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Safe Yield and Sustainable Development of Water Resources in Kansas

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Introduction

The importance of water to every Kansan cannot be overstated. Drinking supplies for urban and rural households, irrigation for crops, and water for livestock, wildlife, recreational, and industrial purposes are uses that touch us all. Water is considered a renewable resource, but on a local or regional level, and in terms of a human lifetime, this is not always apparent. Most of us know of a stream, creek, or river that is now dry or carries less water than it did 25 years ago. The Arkansas River, particularly in western and central Kansas, is a classic example. With the boom in irrigation in the 1960s and 1970s, groundwater levels dropped substantially, again most dramatically in western Kansas (the Ogallala aquifer is an example). In some parts of Kansas, water resources are not being renewed, at least in the short term. Instead, exploitation continues, and aquifers are being depleted and streams are drying up.

State and local agencies have recognized the significance of these problems for some time and have implemented policies that address development of surface and ground water in the state. Termed *safe yield*, these policies attempt to address sustainable development of water resources—the idea of limiting the use of water now so that future generations will have the same opportunities.

This circular will explain why the entire water system (hydrologic cycle) needs to be considered in managing water resources, and how groundwater and surface water interact. It will show why safe yield is *not* sustainable yield, describe the concept of sustainable development of water resources, and illustrate how that concept can be applied to water-resource management in Kansas.Bold terms are defined in the glossary.

Determining the water balance for a river basin or watershed serving 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 whether to restrict expenditures. So, consideration of the water balance enables us to see whether more use can be made of the basin's water resources.

See additional information and illustration of the Water Budget of Kansas.

The Hydrologic Cycle

To understand sustainable development of water resources, it is necessary to understand the relationships between surface water, groundwater, climate, landscape, and the biosphere (**hydrology**). Water on earth circulates endlessly in what is known as the **hydrologic cycle** (fig. 1).

This cycle has no beginning nor end, but from a global perspective, the oceans are the major source of

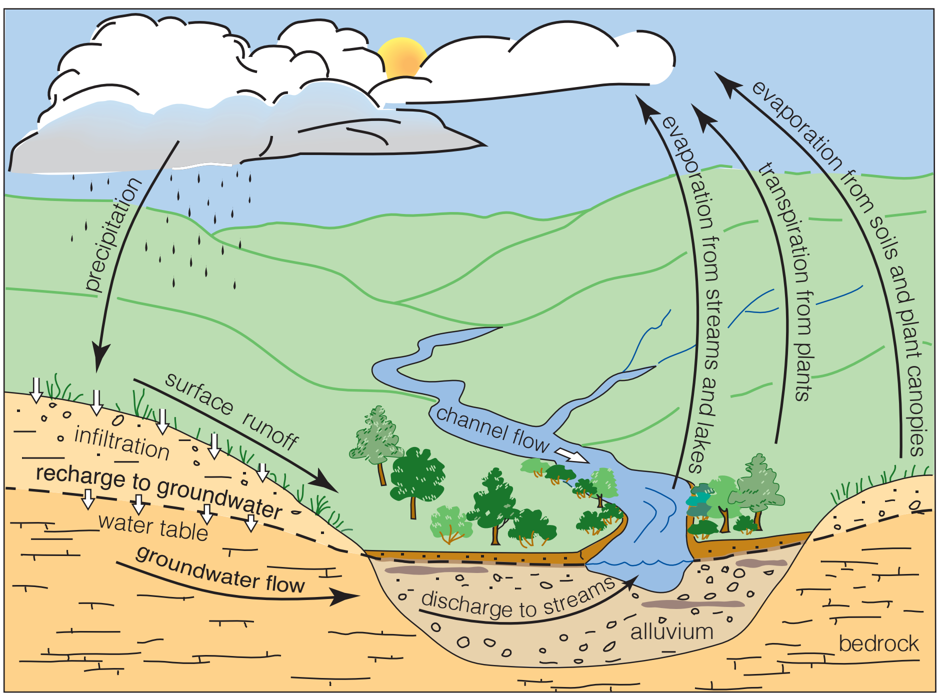


Figure 1. The hydrologic cycle. Precipitation falls to Earth's surface, runs off or infiltrates the ground, then moves back into the atmosphere through transpiration and evaporation.

water. Evaporation from the oceans and, to a lesser extent, the land surfaces supplies the atmosphere with water that condenses to form clouds and falls as precipitation. Most precipitation returns to the atmosphere as evaporation and as transpiration from plants. Transpiration in plants is similar to respiration (breathing) in animals and releases water vapor to the atmosphere. The processes of evaporation and transpiration are usually lumped together and called **evapotranspiration**. Precipitation that falls on the land either infiltrates the ground to replenish soil moisture or become groundwater, or runs off as surface water to form lakes, streams, and rivers. Streams and rivers eventually flow into the oceans, where the cycle starts all over again. This cycle repeats itself over and over again with no loss or gain of water from the global system. On a local or regional level, however, fluctuations of the hydrologic cycle can be dramatic, sometimes producing floods and droughts.

