations, form important aquifer in southeastern Kansas.	505
	CAMBRIAN		65,000,000	Early, climate was dry and many rocks eroded. Later, dolomite, sandstone, limestone, and shale were deposited by seas. Carbonate rocks form part of Cambro-Ordovician aquifer used extensively in Crawford and Cherokee counties.	570
PRECAMBRIAN			3,930,000,000	These rocks are oldest on earth. In Kansas, they are only found deep below the surface and not much is known about them. Many are igneous and metamorphic and have gone through many changes.	4,500?

EONS NOT SHOWN

\*Decade of North American Geology, 1983 Geology Time Scale, Geological Society of America

Figure 7—Kansas geohydrologic timetable, showing the age and characteristics of the major Kansas aquifers.

## Alluvial valleys

All the major rivers and many of the smaller streams in Kansas have alluvial deposits associated with them. Rivers such as the Arkansas and Republican have material from the erosional remnants of the Rocky Mountains so that commonly more coarse sand and gravel is found there. Smaller Kansas streams may have more silty or clay material derived from the limestones and shales of the area they drain. In parts of eastern Kansas alluvial aquifers are the only significant source of ground water, while in western Kansas they often overlie or intersect other shallow unconsolidated aquifers. Figure 8 shows the distribution of these aquifers, which closely follows the major streams and rivers. The thickness of the alluvial material is highly variable, ranging up to 300 feet (90 m) in some of the major river valleys such as the Arkansas. Depth to water is usually shallow (10–30 ft [3–9m]) and in many of the valleys the ground water in the alluvium is directly connected to the stream.

The general flow of ground water is downstream, and there is a close relationship between streamflow and ground water in alluvial aquifers (which in turn are often connected to adjacent or underlying aquifers). During times of high streamflow, water often moves out of the stream channel and hastens recharge of the alluvial aquifers. When streamflow is low, water may flow back out of the alluvial aquifer and into the stream. This is called baseflow, and it maintains streamflow even in times of little precipitation. However, in locations where the water table in alluvial aquifers has been lowered by heavy pumping, water levels may drop to the point that the

aquifer does not replenish the streamflow. Now that widespread conservation practices in agriculture—such as terracing—help keep water on the soil and allow more of it to soak in rather than run off into streams, loss of baseflow further contributes to streamflow declines.

Ground water contributes to streamflow in many of the streams in eastern Kansas. In western Kansas, however, ground-water levels in many stream valleys have declined to the point where ground water's contribution to the stream is less than in the past. In some reaches of streams such as the Pawnee, Walnut, Smoky Hill, Arkansas, and Solomon, no ground water discharges at all and the streams are intermittent, flowing only after runoff from precipitation (streams that flow only in response to precipitation are called "ephemeral streams"). This relationship between streamflow and alluvial aquifers emphasizes that ground water cannot be understood or managed without reference to the larger hydrologic cycle. In essence, ground water and surface water are inextricably linked.

The chemical quality of surface and ground waters in most alluvial valleys is acceptable for most purposes. Saltwater from Permian formations is known to leak into shallow ground water in the Solomon and Smoky Hill River valleys in Saline and Dickinson counties, in the Cimarron River in southwest Kansas, in the Ninnescah River in south-central Kansas, in the Arkansas River valley downstream from Great Bend, and other areas. Similarly, the Dakota aquifer discharges saltwater into the Saline and Smoky Hill rivers in Russell County and the Solomon River in Mitchell and Ottawa counties. High concentrations of total-dissolved-solids in ground waters (a rough measure of water quality) also are known to be

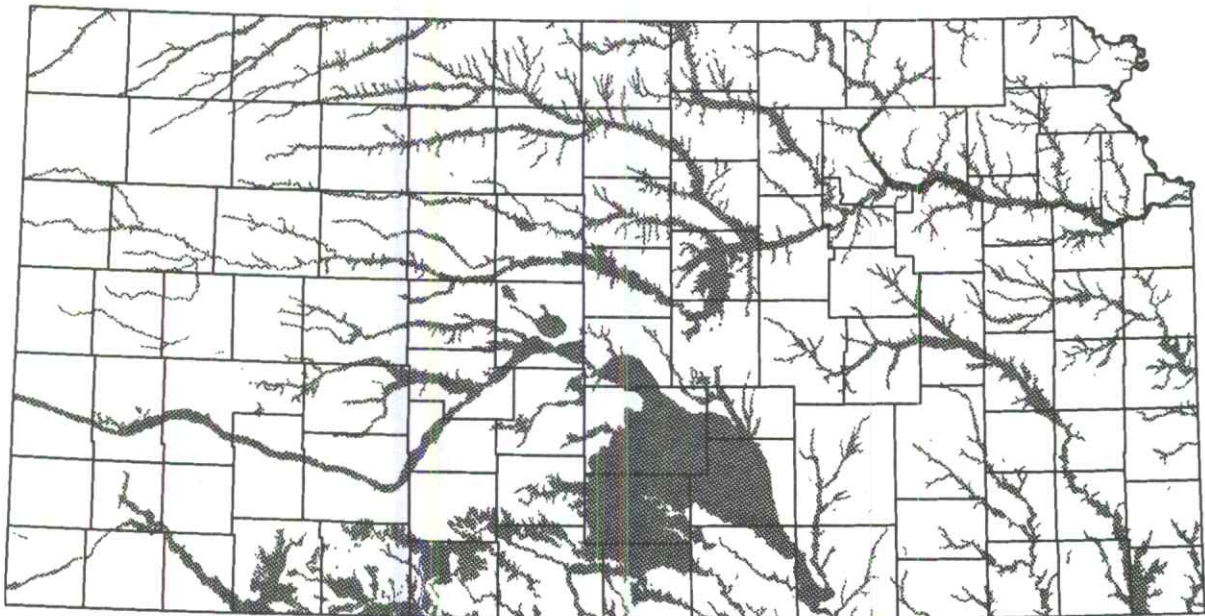


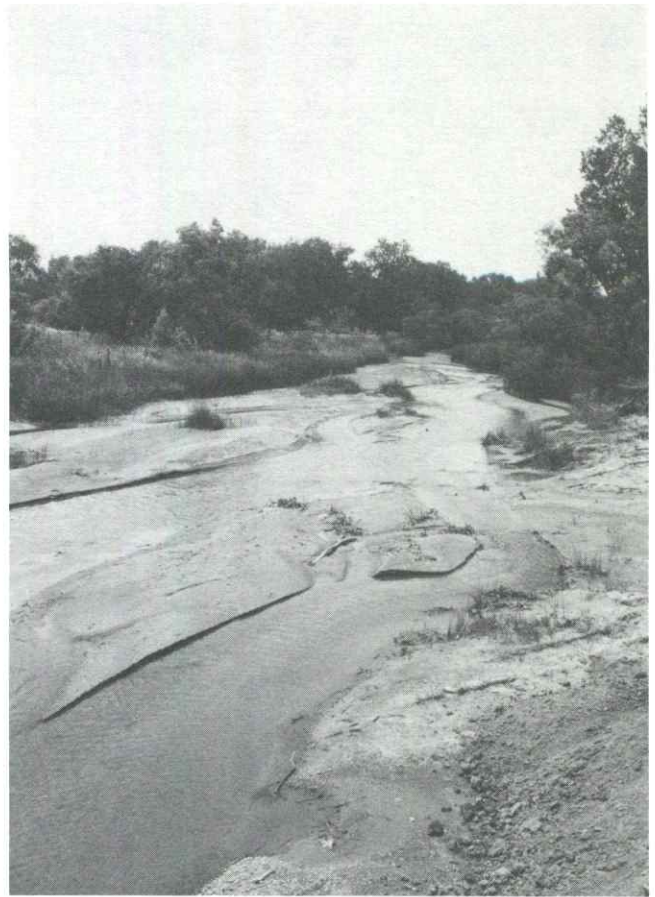
Figure 8—Distribution of alluvial aquifers in Kansas.

present in the upper Smoky Hill Valley in Logan County and in the Arkansas River alluvial aquifer.

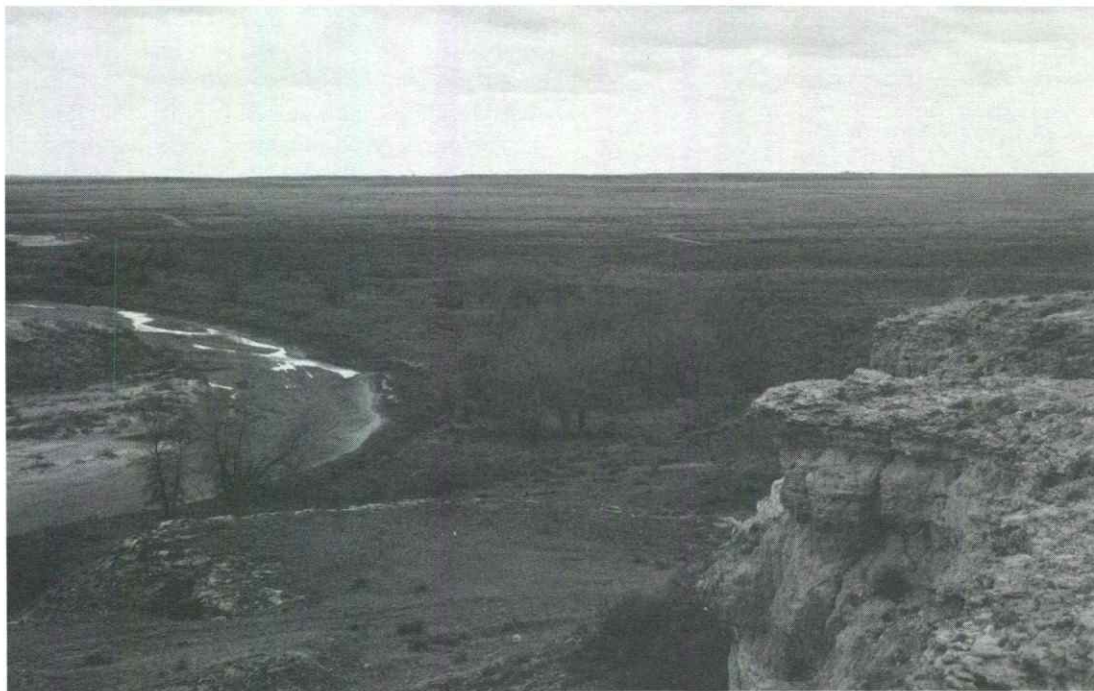
### High Plains aquifer

As was discussed earlier, the High Plains aquifer is a major regional hydrologic unit that can be broken down into different geologic aquifer units formed at different times in various locations. Figure 9 shows the location of the High Plains aquifer and its major constituent formation, the Ogallala Formation. Figure 10 shows the Kansas portion of the High Plains aquifer, which includes not only the Ogallala, but also the Great Bend Prairie, Equus Beds, and alluvial and sand dune aquifers. Like the modern alluvial aquifers, these units were mainly deposited by streams flowing within, into, or through the state.

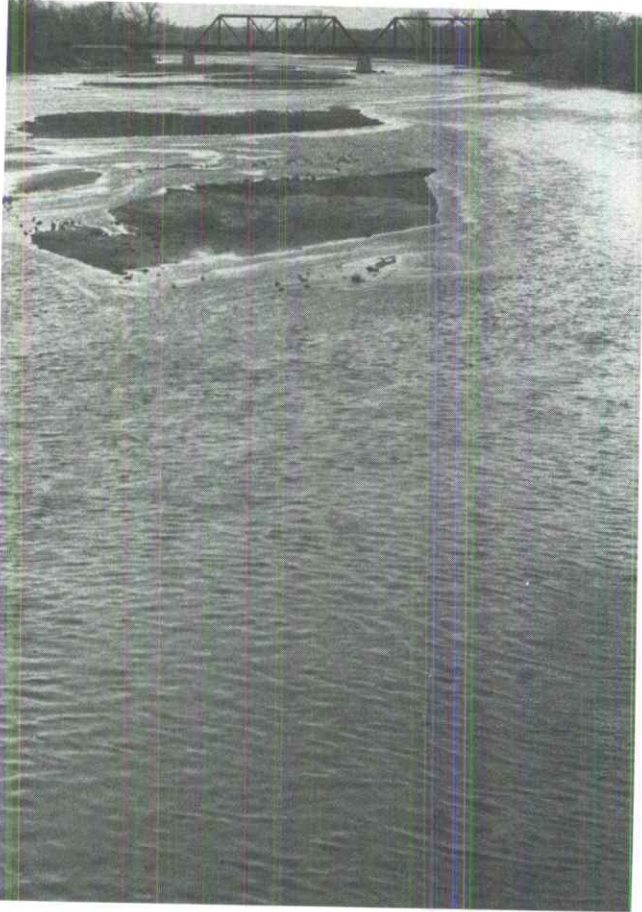
The Ogallala Formation was deposited by streams flowing out of the Rocky Mountains about 3.8 million years ago. Those streams created an enormous alluvial fan extending out from the Rockies. It was originally a continuous layer up to 800 feet (240 m) thick that covered eastern Colorado and western and central Kansas, and extended north into Nebraska, Wyoming, and the Dakotas, and south through parts of Oklahoma and Texas. However, subsequent erosion has reduced the thickness and removed much of the formation from eastern Colorado, and the Ogallala is no longer connected to the Rocky Mountains. Where it crops out at the surface, the Ogallala commonly forms a dense, naturally cemented rock that is known locally as mortarbeds. The Ogallala appears at the surface throughout western Kansas, particularly at



*The South Fork of the Republican River in Cheyenne County.*



*The Cimarron River runs south of Point of Rocks, an Ogallala-capped hill in the Cimarron National Grasslands of Morton County in southwestern Kansas.*



The Arkansas River near Winfield.

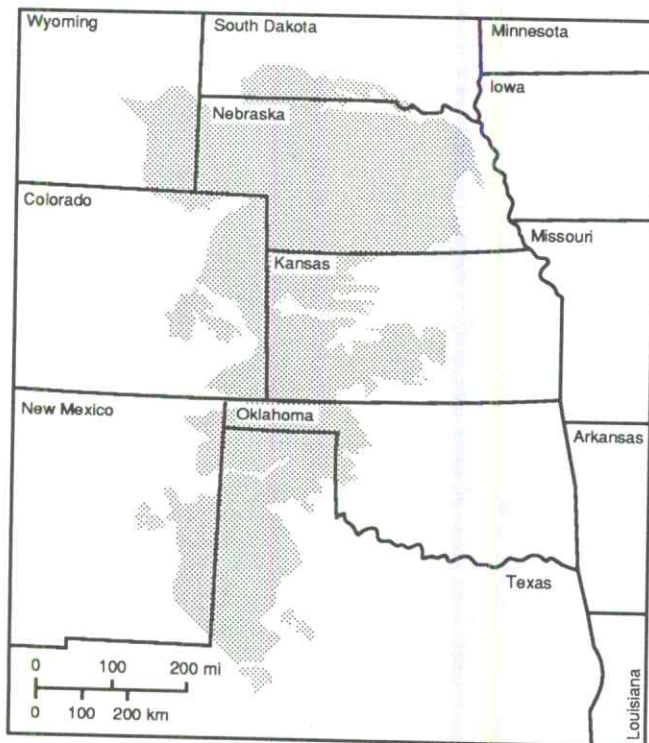


Figure 9—The High Plains aquifer underlies parts of eight states and holds enough freshwater to fill Lake Huron.

locations where streams have eroded through soil, such as in the Smoky Hill River and other drainage areas and at Lake Scott State Park in Scott County. The Ogallala also is found at the surface in parts of central Kansas. Even at the surface, the pore space in the Ogallala is obvious, and it is easy to see why the Ogallala captures and holds water in the subsurface.

In western Kansas, the Ogallala is up to several hundred feet thick in places; it is thickest in southwestern Kansas. In places, tens to hundreds of feet of the Ogallala are saturated with good quality water. The quality of Ogallala water is particularly high because the sands and gravels of the formation have a low solubility and act as a filter and to help purify the water. However, *depth to water* may be substantial and is increasing because irrigation pumping is far in excess of recharge. Recharge to the Ogallala is from precipitation and is limited to approximately 1/4–1/2 inch per year in most of western Kansas. The direction of ground-water flow is from west to east.

In recent years, the High Plains aquifer has come under increasing pressure as a source of water for irrigation. With the introduction of large-capacity pumps and technological improvements such as center-pivot irrigation, the aquifer has been pumped heavily. Water from the aquifer has made it possible to grow thirsty crops such as corn that otherwise could not be raised with the scant rainfall in western Kansas. With the use of that ground water, however, has come a drastic decline in the High Plains aquifer water levels. In west-central Kansas—particularly in the counties of Wichita, Scott, and Finney—and in some areas of southwestern Kansas, more than 50% of the water originally in place in the High Plains aquifer has been used. The situation is less severe in northwestern Kansas, where irrigation has been less developed and the decline has been less substantial; in those locations, the water table is 10–25% lower than it was before the days of ground-water development.

In terms of measured declines in the water table, a 10-foot (3-m) decline has been common across much of western Kansas. The much greater declines—in some cases the water table is now 200 feet (60 m) below its level prior to irrigation—are mostly centered in southwestern and west-central Kansas, where irrigation development has been greatest and the amount of water in the aquifer has been greatest.

Those statistics indicate substantial water use. However, in parts of western Kansas, where the High Plains aquifer was originally several hundred feet thick, considerable water remains. Even in those locations, the drop in the water level has meant that irrigators must pump the water farther to get it to the surface. That extra pumping requires increased energy use, which in turn has slowed use of the water. Increased awareness of the finite nature of the High Plains aquifer also has slowed use of the aquifer in the past few years. Irrigators have employed

increasingly more efficient irrigation methods. Finally, irrigated acreage has decreased somewhat. These factors, and others, have slowed declines. Still, substantial amounts of pumping continue in the High Plains, often in

excess of recharge. The eventual outcome may be some leveling off of use and a stabilization of water levels. In some areas, the High Plains aquifer may become depleted to the point that it is no longer useful for irrigation, 700

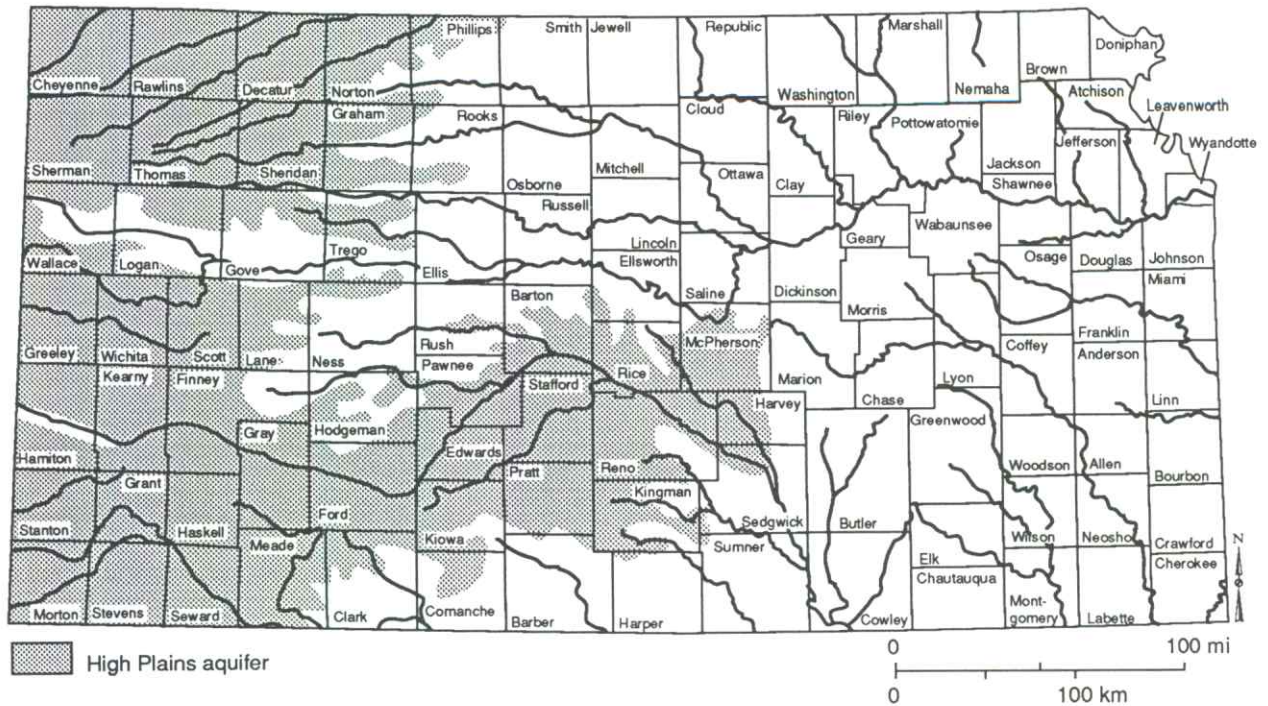
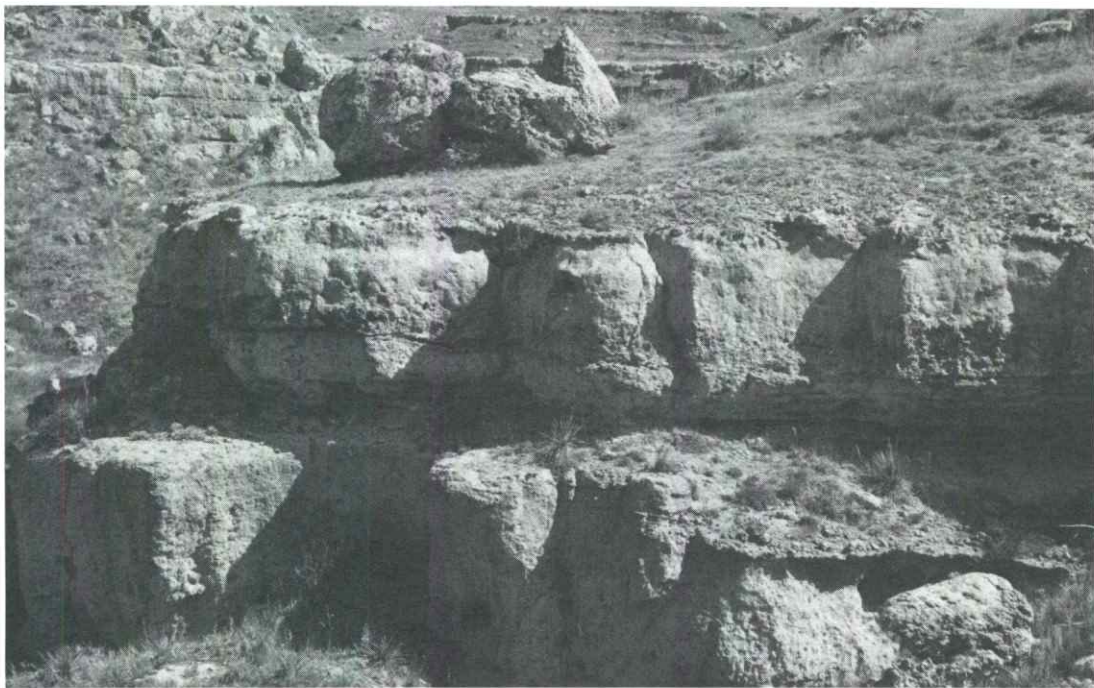


Figure 10—The portion of Kansas underlain by the High Plains aquifer.



The Ogallala Formation as it appears at the surface in Scott County. These naturally cemented sands and gravels are known as mortarbeds.

although it should be able to continue as a source of municipal and domestic water.

The Great Bend Prairie aquifer, in central Kansas, is largely similar in composition to the Ogallala. However, it was deposited by ancestral equivalents of the Arkansas River and other streams such as Walnut Creek and the Pawnee River. The Great Bend Prairie aquifer ranges in thickness from 350 feet (106 m) in areas of Kiowa and Edwards counties to a featheredge in Kingman and Reno

counties. The aquifer overlies the Dakota aquifer in the west and Permian shales and siltstones farther east. It is an unconfined aquifer and yields up to 1,500 gpm to wells. Water quality is variable due to an influx of salty ground water from the underlying Permian rocks (see Figure 11). Where this saltwater intrusion occurs, ground-water depletion results in a further deterioration of water quality. That is because heavy pumping of freshwater may allow upward flow of the underlying saltwater, contaminating

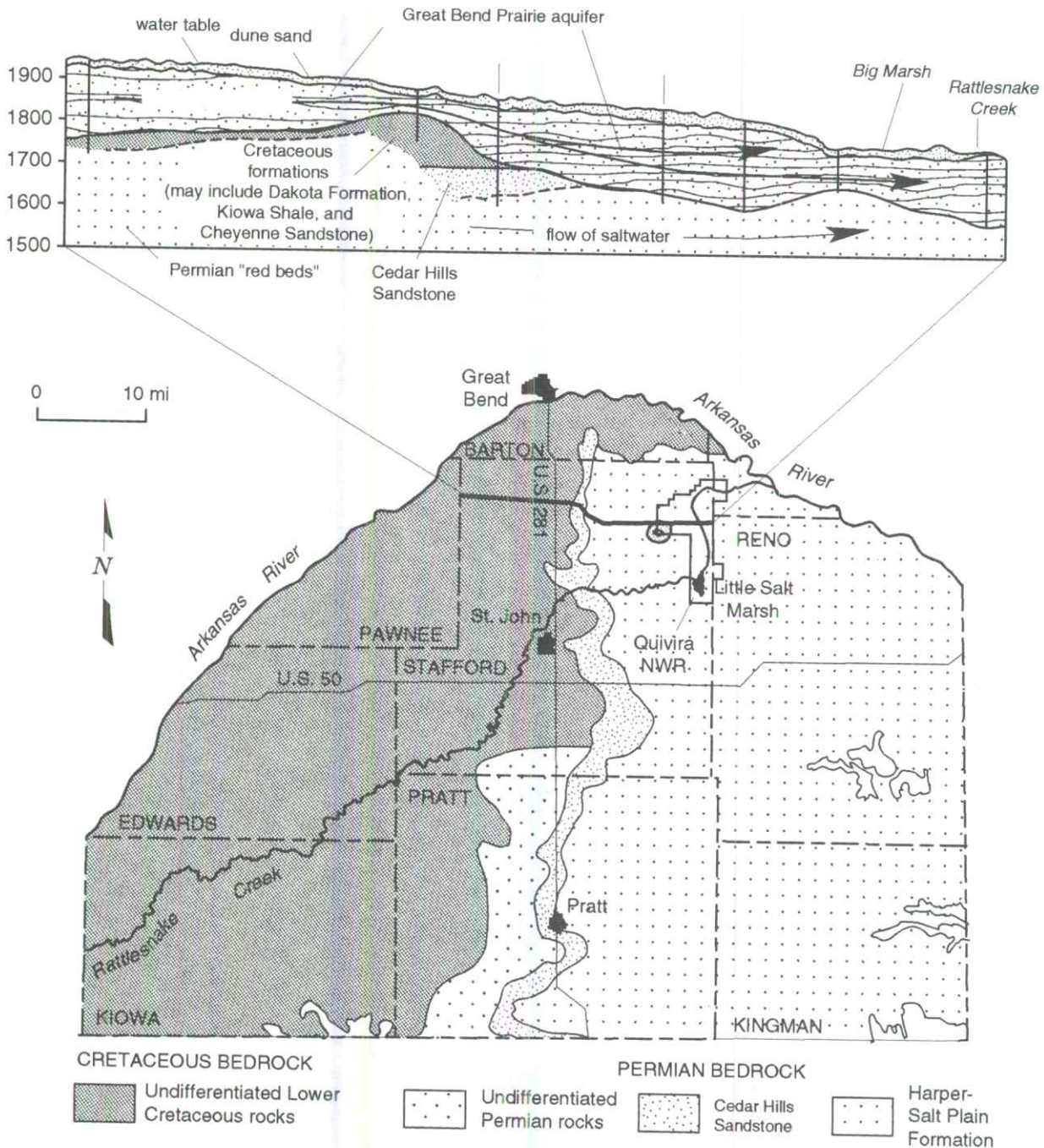
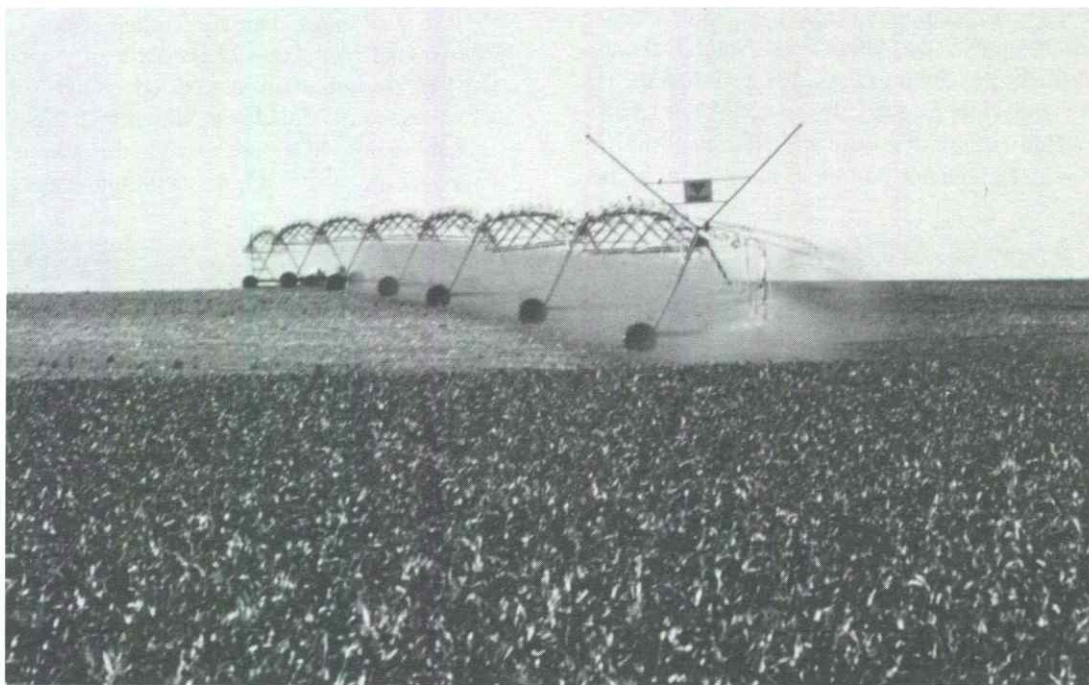


Figure 11—The lower figure shows the bedrock geology of the Great Bend Prairie. The upper figure is a cross section showing that the area is underlain by Permian bedrock. Salty water from those Permian rocks can move into and contaminate the overlying freshwater aquifer.



*A center-pivot irrigation system in Trego County.*

the freshwater above. Depth to water in this aquifer ranges from 5 to 30 feet (1.5–9 m) but may be as much as 150 feet (45 m) in some areas. Natural ground-water flow is primarily from west to east, with some natural discharge occurring to Rattlesnake Creek, the North and the South forks of the Ninnescah River and in and around Quivira Marsh.

The Equus Beds is an alluvial deposit of the ancestral Smoky Hill River, deposited when that stream flowed south into the Arkansas River. The deposit fills an abandoned river channel (known as the McPherson channel) in McPherson and Harvey counties. In places, the alluvium also fills areas of subsidence caused by dissolution of the underlying Hutchinson salt. Thickness ranges from 0 to approximately 270 feet (0–82 m) and depth to water from 5 to 10 feet (1.5–3 m) to 60 or 70 feet (18–21 m). The deep ancestral channel of the Arkansas River lies to the south and southwest of the McPherson channel and has sediment thicknesses of over 300 feet (90 m) in an area where solution of salt beds in underlying bedrock has caused subsidence. Wells yield up to 1,000 gpm, and water quality is generally good for most purposes. However, salt contamination is a concern because of natural brine discharges to the west and human activities (oil-field brine disposal and salt-mining wastes). This aquifer is the primary water source for the city of Wichita, and water-table declines of up to nearly 30 feet (9 m) have taken place in the southern part of the area due to pumping for municipal and agricultural purposes. Ground-water-flow directions in the Equus Beds aquifer are primarily toward and along the axis of the McPherson channel, which trends in a southerly direction in McPherson County and turns to the southeast in Harvey County. The flow in

the Arkansas River alluvium adjacent to the Equus Beds is to the southeast and generally parallels the Arkansas River.

Other alluvial aquifers in Kansas are not as broad as those discussed above, but extend for appreciable distances along major rivers. The Kansas River valley contains a very productive alluvial aquifer extending from Junction City to Kansas City, with saturated thicknesses of more than 40 feet (12 m) along nearly all of this distance. The alluvium of the Republican River also contains saturated thicknesses of more than 40 feet (12 m) from within Republic County to Clay Center, and thicknesses of more than 80 feet (24 m) north of Concordia. The Missouri River alluvium is thickest and most used in Kansas near its junction with the Kansas River valley at Kansas City. Alluvial aquifers in other river valleys in Kansas such as the Smoky Hill, Solomon, Saline, Neosho, Marais des Cygnes, and Verdigris also are locally important sources of ground water. Saltwater intrusion from underlying Permian bedrock limits the use of ground water in the Smoky Hill River valley in eastern Saline and western Dickinson counties.

### **Glacial deposits**

During one of the ice ages, about 750,000 years ago, the northeast corner of the state was invaded by continental glaciers that scraped up and transported large quantities of material ranging in size from boulders to clay. The extent of these glaciers into Kansas was roughly east of the Big Blue River and north of the Kansas River. The farthest penetration of the glaciers is marked in places by

deposits of red quartzite boulders that were hauled by the glacier from the area around Sioux Falls, South Dakota, southwest Minnesota, and northwest Iowa. When the ice melted and the glaciers receded, this material was left behind, especially in low-lying areas. These deposits are now common in an area north of the Kansas River to the

Nebraska state line and east of Tuttle Creek Reservoir to the Missouri River (Figure 12). Some of the most prolific water-bearing formations are buried valleys—ancient river valleys partly filled with alluvium that was covered by glacial debris. The pore space in this alluvium is excellent at trapping and holding ground water. These



*The Equus Beds, an important aquifer in central Kansas, is exposed at the surface in this Marion County quarry.*



*The confluence of the Kansas and Missouri rivers at Kansas City. Alluvial aquifers neighbor both rivers.*

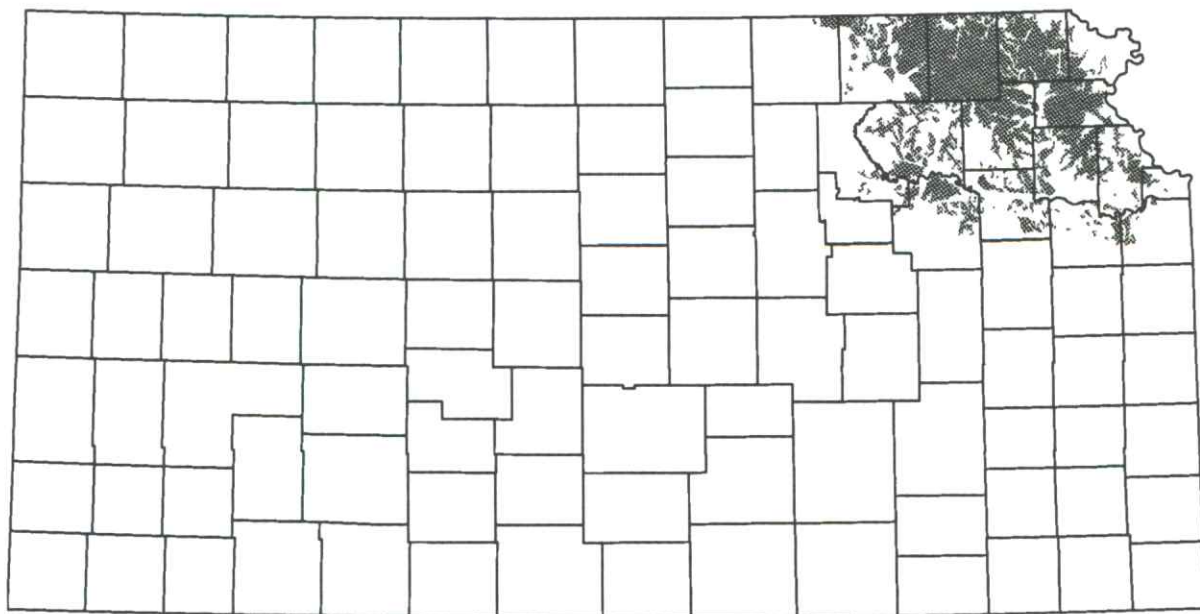


Figure 12—Glacial aquifers in Kansas.

aquifers, however, are not widespread. The alluvial deposits are quite variable and range in thickness from 0 to more than 200 feet (0–60 m). The materials that filled and buried the valleys range from clay to sand and gravel, and the poorly sorted, coarse-grained deposits at the bottom of the valleys yield large quantities of generally good-quality water. The buried valleys may be up to several miles wide, 400 feet (120 m) deep, and tens of miles long. Water levels are commonly between 5 and 50 feet (1.5–15 m) below land surface, but locally they may exceed 100 feet (30 m). Because these valleys are buried, they are difficult to locate. Published reports, water and oil and gas well records, test drilling, and geophysical techniques are used to help delineate the aquifers.

High concentrations of iron, manganese, sulfate, nitrate, chloride, sodium, hardness, and total dissolved solids occur in the ground water in parts of northeastern Kansas. While many of these concentrations result from hydrogeologic conditions and cause only aesthetic, scale, or taste problems, high nitrate concentrations may cause cyanosis in infants and some young livestock. Some high values of calcium, sodium, sulfate, and chloride may result from the movement of poor-quality water from bedrock surrounding the glacial buried valleys.

### Bedrock aquifers in Kansas

In Kansas, ground water occurs in many consolidated sandstones and limestones, and occasionally in fractured shales. Aquifers in consolidated rocks are the only local

source of water for the people living in many parts of the state. This is particularly true for much of eastern and parts of central Kansas where surface waters and shallow aquifers in unconsolidated sediments are scarce or unavailable. The Cambro-Ordovician and Dakota aquifers are the most significant sources of usable water in the consolidated rocks of Kansas. Other locally important sources of fresh water can be found in sandstones in the Codell Formation of central and west-central Kansas. Other important bedrock aquifers are Permian limestones in the Flint Hills of east-central Kansas, Pennsylvanian sandstones and limestones in eastern Kansas, and the Mississippian limestones in extreme southeast Kansas.

### Cambro-Ordovician aquifer

The Cambro-Ordovician aquifer (locally referred to as the Arbuckle or Roubidoux aquifer) is a confined aquifer system in Kansas and is an important source of water for many communities, industries, and rural water districts in Crawford, Cherokee, and southeastern Bourbon counties. In the Ozark region of southern Missouri and northeastern Oklahoma, the Cambro-Ordovician aquifer is the major source of water. In southeastern Kansas, the depth to the top of the aquifer ranges from 200 feet (60 m) in southeast Cherokee County to more than 1,000 feet (300 m) in northwest Crawford County. Well yields typically range from 150 gpm to more than 1,000 gpm. Recharge to the southeast Kansas portion of the aquifer comes from precipitation falling on the Ozark region in southern Missouri where the rocks that comprise the Cambro-

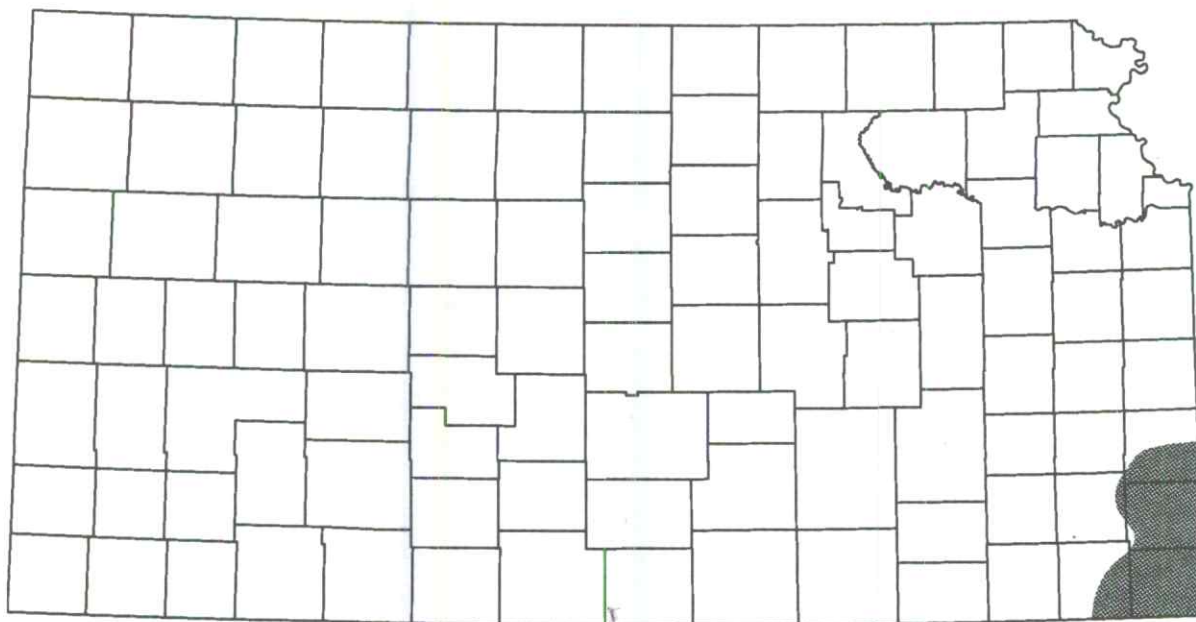


Figure 13—Cambro-Ordovician aquifer in Kansas.

Ordovician crop out at the surface. Figure 13 shows the aquifer location and extent of usable water in the Cambro-Ordovician. In southeast Kansas, the ground-water recharge moving westward and northwestward encounters saltwater present in the Cambro-Ordovician aquifer farther to the west. As a result, the usable portion of the aquifer is restricted to those areas now being developed in southeast Kansas. In this case the entire formation functions as an aquifer, but water quality limits the portion that is useful.

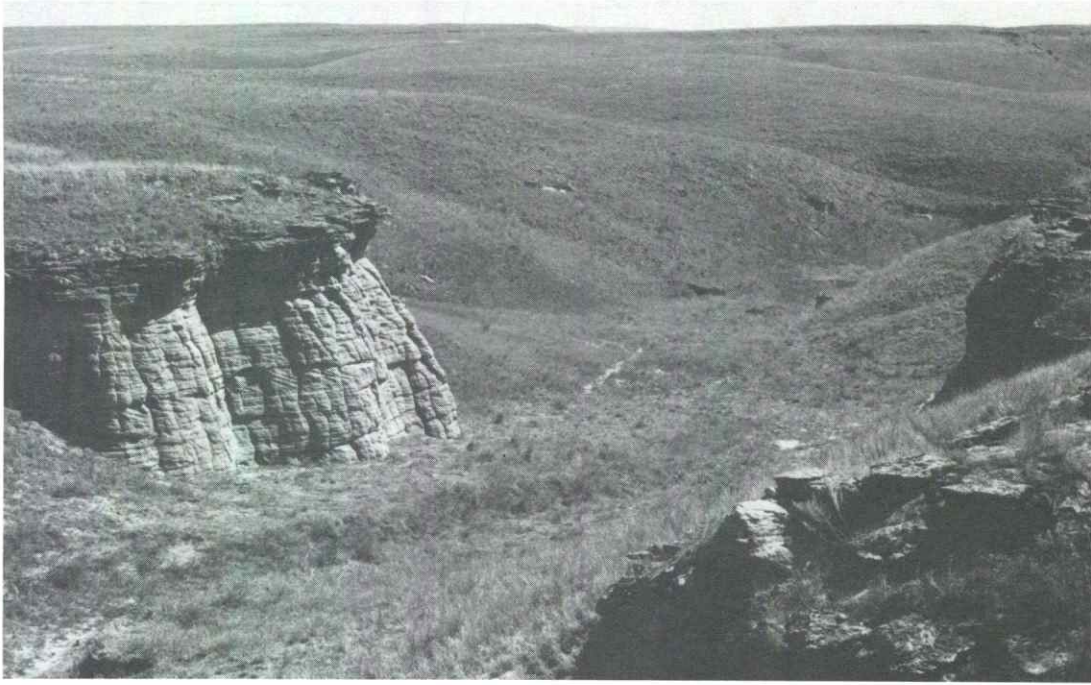
### Dakota aquifer

The Dakota aquifer is used by communities, industries, and agriculture as a source of water in parts of central and western Kansas. At the surface, the Dakota Formation is probably best known for the red sandstones and clays that crop out in central Kansas. This aquifer consists of shales and discontinuous sandstone bodies that were deposited in stream channels and river deltas along an ancient seashore during the Cretaceous Period. Where the aquifer is covered by younger Cretaceous strata, it is confined and the depth to the top ranges up to 2,600 feet (790 m) in extreme northwest Kansas. In central and a few areas of southwestern Kansas, the strata that comprise the Dakota aquifer crop out at the surface and the aquifer is unconfined. In much of the southwestern part of the state, the Dakota underlies and is hydraulically connected to the High Plains aquifer. In parts of central Kansas, the Dakota overlies saltwater-bearing aquifers in Permian

strata and is recharged, in part, by saltwater, making the aquifer's water unusable. This situation is illustrated in Figure 11. The usable portion of the aquifer in southwest and central Kansas is shown in Figure 14.

Ground-water flow in the Dakota aquifer is from recharge areas in southwestern Kansas and southeastern Colorado towards discharge areas in central Kansas and southeastern Nebraska. The directions of regional ground-water flow are shown in Figure 15. Well yields from the Dakota aquifer range from less than 10 to more than 2,000 gpm but average between 50 and 100 gpm. This wide range in wells yields is primarily due to the variation in the proportion and nature of sandstone contained in the Dakota aquifer from one location to another. In southwestern Kansas well yields from the Dakota and underlying Jurassic sandstones are generally higher than the average due to hydraulic connection with the overlying High Plains aquifer.

With the depletion of the High Plains aquifer, there is growing interest in the Dakota aquifer as a possible water source. The Dakota has generally not been used heavily in western Kansas because it is considerably deeper than the Ogallala Formation (and thus water is more expensive to pump to the surface), because its quality is variable, because yields from the Dakota are generally much less than from the Ogallala, and because information about the Dakota is scarce. To help provide guidance in the use of the Dakota aquifer, the Kansas Geological Survey, in conjunction with the U.S. Geological Survey, has under-



*An outcrop of sandstone in the Dakota Formation.*

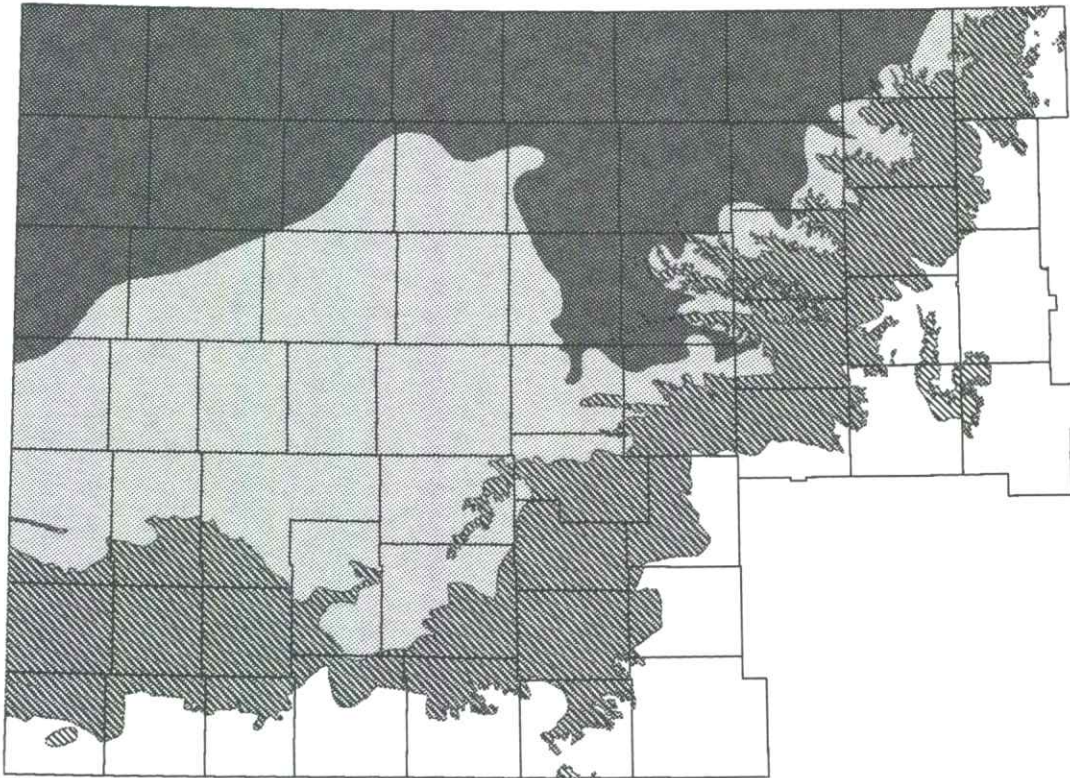


Figure 14—Usable portion of the Dakota aquifer in southwest and central Kansas. The Dakota outcrop/subcrop area is shown with diagonal lines; the usable water quality (less than 2,000 mg/L total-dissolved solids) is shown in light gray. Nearly all outcrop/subcrop area contains usable water. Area shown is the western two-thirds of Kansas (compare with figure 10 for location).

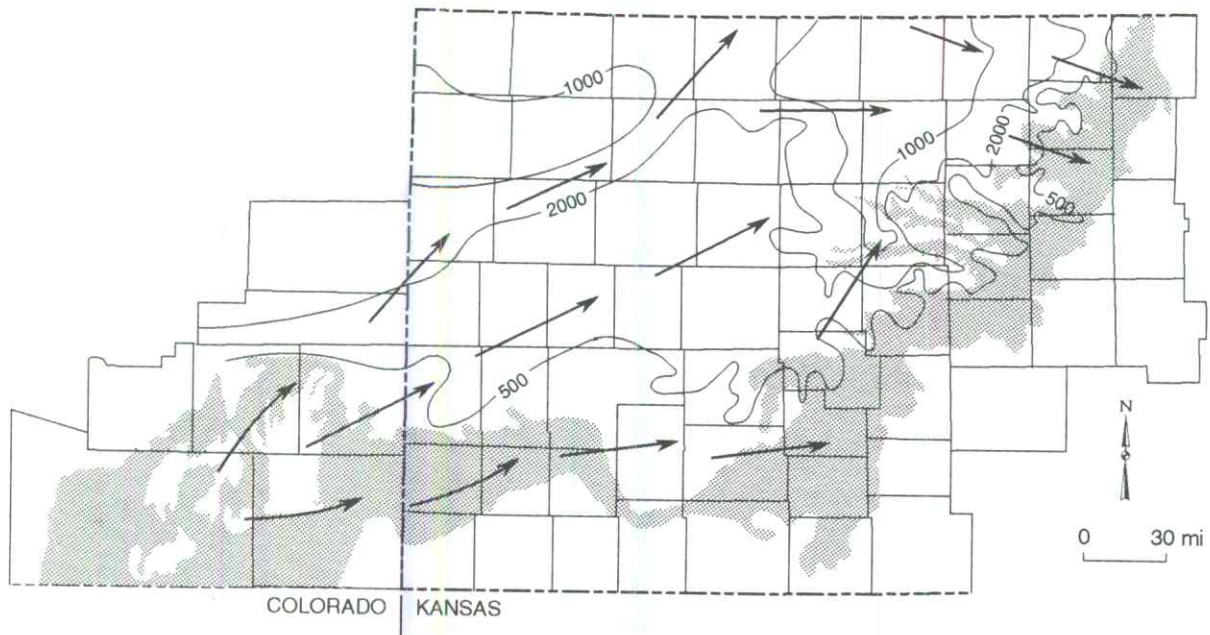
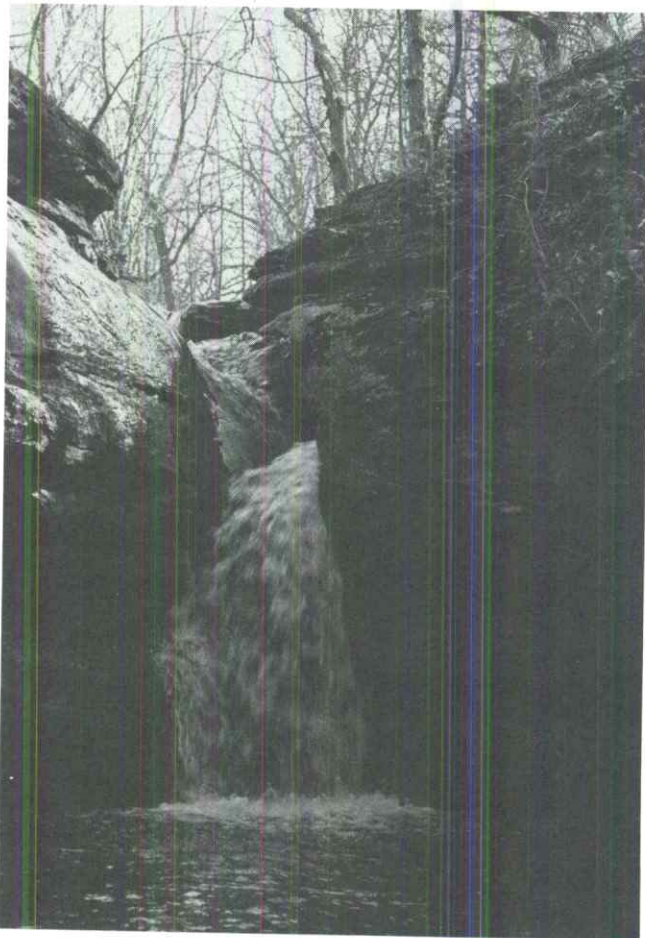


Figure 15—The direction of ground-water flow in the Dakota aquifer. Recharge enters the aquifer in southeastern Colorado and southwestern Kansas, then moves out of the aquifer in central Kansas.



Water flowing over limestones of Mississippian age in Cherokee County in southeastern Kansas.

taken a multi-year study of the aquifer, which should help define its extent and the quality of water it contains.

### Mississippian aquifers

In southeast Cherokee County unconfined aquifers in Mississippian limestones provide limited water for domestic use only. In this area, contamination from past lead-and-zinc mining activities in the Tri-State mining district is a concern. Recharge to these aquifers is from local precipitation falling on the land. Some of this ground water is discharged from springs and seeps in the Spring River valley. Wells yield from less than 10 to more than 100 gpm.

### Sandstone aquifers

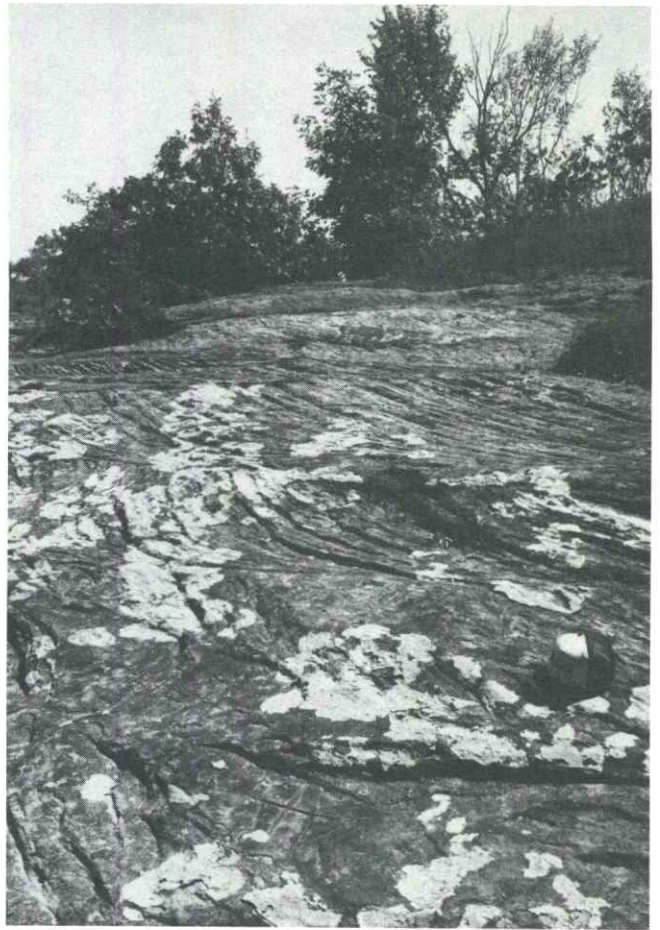
Many small towns, rural water districts, and individuals in eastern Kansas rely on Pennsylvanian sandstones and limestones for water. The principal aquifers here are the Tonganoxie and Ireland sandstones, which are generally medium- to fine-grained, and occur in ancient river valleys cut into older bedrock. Total thickness of these sandstones may exceed 100 feet (30 m) in places. Currently these aquifers supply water to much of the rural population living in upland areas away from accessible sources of surface water such as streams or reservoirs. Typical well yields range from less than 5 to more than 50 gpm. Other units within the Pennsylvanian, including sandstones and fractured limestones, are capable of producing water locally. Typically wells penetrating these

units yield less than 5 gpm. Recharge to the Pennsylvanian aquifers comes primarily from precipitation in areas where the aquifer crops out or occurs in the shallow subsurface. The deeper these units are buried, the higher the total-dissolved solids and chloride concentrations in the water they contain.

Ground-water quality also may pose problems for some people whose supplies come from the sandstones in the Douglas Group in northeastern Kansas. Several public-water-supply well fields are located in areas where this aquifer has a large total-dissolved-solids content but is still usable. Chemical-quality changes caused by the lateral movement of saline waters are likely to occur in these well fields if the wells are pumped too intensively.

### **Permian aquifers**

In the Flint Hills of Kansas, limestone aquifers of Permian age in Chase and Council Grove groups provide water for farmsteads and several small communities. Ground-water flow is toward wells, stream valleys, and springs, such as Diamond Springs in Morris County, a well-known stop along the Santa Fe Trail in the 19th century. Most wells yield water at a rate of 100 gpm or less. However, discharge from individual springs in the region may be considerably higher than 100 gpm. For example, the town of Florence, in Marion County, derives its municipal water supply from a local spring. In central and west-central Kansas, wells in the Codell Sandstone yield water at generally less than 10 gpm.



*The Ireland sandstone at the surface in Douglas County.*

## Water quality

**W**ater quality is a general term used to refer to the amount and type of dissolved or suspended material in the water. When water first contacts the earth as rain or snow (or frost or dew), it is usually quite pure—very close to distilled water in terms of its lack of dissolved materials. As it moves over or through soils, rocks, and sediments, it dissolves or picks up small quantities of the materials with which it comes in contact. These materials may be inorganic or organic, natural or human-made, or even living (such as bacteria and viruses). The total dissolved solids content (often abbreviated TDS, and usually reported as milligrams per liter or parts per million) in a water sample is often used as a general indicator of water quality. Each type of dissolved substance raises different issues with respect to water quality, and scientists and health authorities have established regulations for drinking water. Some regulations are maximum permissible contaminant levels (primary regulations) for public water supplies, while others are recommended levels (secondary regulations). Table 1 shows some examples of the maximum and recommended levels in Kansas for selected natural and artificially introduced contaminants. These are

U.S. Environmental Protection Agency values that are also adopted by the Kansas Department of Health and Environment. Sources of additional or more detailed information can be found in Appendices B and C.

Because ground water is relatively inaccessible, has sources that are diffuse or not well known, and moves very slowly compared to surface water, recognition of a water-quality problem may be separated in both time and space from the events that cause the problem. One example of this is the occurrence of increased nitrate concentrations in ground water as a result of agricultural fertilizer applications. Decades have elapsed between the first use of commercial fertilizers and the recognition of a widespread problem. The result is that large volumes of soil and ground water now contain high nitrate concentrations for which there is no effective removal technique. Remediation of such problems may be difficult or impossible. We have thus come to place greater and greater value on the prevention of problems before they occur. This in turn requires an improved understanding of ground-water processes and their relationship to the hydrologic cycle, which increases the need for hydrologic research.

## Natural factors and controls

Under natural conditions, ground-water quality depends primarily on the nature of the materials the water has been in contact with, and on the length of time it has been in contact. Other factors also play a role: evapotranspiration increases TDS because the dissolved solids are left behind and become more concentrated as the volume of water is reduced by loss of water vapor. Higher recharge during wet periods can, in turn, dilute shallow mineralized waters.

Most salts are quite soluble, which is why salt deposits at surface or salt outcrops are found only in very arid environments. Water flowing through salt deposits or salty soils often becomes saline very quickly because the salt dissolves easily. Salt contamination is a significant problem in Kansas, where thick deposits of salt, deposited during the Permian Period of geologic history, underlie much of central Kansas. Where those salts are near the surface, they may be dissolved by freshwater and naturally contaminate water supplies. Although most salts are not particularly toxic, human physiology cannot tolerate very saline water. Table 2 shows the levels of salt tolerable for drinking water, and presents some natural concentrations

for comparison. Since some of the brines in Kansas' salt-bearing formations are highly concentrated, it's easy to see why natural mixing of different waters can cause water-quality problems. Freshwater is defined as having less than 500 mg/L chloride and less than 1,000 mg/L TDS.

Carbonate minerals (such as are found in limestones) are not as soluble as the salts found in brines, but water that stays in contact with carbonate rocks for long periods tends to become hard. Hardness is caused primarily by dissolved calcium and magnesium carbonates, and some of its symptoms are failure of soaps to lather and the formation of scale deposits in pipes and cooking utensils. Hard water generally presents no major health hazard, but its use can be unpleasant and costly. By contrast, rocks such as granite (common in the Rocky Mountains) are very unreactive and usually have only a small effect on the TDS of water even over long periods of time.

Water that flows through rich soils or is in contact with productive biological communities or buried organic deposits may pick up significant concentrations of natural organics. These are seldom a major problem in themselves, but they may co-occur with microbes or parasites

TABLE 1—Maximum and recommended levels in Kansas for selected natural and artificially introduced contaminants (KDHE).

Constituent	Source Concentration, mg/L n = natural h = human	Concentration, mg/L Maximum Contaminant Level	Recommended Contaminant Level
Arsenic	n, some h	0.05	
Lead	n, h	0.015*	
Mercury	n, some h	0.002	
Nitrate (as N)	n, h	10	
Fluoride	n	4	
Sodium	n, some h		100
Sulfate	n, some h		250
Iron	n		0.3
Benzene	h	0.005	
Trichloroethylene (TCE)	h	0.005	
Atrazine	h	0.003	

\*Treated-water standard

TABLE 2—Levels of salt tolerable for drinking water and some natural concentrations for comparison.

Type of Water	Chloride (mg/L)	TDS (mg/L)
Rain (typical)	0.1–1	5–10
Fresh surface water in Kansas	3–500	100–1,000
Fresh ground water in Kansas	3–500	160–1,000
Drinking water, maximum recommended	250	500
Livestock consumption, satisfactory limit	—	3,000
Saline to brine waters in Kansas	500–190,000	1,000–330,000
Seawater	19,400	35,800

that affect humans or other animal hosts. Although these disease-producing processes have a natural origin, they are

discussed below under the human-effects and water-treatment categories.

## Human effects

When we think of human (sometimes called anthropogenic) effects on water quality, we often focus on the addition of artificial chemicals to the environment. Although this can be important, humans have far greater effects through the modification, acceleration, and redirection of natural processes. Here we provide examples of activities that affect water quality, both by modification of natural processes and by artificial activities and procedures.

### Storage and irrigation

When a large surface area of water is exposed to the atmosphere, either as free water or as moist soil, evapotranspiration results in water loss and an increase in the

TDS of the remaining water. Turning small flowing streams into large, static reservoirs enhances this effect, but normally not to an extent great enough to cause problems, at least in Kansas. Irrigation, however, can have noticeable effects. Most irrigation water applied to crops is lost to evapotranspiration, leaving behind both the salts that were originally contained in the water and soluble materials that may have been mobilized from the soil. This can result in a buildup of salts in the soil, and when irrigation return water or natural flow through the system results in recharge or runoff, the resulting water may be high in TDS (illustrated in figure 16). For example, shallow ground waters in alluvium of the Arkansas River in western Kansas are saline in some locations where irrigation water from the river was used in the past.



*The Salt Fork of the Arkansas River in the Red Hills of Barber County.*

## Fertilizer application

Accelerating the natural cycle of plant and animal productivity through intensive agriculture requires modifying the natural nutrient cycle as well as the natural water cycle. When fertilizers are added to soils in quantities sufficient to maximize crop production, some fraction of the excess may be transported to surface or ground water. This is particularly a concern with respect to nitrate, which is critical for plant growth, but which can also cause the potentially fatal “blue-baby” syndrome in infants. Elevated nitrate concentrations are found in shallow ground water in many parts of Kansas and throughout the Midwest. Although some of this comes from point sources of contamination such as septic tanks or localized areas such as feedlots, at least some of the additional nitrate is believed to result from the non-point source of large-scale fertilizer application.

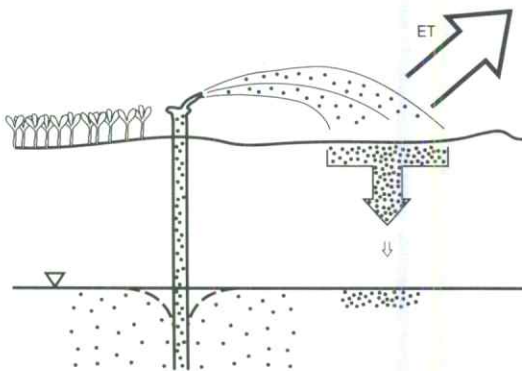


Figure 16—Irrigation causes the evaporation of water, but the natural salts remain in more concentrated form. Soils and ground water gradually become more salty as a result of prolonged irrigation.

## Resource extraction

This is a catch-all term that includes mining, oil and gas production, and even ground-water withdrawal. All of these activities have the potential for causing at least one of two types of ground-water quality problems. In the terminology used above, these tend to be point-source contamination problems, although the points may be so many, so old, and so ill-defined that the problem is now indistinguishable from a non-point problem.

One problem common to all of these activities is the creation of artificial short-circuits between different hydrologic compartments. Boreholes, wells, pits, and mine shafts can all connect different aquifers by penetrating intervening confining layers, or can provide a direct pathway from the surface to the ground water. This can permit poor-quality ground water to mix with and degrade usable water in other aquifers, or it can provide a direct pathway for surface contaminants to reach the ground water without passing through the protective filter of the unsaturated zone. This is an important process in contaminating domestic well waters pumped from poorly constructed wells.

Another potential problem, particularly in mining and oil production, is the production and disposal of toxic or highly contaminating byproducts. Oil in Kansas co-occurs with brine, so large quantities of saltwater are pumped to the surface with the oil; that brine must be disposed of in ways that will not adversely affect surface-water or ground-water quality. In the early days of oil production in central Kansas, that brine was pumped into ponds, with the intent of evaporating the water and storing the remaining salt. Instead, the saltwater moved underground, sometimes contaminating freshwater aquifers. For example, in central Kansas, near the town of Burrton,

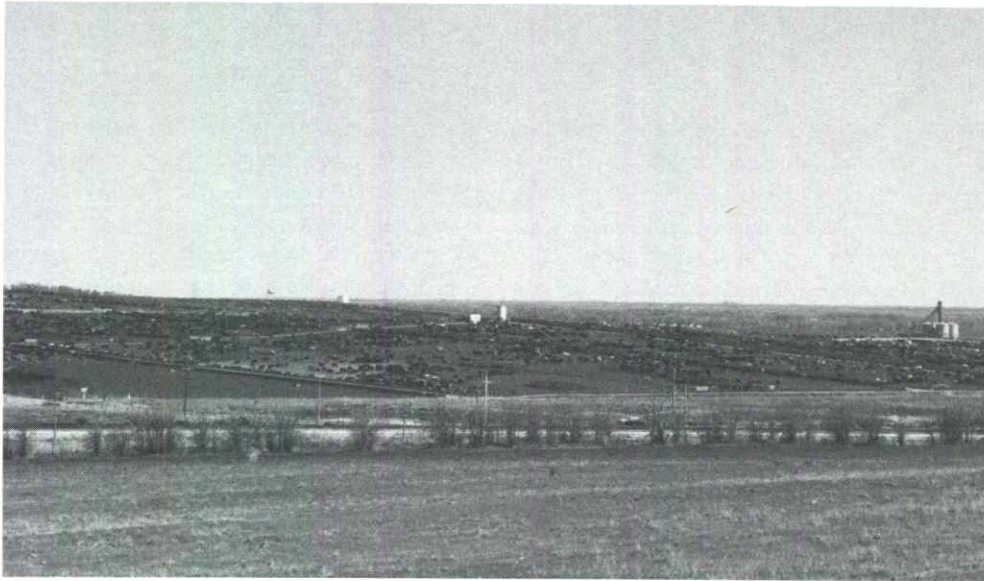
disposal of oil-field brine in shallow ponds has created a plume of underground saline water in the Equus Beds aquifer, which is slowly moving toward the Wichita water-well field. While wells can be drilled to intercept that saltwater and slow its progress, such solutions are costly, only marginally effective, and point out the importance of preventing water-quality problems. Evaporation ponds have since been banned and now the brine is pumped back underground into deep geologic formations, often into the same rocks that produced the saltwater and oil originally.

Certain ore bodies and the processes used to extract them generate toxic or corrosive wastes in large quantities, and their safe and economical storage or disposal has become a major problem. For example, in southeastern Kansas, water entering underground lead and zinc mines sometimes is contaminated by the weathering of sulfide minerals, including pyrite, in the mine walls. Weathering

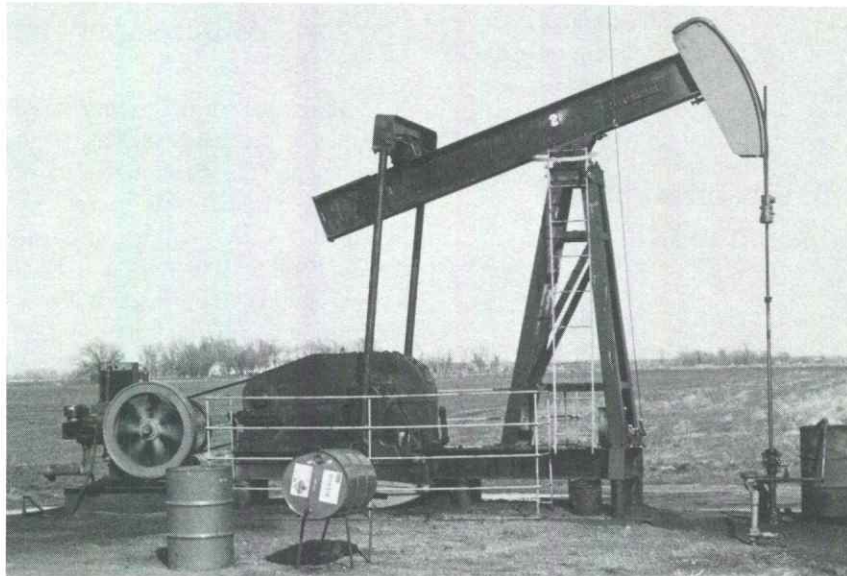
of pyrite in coal mines in southeastern Kansas can also lead to contamination of surface and shallow ground waters by acid mine drainage. This water can become highly acidic; where it exits from the mines, it can create problems for plants and animals. As is often the case with ground-water contamination, cleaning up the contamination is extremely expensive; the contaminated ground-water remains as a hazard and a warning for future generations.

## Industrial and agricultural chemicals

Synthetic chemicals, such as solvents and pesticides, are relatively new additions to both ecosystems and human diets. They tend to be the focus of concern because they



*A feedlot near Dodge City.*



*A Barton County oil well.*



*Pits where coal was strip-mined, now filled with water in Cherokee County.*

are toxic or else we have no good basis for assessing the long-term effects for many of them, and organisms (including people) have not evolved methods of coping with their possible toxicity. As the sensitivity of analytical methods improves, we find traces of these artifacts of technology virtually everywhere at or near the land surface. The public debate about acceptable levels and the relative risks, costs, and benefits of pollution prevention or clean-up will be with us for a long time. From the standpoint of the hydrologic sciences, dealing with this type of contamination has taught us two major lessons. One is that remediation or cleanup of ground-water pollution is usually slow, extremely costly, and incomplete—so prevention, prediction, and containment are the practically preferable alternatives. The second is that two factors are critical to understanding and preventing ground-water pollution. The primary factor is how water moves through both the unsaturated and saturated zones, and a secondary factor is how the contaminant interacts with soil, aquifer, and water in ways different from water itself.

### Population, urbanization, and concentration

We discussed issues of scale with respect to the hydrologic system; they also play an important role in water-resource problems. The population and transportation patterns of Kansas were firmly established in an era when domestic water consumption was measured in buckets per day per household, virtually all agriculture was dry-land farming, and a community of more than 10,000 people was a major metropolis. Now, populations are vastly larger and more concentrated, and water demand is enormously greater. Some Kansas cities are not located in

places where water is abundant. It is not surprising, then, that communities such as Hays are having trouble meeting present water demands, or that the Wichita area is looking farther and farther afield for possible future water supplies.

In terms of water quality, population and economic concentration also have a potentially enormous effect. The absolute amounts of wastewater, industrial contaminants, and solid waste per unit area have risen phenomenally in urbanized areas. It thus becomes harder and harder to protect water supplies from becoming unacceptably contaminated. The high cost (relative to present market value) of either purifying or transporting large volumes of water explains why it is considered possible that the price and availability of water may ultimately be a more stringent limit to growth than the price and availability of energy.

### Water-supply treatment

Municipal water systems typically treat surface-water supplies by processes such as coagulation and settling, aeration, and chlorination to remove distasteful or harmful materials. Ground-water supplies have traditionally required less treatment because recharge moves through soil and aquifer materials, and the natural filtering processes eliminated most solids and organisms. This perception is still valid in many areas, but increasingly stringent water-quality standards and concerns about ground-water contamination are bringing more attention to ground-water treatment. Regardless of their source of water, concerned citizens are increasingly turning to the use of bottled water and to home purification devices. Ironically, the quality of as-delivered municipal water can be substantially better than water passing through poorly maintained water dispensers or home purification equipment.

## Well construction and ground-water production

**T**hree categories of use account for most of the wells installed in Kansas. By far the largest number are production wells, used to pump ground water to the surface for irrigation, domestic, livestock, or municipal use. Another important category includes monitoring wells that measure water levels or water quality in an aquifer. Finally, injection wells are used to dispose of oil-field brines and, in a few cases, industrial wastes by injecting them into deep, brine-containing aquifers where there is no significant probability that they will contaminate usable ground water. Although the details of well design and installation vary, the basic concepts and approaches are similar for almost all wells.

Figure 17 shows examples of the three types of wells mentioned. Common to all of them is: 1) a hole in the ground deep enough to reach a useful aquifer; 2) a casing (usually either steel or PVC plastic) to keep the hole open and permit installation of the necessary pumping or injection equipment; 3) screened or open intervals to allow water to enter the well casing from the aquifer; and 4) an installation treatment that couples the well casing to the surrounding earth material in an appropriate fashion. This last point is extremely important from the standpoint of ground-water protection. All of the wells shown have a grout (cement-type) seal between the upper portion of the casing and the surrounding formation. This, combined with a concrete pad around the wellhead, prevents the space and disturbed soil of the borehole outside of the casing from functioning as a direct conduit for contaminant movement from the surface to the ground water (see also Water Quality section). Well siting also is important for ensuring water quality; the well must be distant (and preferably up the hydrologic gradient) from such potential

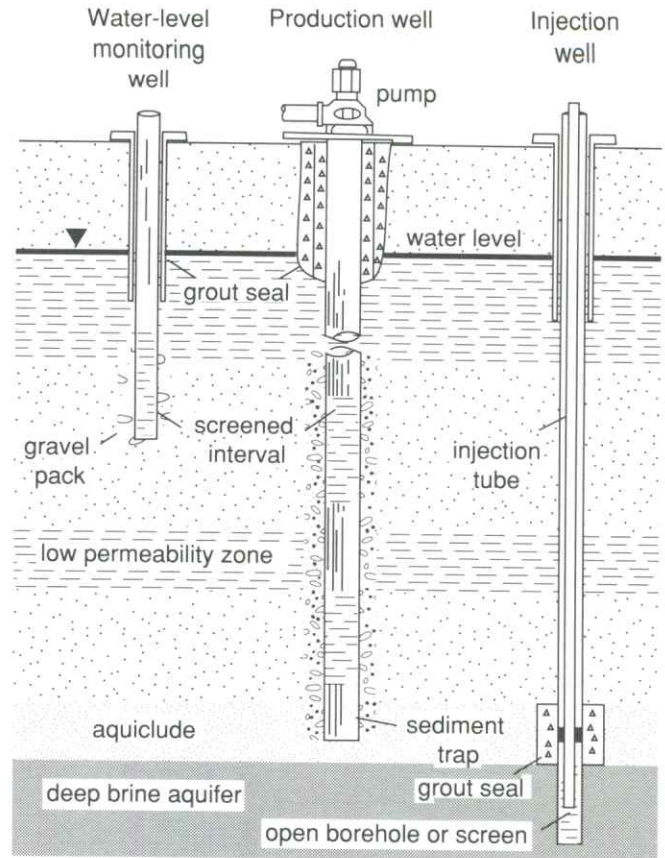


Figure 17—Three types of water wells used in Kansas. In actual practice, injection aquifers are much further below usable aquifers than shown here.

contamination sources as septic tanks, feedlots, fuel and chemical storage, etc.

## Production and monitoring

For production or sampling of water from wells without open boreholes below the casing, a high permeability connection between the screened interval and the aquifer is required. A coarse gravel pack is normally used. Wells with open boreholes in the production interval exist only in some consolidated rocks in Kansas, such as the Cambro-Ordovician aquifer. After installation, wells are developed and, in some cases, tested. Development is a process of removing the fine particles and drilling fluids left behind by the well construction process; it is often done by pumping, but in some cases can involve the use of air or water pressure or chemical treatment. Simple well

tests are often done to determine the sustainable pumping yield (technically known as the specific yield) of the aquifer; however, researchers may also use more sophisticated pump tests and other measurements to better understand the geologic and hydrologic characteristics of the aquifer.

Over short periods, the amount of water that can be extracted from a well is determined by the permeability and thickness of the aquifer, the length of the screened or open interval, and the diameter of the well. Monitoring wells are commonly 2–6 inches in diameter, while large-capacity wells may be several feet in diameter. When a

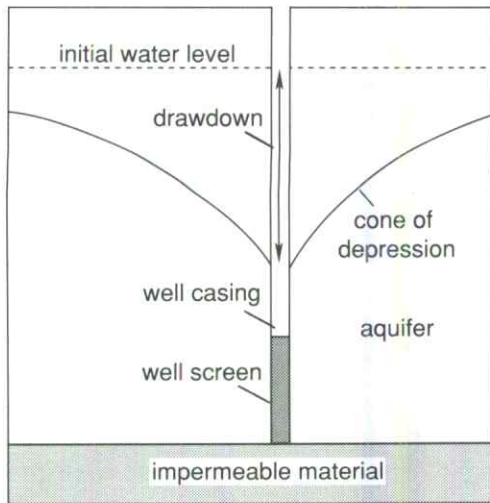


Figure 18—When a well is pumped, the ground-water level near the well forms a cone of depression, as shown by the solid line in this figure.

well is pumped, the withdrawal of water results in a local decline (*drawdown*) of the water table in the vicinity of the well. Figure 18 shows a *cone of depression* (also called a zone of influence) for well and aquifer characteristics common to western and south-central Kansas. If the saturated thickness above the pump is too small for the pumping capacity, the well can be temporarily pumped

dry, and the water table must be allowed to recover. Where pumping wells are close together, their zones of influence may overlap and result in a combined lowering of the water table (Figure 19).

When withdrawal has been small compared to the total aquifer storage, the water table will recover to approximately its original level when the well is shut off for some time. In the case of high-capacity irrigation wells in the High Plains aquifer, for example, up to six months after the end of pumping may be required for water-table recovery (Figure 20). Figure 21 shows the pattern of drawdown and recovery in monitoring wells located in an area of Stafford County subject to high irrigation pumping.

When ground-water withdrawals exceed recharge for protracted periods over large areas, systematic declines of the water table occur. This is the case over much of western and some of south-central Kansas, as is demonstrated in the maps shown in Figure 22 and the hydrographs shown in Figure 23. If large areas experience water-table declines, wells do not recover when local pumping ceases, because it may take decades or centuries for water to flow from the fringes of the depression to the center even if an adequate source is available. Such declines can interfere with water supply either by drying up the wells or by lowering the water table to depths that make the water uneconomical for agricultural use because of the cost of pumping.

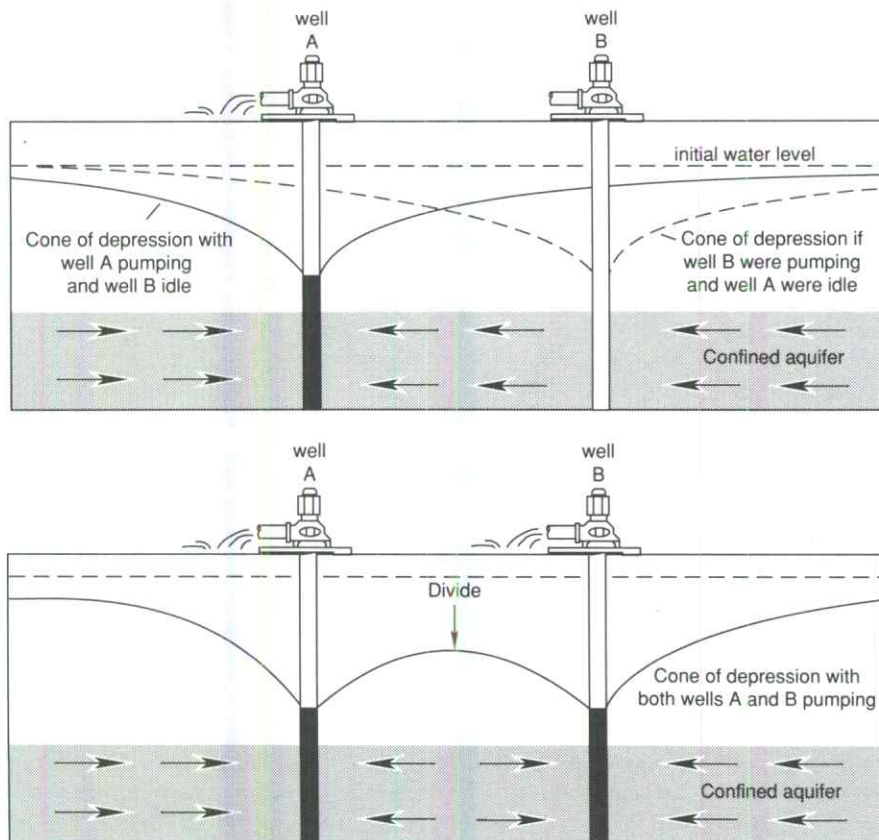


Figure 19—When two nearby wells are pumping, they each create a cone of depression, which overlap to form complicated patterns of ground-water elevation.

## Injection

Underground injection is the process of using wells to dispose of fluids by pumping them into aquifers. This technique is used to dispose of brines produced along with the recovery of oil, as well as some fluid wastes from municipalities, industry, and manufacturing. This process has been a waste-disposal practice in Kansas at least since the early 1930s when the Kansas State Board of Health began issuing permits to oil companies for the disposal of brines produced along with oil. Since then underground injection has been used to dispose of some industrial fluid wastes where other alternatives are not feasible. Nationwide, interest in underground injection of hazardous and other industrial fluid wastes increased in the late 1960s and 1970s as federal water-pollution control regulations became more stringent. In other parts of the world, underground injection techniques also are used for artificial recharge, remediation of contaminated aquifers, and prevention of saltwater intrusion.

Before installing an injection well, a suitable aquifer must be identified. This aquifer should be able to contain the disposed fluids in the subsurface and keep them away from sources of freshwater. Regulatory agencies use the following criteria to identify suitable zones for underground injection in Kansas: 1) the presence of thick confining units above the rock formations into which the waste will be injected; 2) the presence of simple geologic structure, free of faulted and fractured zones that might allow the disposed fluids to migrate; 3) saltwater must be present in the aquifer; 4) low seismic risk; 5) negligible or

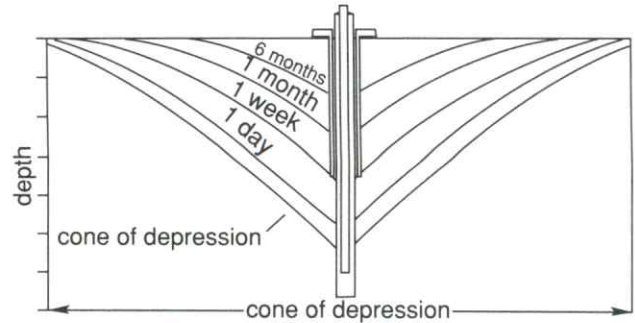


Figure 20—After pumping in a well stops, the water level slowly recovers its previous level and the cone of depression disappears.

low ground-water flow rates in the injection zone; and 6) a long ground-water flow path to areas of ground-water discharge. The most commonly used zones for underground injection of oil brines and wastewaters in Kansas are saltwater aquifers in the Arbuckle Group, Mississippian strata, the Lansing and Kansas City Groups, and the Cedar Hills Sandstone. These zones fit most or all of the criteria for a suitable underground-injection horizon listed above.

When suitable zones for underground injection have been identified and it has been established that underground injection is feasible, a well is constructed and tested (Figure 24). The geologic and engineering charac-

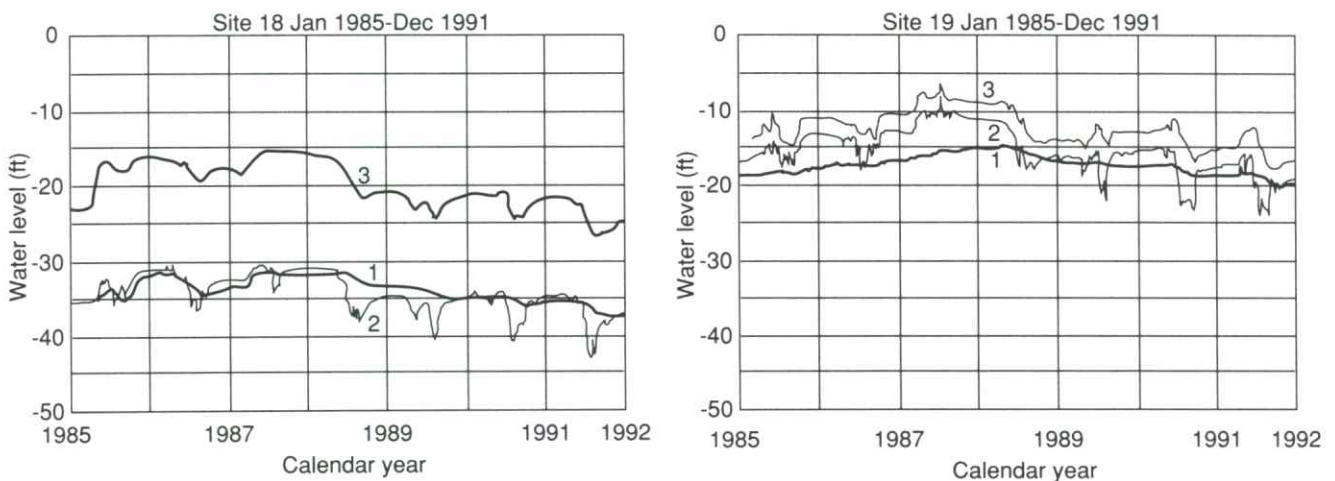


Figure 21—Water levels (heads) change in various parts of an aquifer system in response to both pumping and natural variations. These figures show the variation in head at two sites in Stafford County. Line 1 in each case is from a well in the bedrock (a brine-containing Permian aquifer). Line 2 is from the lower part of the Great Bend Prairie aquifer, and line 3 is from the upper regions of the aquifer.

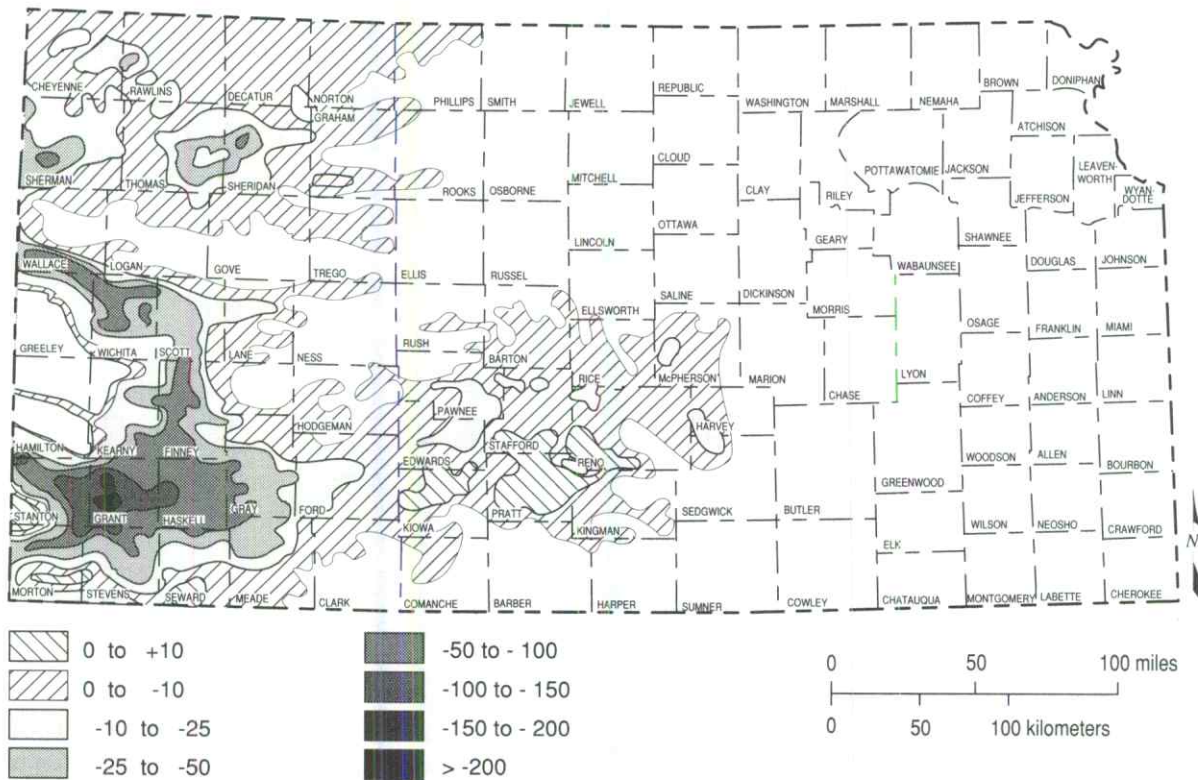


Figure 22A—Changes in elevation of ground water in the High Plains aquifer, shown in feet, from predevelopment to January 1989.

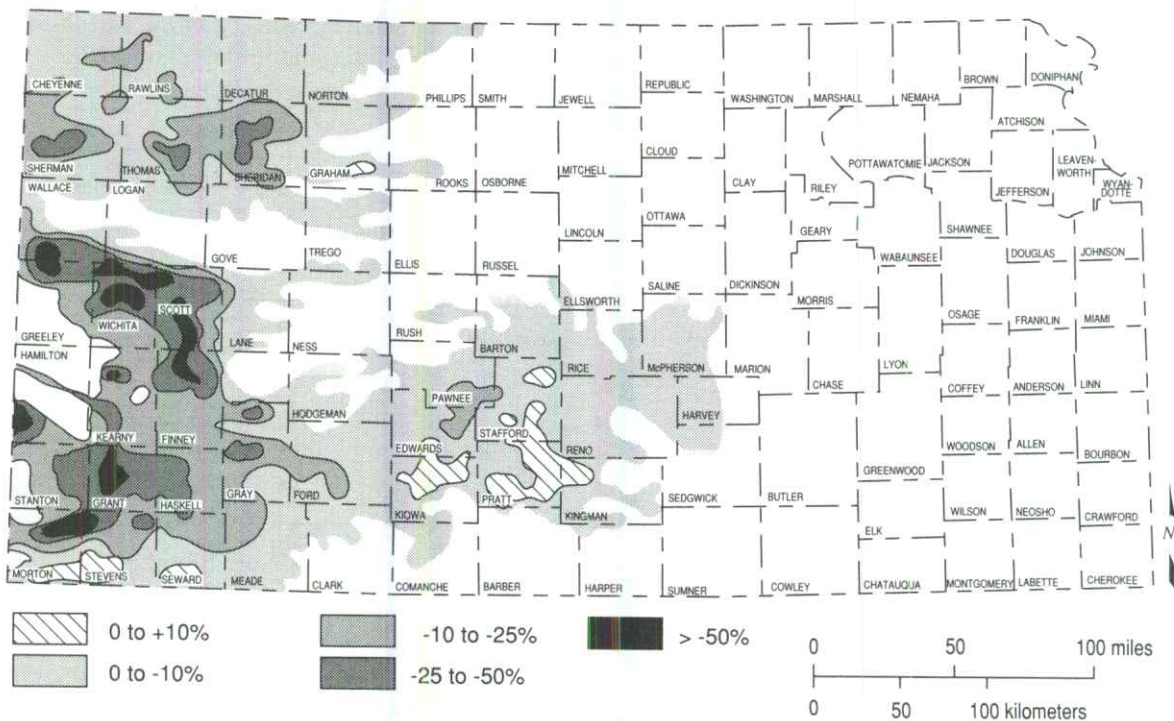
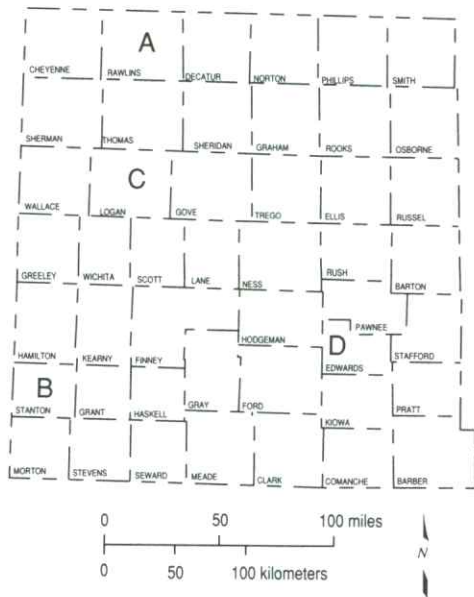


Figure 22B—Changes in saturated thickness in the High Plains aquifer, from predevelopment to January 1989, displayed as a percentage of decline in the saturated thickness. Because some areas are underlain by thicker aquifers than other areas, this figure provides a reflection of ground-water depletion. For example, a decline of 10 feet (3 m) in an area with an original saturated thickness of 100 feet (30 m) would yield a decline of 10%.



teristics of particular importance are those relating to the engineering performance of the well and the protection of the environment and the public. For example, one important consideration is the nature and thickness of the disposal zone and confining units in the vicinity of the injection well. Another consideration is the compatibility of the native water chemistry with that of the injected fluids to prevent clogging of or adverse chemical reactions in the injection zone. Once the well has been constructed, tests are made on the integrity of the casing, tubing, and cement used in construction and the condition of the wellbore. These tests, which demonstrate the mechanical integrity of the installation, also are made periodically during the life of the well. Other methods also are used to monitor the safety and performance of the injection well, including periodic measurement of injection pressures at the wellhead and in the annular space.

Another design feature for environmental protection in injection wells (and also monitoring wells that penetrate

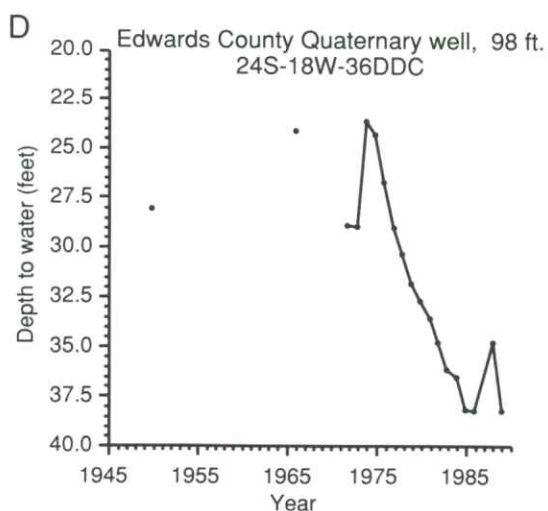
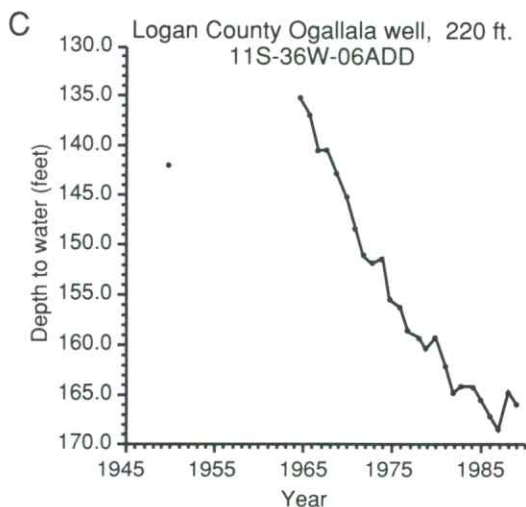
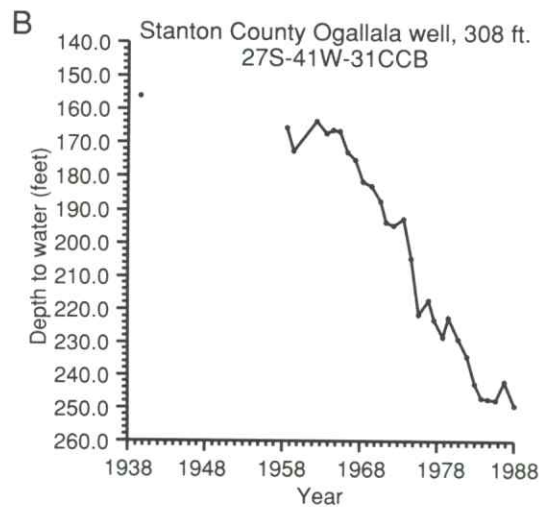
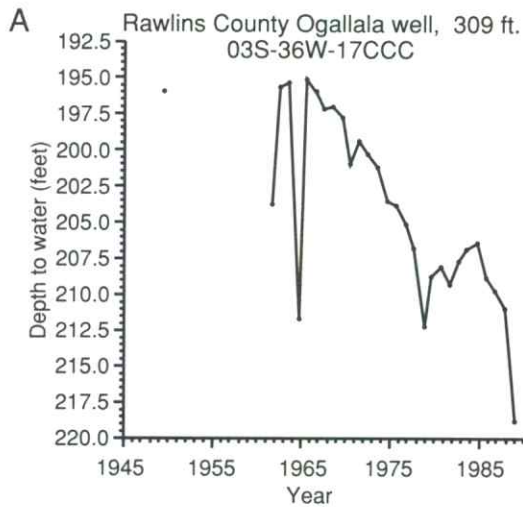


Figure 23—Hydrographs for four representative wells in western Kansas. Hydrographs show the depth-to-water plotted over time.

zones of unusable water) is a grout seal at the impermeable zones separating brine aquifers from overlying usable water-bearing formations. A separate injection tube

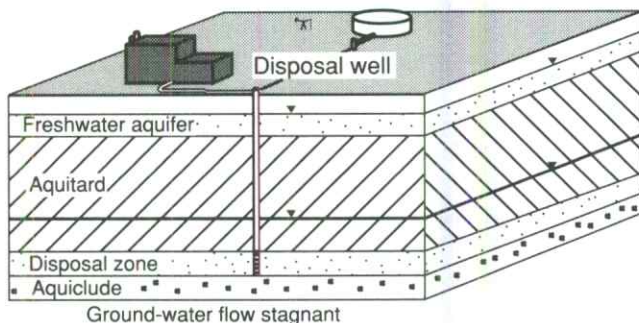


Figure 24—A schematic representation of an injection well.

isolated within the casing permits operators to monitor for fluid in the casing, which indicates when either the casing or the injection tube has failed and must be repaired or replaced.

Kansas has maintained an active program to regulate underground-injection practices since the 1930s and is currently managing a federally mandated program of underground-injection control in the state through provisions of the Federal Water Pollution Control Act Amendments of 1972 and the Safe Drinking Water Act. The intent of this regulatory framework is the controlled emplacement of fluid wastes in the subsurface so that freshwater sources are protected from contamination. Underground injection is currently regulated by the Kansas Corporation Commission (disposal of produced oil brines) and the Kansas Department of Health and Environment (disposal of hazardous and industrial fluid wastes) with oversight from the U.S. Environmental Protection Agency.

## Ground-water management

Working out the water balance for a river basin, watershed, or aquifer that serves individual towns or cities with water is in some ways like checking the financial balance of a household—it helps us to see where the expenditures are going and whether we can afford to spend more or need to restrict expenditures. The water balance enables us to see whether more use can be made of the area's water resources. Because detailed information about water is often unavailable, it is difficult and time-consuming to prepare a detailed and accurate water budget for a watershed or an aquifer. However, enough information exists to prepare an approximate annual budget for the state as a whole as an example of the analysis that has to be done in more detail for local areas.

Although our interest here is in ground water, it is easier to construct our overall water balance in terms of water arriving at and leaving the land surface. The inputs of water (precipitation in the form of rainfall and snowfall, or streams and ground water flowing in from outside the state) may be considered credit items; amounts of water withdrawn or depleted (including the outflow of streams and ground water; evaporation from lakes, ponds, rivers, and moist soil; and transpiration from plants) represent debit items. Precipitation (the dominant input) averages approximately 115 million acre-ft (MAF) over Kansas annually (if water were placed 1 foot deep over the entire state, the volume required would total 52.55 MAF.). Of the output terms, the largest is evapotranspiration, which averages about 105 MAF per year from the state. The annual outflow of Kansas rivers that originate within the state amounts to approximately 9.9 MAF (for this analysis,

flow that originates outside the state is simply subtracted from total outflow). This flow leaves the state and eventually reaches the Gulf of Mexico. Ground-water recharge quantities are not precisely known, but they are smaller than the uncertainties of the other budgetary terms, most probably less than 0.9 MAF per year. Much of this is returned to the streams as baseflow, which sustains the rivers throughout dry weather. If the recharge number were actually 0.9 MAF per year and all of it reached the ground water, this would correspond to about 0.8 billion gallons per day—a far smaller number than the average statewide withdrawal rate of 5.6 billion gallons per day, or 6.3 MAF per year. To pursue the financial analogy, our ground-water usage clearly exceeds present income and is cutting into capital; this is possible because of the large amount of ground water stored in the aquifers. The terms in this large-scale water budget are portrayed in Figure 25. When we focus specifically on analysis of ground-water systems, a very similar process is used, but different budgetary terms become important on the time scales of ground-water movement. Figure 26 gives a schematic example of an approach to ground-water balance calculations.

Although precipitation, evapotranspiration, and other factors in the water budget vary widely from year to year at any one location and from place to place within the state, the large-scale, long-term averages remain nearly constant. That permits us to construct the approximate state water budget with ease. Unfortunately, this is of little use in managing the day-to-day reality of local water supplies—we can't effectively move the rainfall of eastern

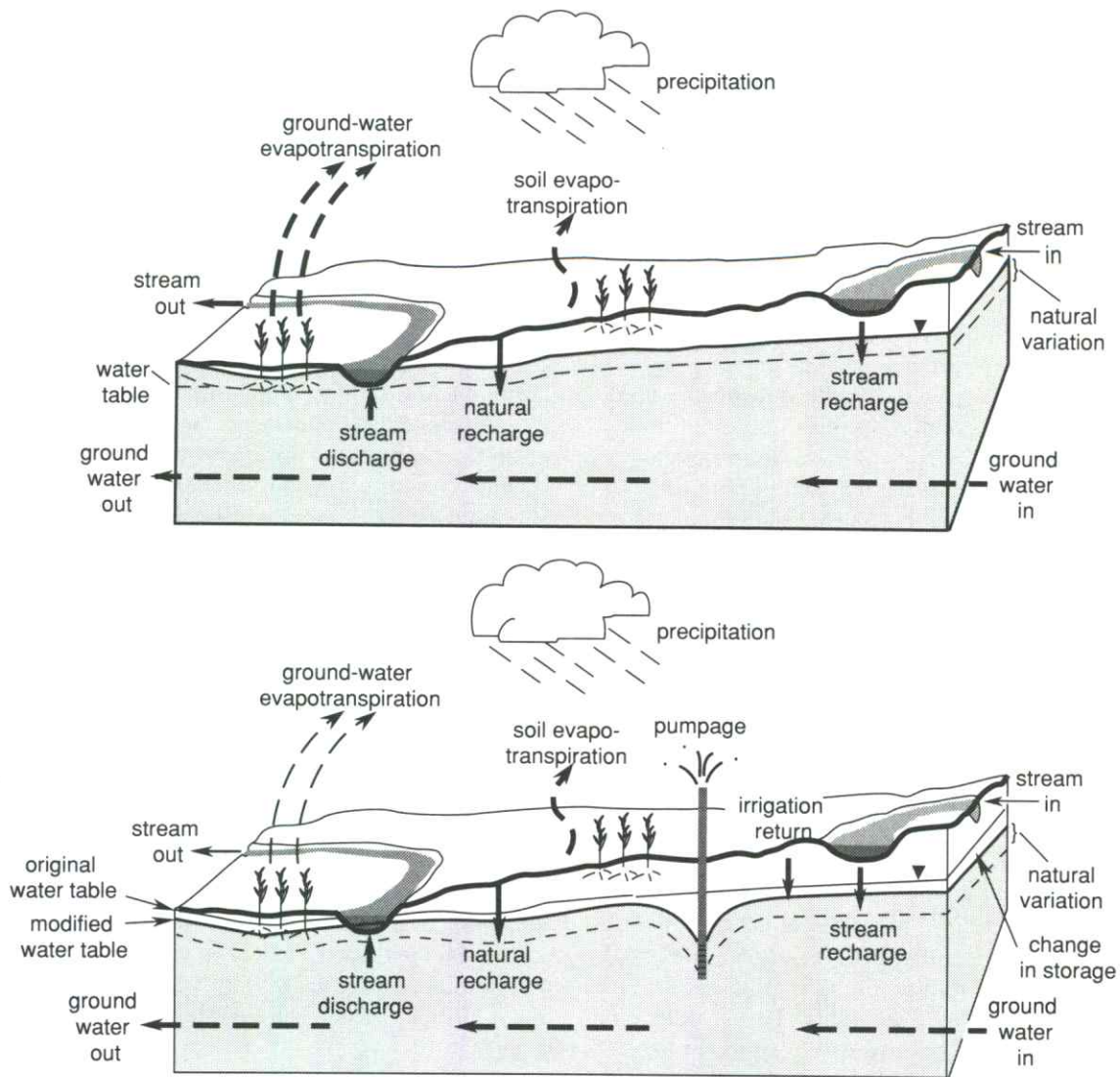


Figure 25—A water budget schematic as it might be applied to a specific region. Part A shows the natural condition; part B indicates the kind of changes that must be considered when extensive ground-water withdrawal occurs.

Kansas to the west, or transplant the western aquifers to the east. For dealing with local issues we need local data—usually more of it and over a longer time period than actually exists. To meet these needs, a number of state and federal agencies maintain monitoring programs for critical hydrologic data. Figure 27 shows the distribution of wells in the Kansas ground-water-level monitoring network; the density of points corresponds reasonably well with the availability of ground water. That is, the more points on the map, the more ground water. Other key hydrologic variables are streamflow and climate, and the measurement stations for these are shown in Figures 28 and 29. Other programs monitor water quality, reservoir water levels, etc. This network of measurement may seem extensive, but it has been carefully designed to obtain the essential information with minimum cost and effort. Building the data base needed to understand and manage

the hydrologic system is time-consuming and expensive—but not nearly as expensive as the consequences of ignorance.

The basic tool for managing water resources on a statewide basis is the system of water rights appropriations administered by the Division of Water Resources (DWR) of the State Board of Agriculture (for an annotated list of water research and regulatory agencies and organizations, see Appendix C). Certain minimal uses of ground water, such as domestic and livestock wells, are exempt from water-rights regulation, but large-scale water users must apply for and be granted water rights—essentially, a permit to divert surface water or pump ground water in specified amounts. Local levels of management are provided in some areas by groundwater management districts; these bodies were created in the 1970s and are authorized under state law to provide more detailed levels

of ground-water use administration and planning. Today, five groundwater management districts (GMDs) exist and are shown in Figure 30. All districts correspond to major portions of the High Plains aquifer system (GMDs 1, 3, and 4 overlie the Ogallala aquifer, GMD 5 corresponds to the Great Bend Prairie aquifer, and GMD 2 covers the Equus Beds aquifer and part of the alluvial aquifer of the lower Arkansas River). Primary ground-water uses in the groundwater management districts are irrigation, although the Wichita area obtains part of its municipal supply from the Equus Beds aquifer. These districts are governed by local boards and have been instrumental in providing information and identifying research and regulatory needs in their boundaries. Several of the districts, for example, have worked with the Division of Water Resources to identify intensive ground-water use control areas (or IGUCAs), locations where there have been substantial ground-water declines or water-quality problems. In those areas (which also have been declared for locations outside of groundwater management districts), limits are placed on the drilling of new wells or on pumping from existing wells. Groundwater management districts also have been involved with water-education programs and some districts have even carried out cloud-seeding programs designed to increase rainfall and suppress hail.

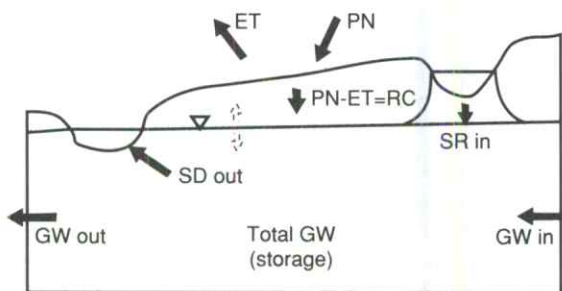
Access to water was historically an issue long before the present level of hydrologic understanding was available, and Kansas, like most western states, adopted a seniority system to deal with uncertainties in water supply. "First in time, first in right" is the traditional slogan, meaning that when water supplies are not adequate to supply all of the water rights, priority is established according to the seniority of the rights. That is, older (or senior) water rights take priority over more recent (or junior) water rights. This rule is reasonably straightforward when applied to surface water, but the concept is harder to apply to ground water because ground-water-system response times are long compared to the time

scales of local human perturbations, and we usually have only an approximate idea of the exact size or renewal rate of the resource. In other words, heavy pumping of one water right may limit pumping of another right, but that is difficult to prove and may take years to show up.

At present, state and local policies indicate that aquifers should be managed on a safe-yield basis, but this is a goal rather than an accomplished fact. Many major Kansas ground-water resources were over-allocated in terms of pumping rights before safe-yield policies were in place. State and local agencies and water users are grappling with the issues of how to deal with the situation. The problem is further complicated by the fact that our predecessors did not understand the degree to which streamflow and ground water are interconnected when separate systems of ground-water and surface-water rights were established. As we discussed earlier, permanent streamflow is usually the result of ground-water discharge, so that if ground-water pumping lowers the elevation of the water table below that of the stream bed, streamflow will be reduced or interrupted. On the other hand, streamflow may be the major source of recharge to some alluvial aquifers, so that streamflow regulation or diversion may alter the recharge characteristics, and therefore the safe yield of the ground water in the area. For example, in 1991 and 1992, the state's Division of Water Resources held hearings concerning streamflow in Wet Walnut Creek (which provides some of the water for Cheyenne Bottoms). The DWR eventually decided that streamflow was being lowered because of ground-water pumping for irrigation, created an IGUCA, and limited pumping on existing wells. This was an historic recognition of the relationship between streamflow and ground water.

Water-resource management also must consider other needs and values, among them water quality, flood control, wildlife habitat, and recreation. The conflicts between the multiple uses are well expressed by the observation that for flood control a reservoir should be empty, for water supply it should be full, and for recreation the level should remain constant. Ground-water issues come into play most strongly with respect to biological habitat concerns. Wetlands and marshes, like the baseflow of streams, are generally related to ground-water discharge. They are therefore vulnerable to water-table fluctuations as well as surface-water balance, and concerns about the major wetlands habitats of central Kansas (Cheyenne Bottoms and Quivira Marsh) have sparked interest in the water budgets of those areas.

Keep in mind, however, that the legal process, and not social or scientific policy, determines how water is allocated to different interests. Very often, cases boil down to senior water-rights versus junior water-rights. Older rights, quite simply, give their owner the priority for access to water when supplies are tight. In the case of Wet Walnut Creek, again, the rights to water flowing into the stream (and eventually to Cheyenne Bottoms) were older,



$$\text{Input} = \text{SR} + \text{RC} + \text{GWIN}$$

$$\text{Outflow} = \text{SD OUT} + \text{GW OUT}$$

$$\text{At Equilibrium, input} = \text{output}$$

$$\text{Residence time} = \frac{\text{Total GW}}{\text{Input}}$$

Figure 26—A large-scale schematic depiction of a water budget. ET = evapotranspiration, PN = precipitation, RC = recharge, SR = stream recharge, SD = stream discharge, GW = ground water.

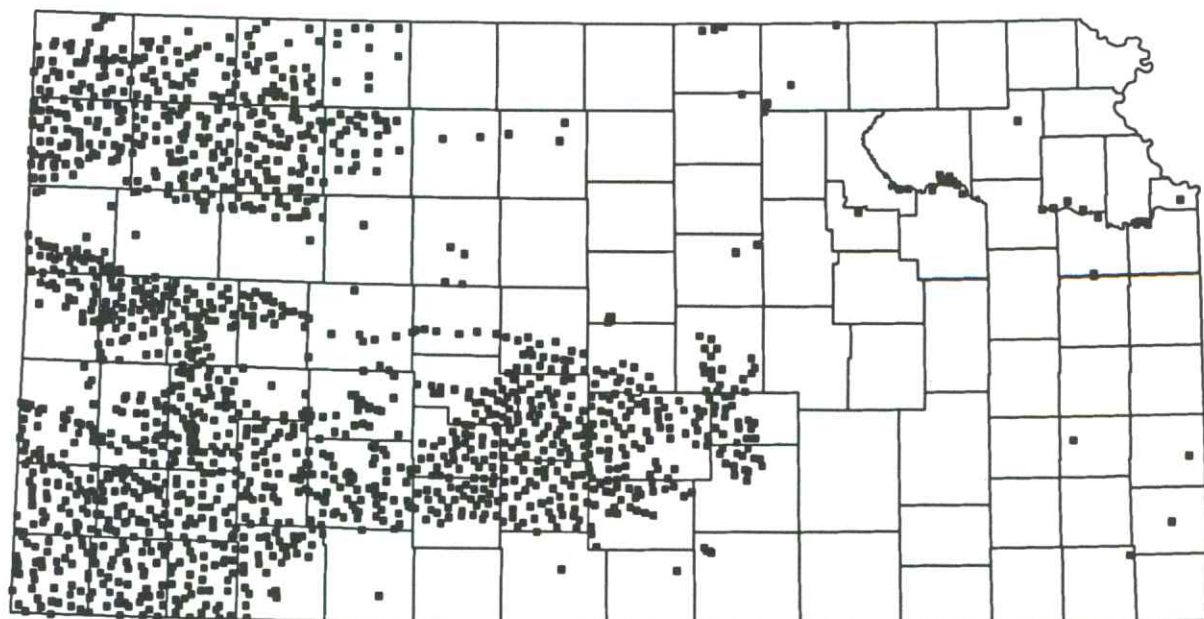


Figure 27—Kansas ground-water-monitoring network.

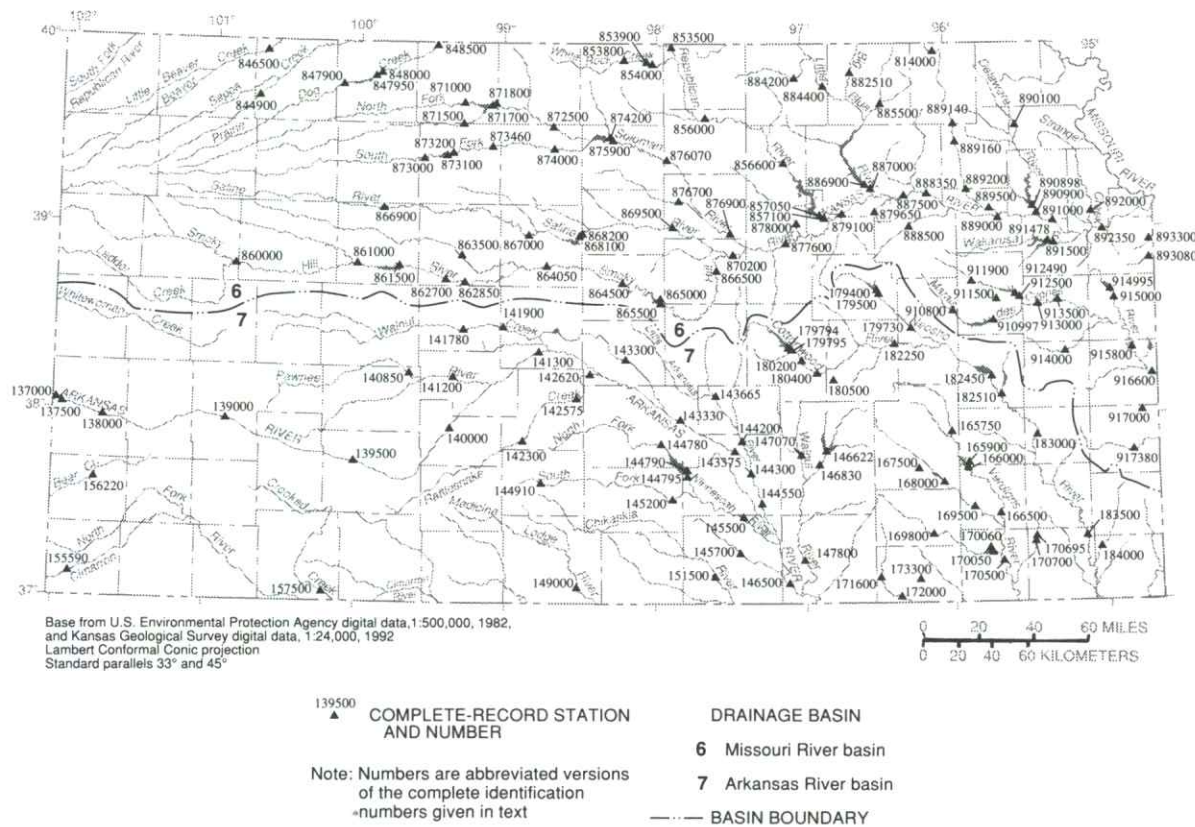


Figure 28—Streamflow-measurement stations in Kansas.

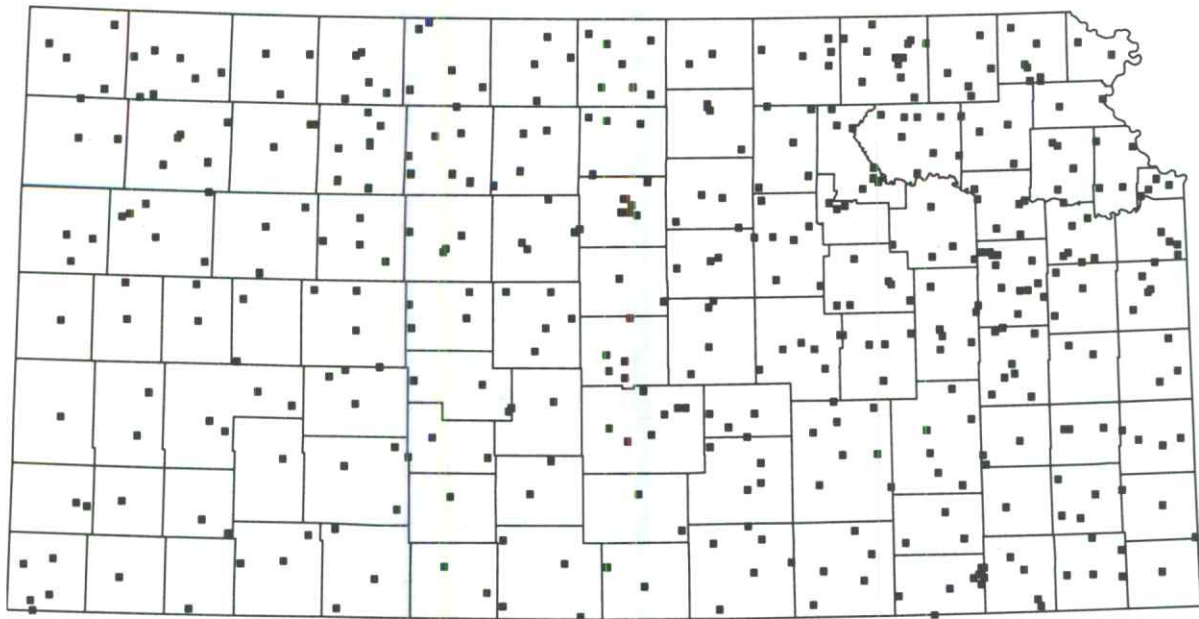


Figure 29—Climate-measurement stations in Kansas.

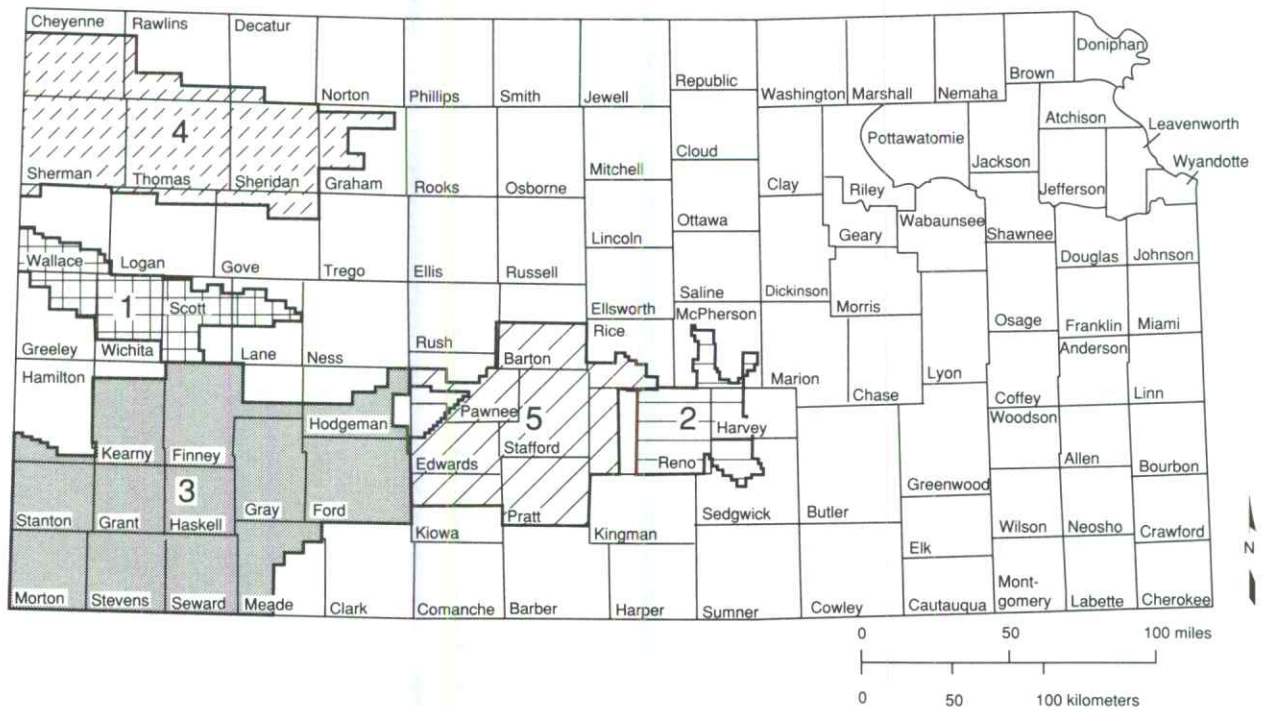


Figure 30—The state’s five groundwater management districts.

or more senior, than rights for pumping ground water. Thus, the case was decided not on the desirability of maintaining streamflow for the sake of Cheyenne Bottoms, but on the legal issue of the age of the right to acquire water.

Water management is a complex and difficult process and will become more so as demands increase while available resources decrease. Fortunately, Kansans have taken a forward-looking step in creating the Kansas Water Plan. The Kansas Water Office (under the direction of the Kansas Water Authority) is responsible for centralized planning and coordination for all water-related issues, while leaving intact the specific responsibilities of existing state water agencies. Much of the water-resources planning for Kansas is currently accomplished on the basis of the state's twelve major drainage basins, a division based on the philosophy that areas drained by the same stream often have many similar water issues in common.

This current approach to water planning and regulation in Kansas attempts to avoid the problems inherent in dealing with an integrated system (the hydrologic cycle) on a piecemeal and patchwork basis, while still retaining local control and the advantages of specialized expertise. If successful in this effort, Kansas will be better positioned than most states to address the water problems of the future.



*The dry, sandy riverbed of the Cimarron River in Grant County.*



*Siphons draw irrigation water for corn from a ditch in Republic County.*



*Cheyenne Bottoms, Barton County.*

## Problems and issues

It is important to keep clearly in view the fact that many—perhaps most—of the problems involving water resources are not hydrologic or geologic problems. We can identify three classes of problems: political, technical, and scientific.

The term political is used in its broadest sense, relating to the process of determining and implementing societal values and goals. Questions such as whether to dam a free-flowing stream to provide flood control or water supplies, or whether to maintain some elevation of the ground-water table or to deplete ground-water reserves by pumping at rates greater than the *safe yield* level, are fundamentally political decisions. Scientists can offer information on the probable effects of a given action or the best way to achieve a particular goal, but the ultimate value judgment is not scientific in nature.

Technical problems are those in which some well-defined information is needed and obtainable in a straightforward fashion, but not available at present. Also termed assessment, characterization, or monitoring studies, these problems are typically solved by the application of scientific measurements or calculations to a hydrologic system that can be described in a standard fashion. The design and placement of a dam or the determination of whether water quality is adequate for a municipal supply are examples of problems or questions in this category.

Scientific questions are those requiring research—problem definition, experimental design, observation or calculation, and interpretation. They often involve systems too large, too complex, or with too long a time constant to be completely described. Models and sampling strategies must be designed and validated to produce adequate information within the time and resources available. Determining the safe yield of an aquifer system or the origin and pathways of ground-water contamination are real examples of problems in this category.

In keeping with the scientific mission of the Kansas Geological Survey, the problems we identify as critical for the future of Kansas ground water are scientific in nature—but we note that their importance is due in large part to the deficit in the water budget discussed earlier. Demand for water exceeds the long-term supply in many areas, and ground water is being withdrawn much faster than the rate of recharge. Adding to the complexity of the problem is the fact that surface-water and ground-water resources are interconnected and interactive. Among the critical areas where improved understanding will help us to make the most effective use of our limited water supply are:

- 1) Deep aquifer characterization: Deep aquifers, such as the Dakota, represent the next available source of ground water once the shallower aquifers are depleted,

and these deep aquifers are already being used in some areas. In some areas they provide avenues for the flow of saltwater that mixes with and degrades freshwater in the deep or shallower aquifers. The extent, hydrologic characteristics, and distribution of water quality in these aquifers needs to be much better known to understand both their water-resource potential and the safe yield at which they can be exploited.

- 2) Stream-aquifer interactions: We need a much better understanding of the dynamics of ground-water discharge and recharge in stream systems. The relationship between recharge and streamflow needs to be studied over a range of time scales and water levels to provide an information base for managing the combined resource on a long-term basis. Some of the questions involve alteration of the hydrologic character of the system. High flow rates and floods can act to scour out a stream channel, so human control or reduction of streamflow may result in a gradual reduction of the permeability of the channel and change the coupling of the ground water and surface water.
- 3) Water-quality issues: Water quality can be a problem because of natural factors or because of artificially introduced contaminants. Kansas faces both types of problems.
  - a) Mineral intrusion: The salt beds and brine-containing aquifers that are near the surface in much of central Kansas represent a special problem for water supply and management. Freshwater heads and flow rates can often be maintained at a level adequate to either keep the underlying saltwater from discharging or to dilute it to tolerable levels where it does discharge. However, managing this sort of balanced system requires a detailed understanding of the hydrology, geology, and geochemistry of multiple
- interacting aquifers. It is a challenging research problem, but the issues are important. A substantial fraction of the irrigated agriculture and municipal water supplies of south-central Kansas are vulnerable to salt problems, and aquifers tend to have a memory effect—a temporary introduction of brine into a freshwater aquifer may leave behind long-term residual contamination.
- b) Human contamination: The so-called point sources of ground-water contamination (landfills, industrial discharge, underground storage tanks, injection wells, etc.) are gradually being brought under regulatory control that will reduce some of the problems in the future, but improved methods for locating and predicting the movement of contaminant plumes resulting from past practices are still needed. As attention turns to the non-point sources of pollution (such as agricultural chemicals or urban runoff), we find that we need a greatly improved understanding of how both water and contaminants move through the unsaturated zone and mix into the ground water. Such studies can improve our understanding of the recharge process as well as of pollution-related mechanisms.
- 4) Regional-scale hydrology: We have mentioned several times the fact that hydrologic observations are made at a very local scale, and that our climate and budgetary insights work best at a very large scale. The National Research Council has identified the link between local (watersheds or sites) and continental-scale hydrologic systems as one of critical importance. This focus on dimensions typical of aquifers or river basins is particularly relevant to the Kansas approach to water planning based on river basins. It is also critical to the future of water planning, since this is the scale of understanding required to link global or regional climate-change effects to local water resources.

## Conclusion

The aim of this book is to provide useful information about ground water and its place in the larger water-resource picture. An introductory volume of this sort limits the details we can provide; the appendices that follow provide some suggestions, additional reading, and

lists of agency responsibilities. Above all, we hope that we have convinced the reader that “out of sight” should not be “out of mind,” that Kansas ground water is a vital and valuable resource that cannot be taken for granted.

## Acknowledgments

We wish to acknowledge the following individuals and agencies for reviewing the manuscript of this book: James J. Butler and Margaret A. Townsend of the Kansas Geo-

logical Survey, the Division of Water Resources of the State Board of Agriculture, the Kansas Water Office, and the U.S. Geological Survey–Water Resources Division.



## Appendix A. Glossary

- Acre-foot*: The amount of liquid necessary to cover an acre of ground to a depth of 1 foot. In terms of water, 1 acre-foot equals 325,851 gallons.
- Alluvium*: Unconsolidated sediment—usually sand, gravel, silt, and clay—that has been deposited by running water, such as rivers and streams. The alluvium along many Kansas rivers is a ready source of water.
- Aquiclude*: An impermeable layer of rock that does not allow water to move through it. Some shales, for example, have such low permeability that they effectively form an aquiclude.
- Aquifer*: A rock formation, either consolidated or unconsolidated, that is capable of holding and yielding significant amounts of ground water.
- Aquitard*: A layer of geologic material that has low permeability and thus allows water to move through it slowly.
- Artesian well*: A well in which the water level rises above the level of the aquifer and may flow at the surface. In a flowing well, water exits at the surface.
- Bedrock*: The solid rock that underlies any unconsolidated sediment or soil. Limestone and sandstone are common types of bedrock in Kansas. Most Kansas bedrock is in formations of Cretaceous age or older.
- Brine*: Highly salty water, commonly with more than 10,000 milligrams per liter of chloride. In parts of Kansas, ground water may be naturally salty. Brine also is regularly produced along with oil in Kansas.
- Cone of depression*: A cone-shaped depression in the water table around a well or a group of wells. The cone is created by withdrawing ground water more quickly than it can be replaced.
- Confined aquifer*: An aquifer that is bounded above and below by confining layers. Because of the pressure created in a confined aquifer, the water level in a well drilled into a confined aquifer will rise above the top of the aquifer and, in some instances, above the land's surface.
- Depth to water*: The depth of the water table below the earth's surface.
- Drawdown*: The decline in ground-water level caused by the withdrawal of water from an aquifer.
- Evapotranspiration*: Water that moves into the atmosphere from evaporation (from the surface of either land or water) and the transpiration of plants.
- Freshwater*: Water containing only small quantities (generally less than 1,000 milligrams per liter) of dissolved minerals.
- Gaining stream*: A stream that receives water discharge from the zone of saturation.
- Ground water*: Underground water that is generally found in the pore space of rocks or sediments.
- Hydraulic head*: In hydrologic terms, the height that water in an aquifer can raise itself above an (arbitrary) reference level (or datum) and is generally measured in feet. This term defines how much energy water possesses. When a borehole is drilled into an aquifer, the level at which the water stands in the borehole (measured with reference to a horizontal datum such as sea level) is, for most purposes, the hydraulic head of water in the aquifer.
- Hydrogeology*: The study of ground water and its relationship to geology. Also sometimes known as geohydrology.
- Hydrologic cycle*: The complete cycle that water can pass through, beginning as atmospheric water vapor, turning into precipitation and falling to the earth's surface, moving into aquifers or surface water, and then returning to the atmosphere via evapotranspiration.
- Losing stream*: A stream that contributes water to the zone of saturation.
- Permeability*: The capacity of a rock for transmitting a fluid. Permeability depends on size and shape of pores in the rock, along with the size, shape, and extent of the connections between pore spaces.
- Porosity*: The volume of open or pore space in a rock. Porosity determines the capacity of a rock formation to absorb and store ground water.
- Recharge*: The replenishment of ground water in an aquifer. It can be either natural, through the movement of precipitation into an aquifer, or artificial—the pumping of water into an aquifer.
- Safe yield*: The amount of water that can be removed from a source (aquifer, river, etc.) on a sustained basis without unacceptable depletion of the resource.
- Saturated thickness*: The vertical thickness of an aquifer that is saturated with water.
- Saturated zone*: That portion of soil or an aquifer in which all of the pore space is filled with water.
- Specific yield*: The quantity of water given up by a unit volume of a substance when drained by gravity.
- Spring*: The point at which ground water is naturally discharged at the earth's surface.
- Surface water*: Water found at the earth's surface, usually in streams or lakes.
- Terraces*: In geologic terms, these are flat broad benches of land that lie above the immediate floodplain of a stream. Terraces represent a prior floodplain level of the stream.
- Unconfined aquifer*: An aquifer that has no confining layers above it and is not under pressure. The water table forms the upper boundary of the aquifer.
- Unsaturated zone*: Also known as the vadose zone, this is the area of soil or rock just above the water table.
- Water balance*: A mathematical construction that shows the amount of water leaving and entering a given watershed or aquifer.
- Watershed*: The area drained by a single stream or river. The Arkansas River watershed, for example, includes that area from which water eventually flows into the Arkansas River.
- Water table*: The top of the saturated zone in an unconfined aquifer.
- Well*: A vertical excavation into an underground rock formation.

## Appendix B. Further reading

The following books provide additional information about ground water and Kansas geology. In addition, the Kansas Geological Survey has published bulletins describing the geology and ground-water resources of many of the counties of the state. For a list of those publications, contact the Survey publication sales office.

- Rex Buchanan (editor), *Kansas Geology. An Introduction to Landscapes, Rocks, Minerals, and Fossils* (Lawrence: University Press of Kansas, 1984), 208 p.
- Ralph C. Heath, *Basic Ground-Water Hydrology*, U.S. Geological Survey, Water-Supply Paper 2220 (Washington, D.C.: Government Printing Office, 1982), 85 p.
- Kansas Water Office, *Kansas Water-Related Programs Manual* (Topeka: Kansas Water Office, 1990), 60 p. A list of water agencies and responsibilities.
- Kansas Water Resources Board, *A Kansas Water Atlas*, Kansas Planning for Development "701" Project Number P-43—Report Number 16-a (Topeka, Kansas: Kansas Water Resources Board, 1967), 57 p.
- Joan F. Kenny, *Reported Water Use in Kansas, 1987*, U.S. Geological Survey, Open-File Report 91-212 (Lawrence: U.S. Geological Survey, 1991), 39 p.
- David E. Kromm and Stephen E. White, *Conserving Water in the High Plains* (Manhattan: Kansas State University, 1990), 12 p. A discussion of the results of a study of water-saving practices on the High Plains.
- David E. Kromm and Stephen E. White (eds.), *Ground-water Exploitation in the High Plains* (Lawrence: University Press of Kansas, 1992), 240 p. A collection of articles by scholars and water professionals concerning ground-water use on the High Plains.
- Luna B. Leopold, *Water: A Primer*, (San Francisco: W. H. Freeman and Co., 1974), 172 p.
- \_\_\_\_\_, *Ground-water Regions of the United States*. Water-Supply Paper 2242 (Washington, D.C.: U.S. Geological Survey, 1984), 78 p.
- John C. Manning, *Applied Principles of Hydrology* (New York: Merrill Publishing Company, 1987), 288 p. An outline of elementary hydrology for non-science undergraduate majors.
- Raymond C. Moore, 1940. *Ground-water Resources of Kansas* (Lawrence: Kansas Geological Survey, Bulletin 27), 113 p. An historic Survey bulletin on the state's ground water.
- Marc Reisner, *Cadillac Desert: The American West and Its Disappearing Water* (New York: Viking Press, 1986), 582 p. A popular historical account of water-use and irrigation in the American West.
- Walter H. Schoewe, *The Geography of Kansas*, Transactions of the Kansas Academy of Science, "Part I. Political Geography," 1948, v. 51, no. 3, p. 253-288; "Part II. Physical Geography," 1949, v. 52, no. 3, p. 261-333; "Part III. Hydrogeography," 1951, v. 54, no. 3, p. 263-329; "Part III-concluded," 1953, v. 56, no. 2, p. 131-190.
- Huber Self, *Environment and Man in Kansas* (Lawrence: The Regents Press of Kansas, 1978), 288 p.
- James Earl Sherow, *Water the Valley: Development Along the High Plains Arkansas River, 1870-1950* (Lawrence: University Press of Kansas, 1990), 222 p. Traces the history of attempts at large-scale irrigation from the Arkansas River in eastern Colorado and western Kansas.
- Frank W. Wilson, *Kansas Landscapes: A Geologic Diary*, Educational Series 5 (Lawrence: Kansas Geological Survey, 1978), 50 p.
- Donald Worster, *Rives of Empire: Water, Aridity, and the Growth of the American West* (New York: Pantheon Books, 1985), 402 p. An articulate discussion of the development of water policy in the American West by a respected environmental historian.

## Appendix C. Water-related agencies

Following is a list of State, Federal, and local agencies with responsibilities for some aspect of water regulation, planning, research, or education in Kansas. For a complete list of water-related programs, and a listing of the names and addresses of State agency personnel involved, see the *Kansas Water-Related Programs Manual*, published by the Kansas Water Office.

### STATE AGENCIES

#### Cooperative Extension Services

115 Waters Hall  
Kansas State University  
Manhattan, KS 66506  
(913) 532-7137

Responsibility for education in water quality and soil and water conservation. Kansas State University (KSU) Extension has offices in all 105 counties of the state. As part of KSU Extension, the Kansas Agricultural Experiment Stations undertake water research, particularly for irrigated and dryland crop production, on the KSU campus and at experiment stations in Colby, Garden City, Hays, and Parsons.

#### Division of Water Resources

Kansas State Board of Agriculture  
Mills Building  
109 SW 9th, Suite 202  
Topeka, KS 66612-1283  
913-296-3717

Statutory responsibility for floodplain management, interstate water matters, work with groundwater management districts, intensive groundwater use control areas, the formation of watershed districts, and the Water Transfer Act. DWR regulates changes in course, current, or cross section of a stream and oversees all applications for permits to appropriate water.

#### Kansas Biological Survey

Foley Hall  
West Campus, University of Kansas  
Lawrence, KS 66047  
913-864-7725

Undertakes water research in Kansas related to biological water quality, riparian and wetlands, and aquatic toxicology. The Biological Survey is a division of the University of Kansas and has no regulatory authority.

**Kansas Corporation Commission  
Conservation Division**

202 West 1st  
Wichita, KS 67202-1286  
913-263-3238

This agency, with main offices in Topeka and Wichita and a number of branch offices, has regulatory responsibility for plugging dry or abandoned oil and gas wells, for permitting the construction of surface ponds, and for underground injection control.

**Kansas Department of Health and Environment**

Division of Environment  
Building 704, Forbes Field  
Topeka, KS 66620  
913-296-1535

This State agency is responsible for identifying water-quality and water-pollution problems and recommending remediation; for regulating coal mining and the reclamation of lands that have been mined for coal; for regulating non-point-source pollution, such as fertilizer runoff from fields; for regulating runoff from livestock feedlots; for protecting the quality of public water supplies; for cleaning up environmentally contaminated sites; for regulating hazardous-waste storage and remediation; for permitting waste-treatment facilities; and for regulating solid-waste disposal facilities, such as landfills. This agency is also a source of information about water-quality concerns and about water wells drilled in the state.

**Kansas Department of Wildlife and Parks**

Box 54-A, Route 2  
Pratt, KS 67124  
316-672-5911

This agency regulates State park land in Kansas and provides information, education, and regulation related to the state's wildlife and fish. Its water-related responsibilities include development of State parks, fisheries assistance for community lakes, investigation of pollution and fish kills, improvement of wildlife habitat, and working toward recreational access to Kansas streams.

**Kansas Geological Survey**

Moore Hall  
1930 Constant Ave.  
West Campus, University of Kansas  
Lawrence, KS 66047  
913-864-3965

As a research and service division of the University of Kansas, the Kansas Geological Survey has no regulatory authority. It undertakes research in the analysis of hydrologic basins, the Dakota aquifer, recharge, and stream-aquifer interaction. The KGS also supplies information about geology and ground-water development, including records of wells drilled in search of water.

**Kansas Water Office**

109 SW 9th St., Suite 200  
Topeka, KS 66612-1215  
913-296-3185

This State agency operates under the purview of the Kansas Water Authority. The Water Office is heavily involved in planning, including formulation and revision of the State Water Plan, and in gathering water-resource information. The Water Office also oversees the State's basin advisory committees and the State's water marketing program, monitors water research by governmental agencies, develops water supply and demand

estimates for State government, and establishes and monitors minimum desirable streamflows for a number of Kansas rivers.

**Kansas Water Resources Research Institute**

Kansas State University, University of Kansas  
144 Waters Hall  
Kansas State University  
Manhattan, KS 66506  
913-532-5729

This institute conducts and supports research related to Kansas water resources. Much of that research is in support of the objectives of the State Water Plan.

**State Conservation Commission**

Mills Building, 3rd floor  
109 SW 9th  
Topeka, KS 66612  
913-296-3600

This agency is charged with providing state aid to a variety of programs, including conservation districts, non-point-source pollution control, watershed-dam construction, small-lakes construction, water-rights purchases, and watershed-planning assistance. The Conservation Commission also works toward wetlands protection and stream rehabilitation.

**FEDERAL AGENCIES**

**Kansas State Agricultural Stabilization and  
Conservation Service**

3600 Anderson  
Manhattan, KS 66502  
913-539-3531

This agency works toward soil and water conservation. Its programs include the agricultural conservation program, the conservation reserve program, and the rural clean water program.

**Bureau of Reclamation**

Nebraska-Kansas Projects Office  
P.O. Box 1607  
Grand Island, NE 68802  
308-381-5501

Administratively responsible for several reservoirs constructed in Kansas. The Bureau also operates a program for funding small reclamation projects and undertakes planning for regional or river basin studies.

**U.S. Army Corps of Engineers**

Kansas City District  
700 Federal Building  
Kansas City, MO 64106  
816-374-3896

Tulsa District  
224 S. Boulder  
Tulsa, OK  
918-581-7395

Responsible for several major reservoirs and dams in the state, including flood control, navigation, water supply, and the recreational aspects of those lakes. The Corps has two districts that cover parts of Kansas: the Kansas City district and the Tulsa district. They also provide water-related planning assistance to the state; assist in emergency responses, primarily related to flooding; regulate navigation on the Missouri River and other navigable waterways in the state; undertake streambank and shoreline stabilization; and provide advice related to floodplain management.

**Environmental Protection Agency**

726 Minnesota Avenue  
 Kansas City, KS 66101  
 913-236-2815

Responsible for Federal environment regulation, this office provides support for State ground-water programs. EPA has an office in Kansas City that is responsible for Region VII, which includes Kansas. It has a program of protecting wellhead areas for wells that produce drinking water, provides grants for constructing publicly owned wastewater-treatment plants, provides loans for pollution-control activities, oversees the Safe Drinking Water Act, regulates permits for pollutant discharges, administers a non-point source pollution-control program (in concert with the Kansas Department of Health and Environment), sets water-quality standards for state surface water, has a program for protecting and restoring publicly owned lakes, and is responsible for underground injection control (along with the Kansas Department of Health and Environment and the Kansas Corporation Commission). The EPA also administers a revolving loan fund for communities to construct wastewater-treatment facilities.

**Farmers Home Administration**

444 SE Quincy  
 Topeka, KS 66683  
 913-295-2876

This Federal agency provides loans and financial assistance for a variety of rural areas, towns, and watersheds.

**Federal Emergency Management Agency**

911 Walnut Street, Room 200  
 Kansas City, MO 64106  
 816-283-7060

Administers a program for flood insurance.

**Soil Conservation Service**

U.S. Department of Agriculture  
 760 South Broadway  
 Salina, KS 67401  
 913-823-4565

A Federal agency that deals primarily with issues of soil conservation. Through 105 local conservation districts, the SCS provides technical assistance for soil and water conservation plans. It is also involved with rural abandoned mines, cooperative river basin studies, emergency watershed protection, watershed planning, and developing an inventory of information on soil and water resources for Kansas. Working with the Kansas Agricultural Experiment Station, the SCS conducts soil surveys.

**U.S. Fish and Wildlife Service**

315 Houston, Suite E  
 Manhattan, KS 66502  
 913-532-7320

This Federal agency supports research on environmental contaminants, consults on actions related to endangered species, and has a program for fish and wildlife enhancement.

**U.S. Geological Survey**

Water Resources Division  
 4821 Quail Crest Place  
 Lawrence, KS  
 913-842-9909

A division of the U.S. Department of the Interior. In Kansas, this agency's Water Resources Division undertakes

interpretive ground-water hydrology studies, research in geochemistry, interpretive studies in water quality, and interpretive studies in surface-water hydraulics and hydrology. It also has developed a network for collecting water-resources data. The U.S. Geological Survey also maintains a field office in Garden City.

**LOCAL AGENCIES**

Kansas has five groundwater management districts that provide local management and information related to ground water.

**Western Kansas Groundwater Management**

District #1  
 Box 604  
 Scott City, KS 67871  
 316-872-5563

**Equus Beds Groundwater Management District # 2**

P.O. Box 232  
 Halstead, KS 67056-1925  
 316-835-2224

**Southwestern Kansas Groundwater Management**

District #3  
 409B Campus Drive  
 Garden City, KS 67846  
 316-275-7147

**Northwest Kansas Groundwater Management**

District # 4  
 1175 South Range Ave.  
 Box 905  
 Colby, KS 67701-0905  
 913-462-3915

**Big Bend Groundwater Management District # 5**

P.O. Box 7, 125 South Main  
 Stafford, KS 67578  
 316-549-3891

**ORGANIZATIONS****Kansas Water Well Association**

P.O. Box 654  
 Garden City, KS 67846  
 (316) 276-6930

This is a professional society primarily composed of people with interests in water, water wells, and water-well drilling in the state.

**Kansas Rural Center**

P.O. Box 133  
 Whiting, KS 66552  
 (913) 873-3431

This non-profit organization has produced a number of non-technical publications concerning water issues in Kansas.

**Kansas Natural Resources Council**

1516 SW Topeka Blvd., Suite 1  
 Topeka, KS 66612-1851  
 (913) 233-6707

This organization focuses on environmental concerns in Kansas, including water issues. KNRC regularly testifies concerning water issues before the State legislature and provides updates on water-related legislation being considered during the legislative session.

**State of Kansas**  
Joan Finney, Governor

**Board of Regents**

Stanley Z. Koplik, *Executive Director*  
Robert Caldwell  
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John Prather  
Richard D. Smith

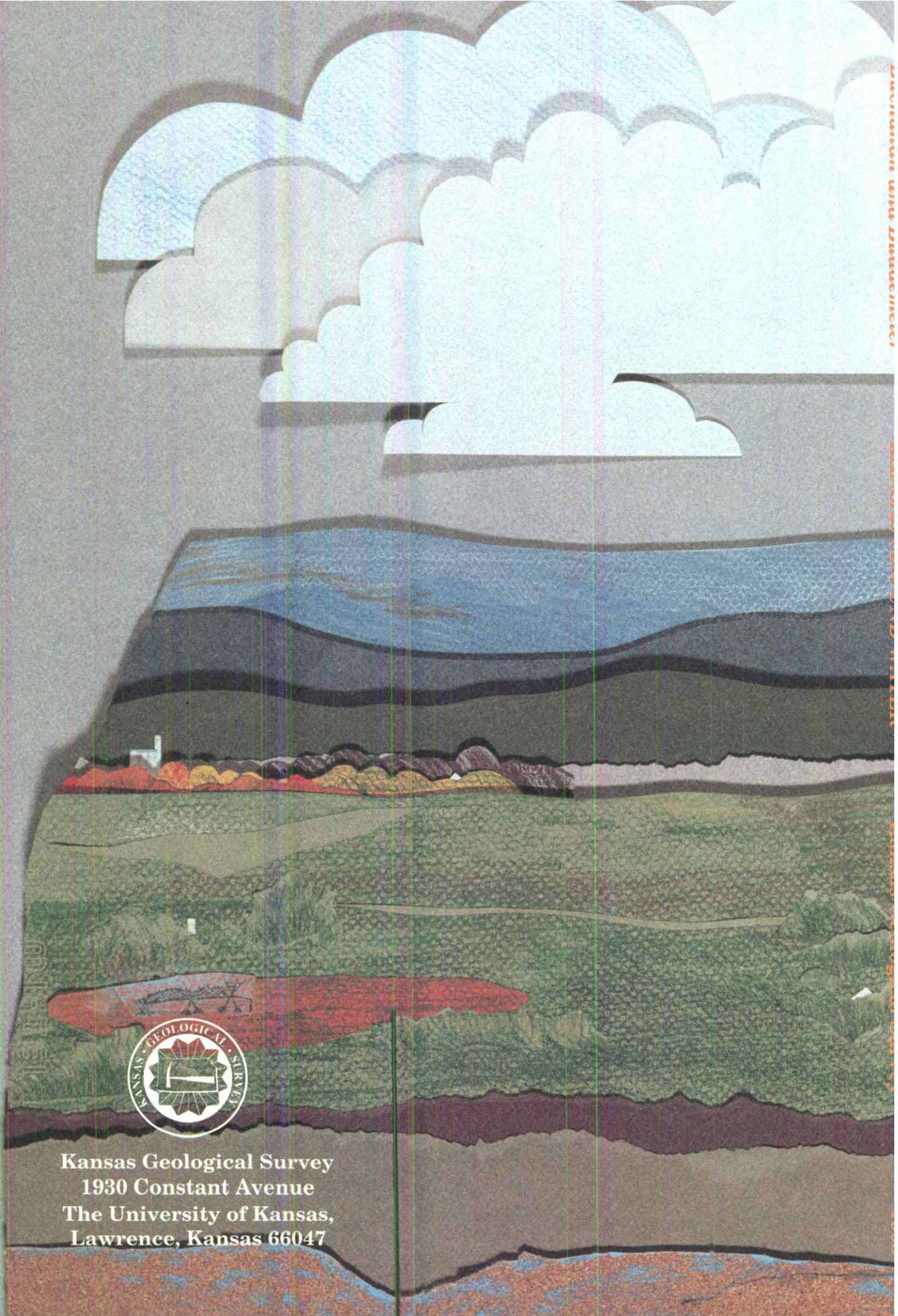
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