Stream-Aquifer Interaction

Precipitation and surface water that percolate through the soil and reach the aquifer are called **recharge**. Groundwater slowly flows through the aquifer from areas of recharge (usually uplands) to areas of **discharge** (usually lowlands), such as springs, streams, or wetlands. Under natural conditions (prior to development by wells), aquifers are in a state of approximate dynamic equilibrium, which means there is a balanced inflow and outflow of water in the system (fig. 2A). Over hundreds of years, wet times (in which recharge exceeds discharge) offset dry times (when discharge exceeds recharge). Pumping water from wells upsets this balance, oftentimes causing water-table levels to drop (fig. 2B), thereby producing water loss from aquifer storage.

The decline of groundwater levels around pumping wells located near streams captures some of the groundwater flow that would have, without pumping, been discharged to the streams. In fact, if enough water is pumped out of the aquifer, these declining groundwater levels can induce flow out of a body of surface water into the aquifer, a process known as induced recharge. The sum of these two effects leads to streamflow depletion.

As pumping continues, a new state of dynamic equilibrium can be reached only when the amount of water removed from the aquifer is balanced by an increase in recharge (i.e., induced recharge), a decrease in natural discharge, a loss of storage in the aquifer, or a combination of these factors (Theis, 1940). Thus, pumping uses water from two sources, induced recharge and groundwater storage.

Since permanent streamflow is usually a result of groundwater discharge, lowering the water table below that of the streambed will reduce, or perhaps stop, streamflow. The same thing happens to wetlands and springs. Because streamflow is sometimes a source of recharge to some aquifers, a reduction in streamflow can also affect groundwater levels.

Problems in the Smoky Hill River watershed, described below, illustrate these interconnections between streams and aquifers.

In short, groundwater and surface water are both part of a very complex hydrologic system, in which the

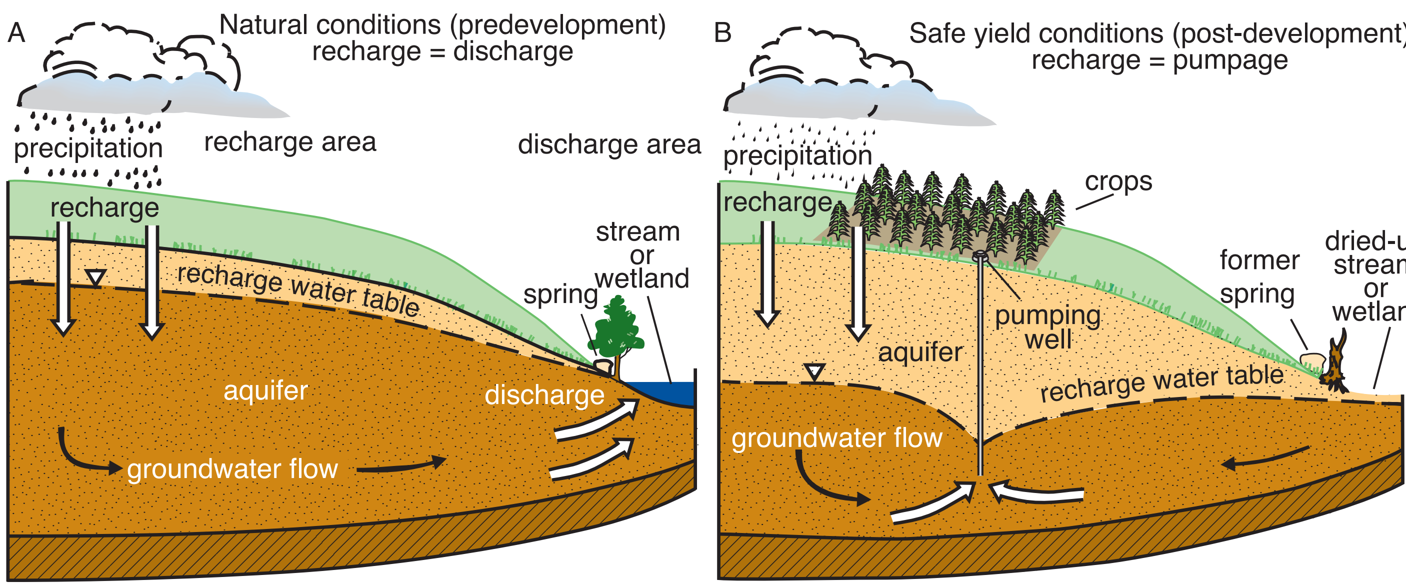
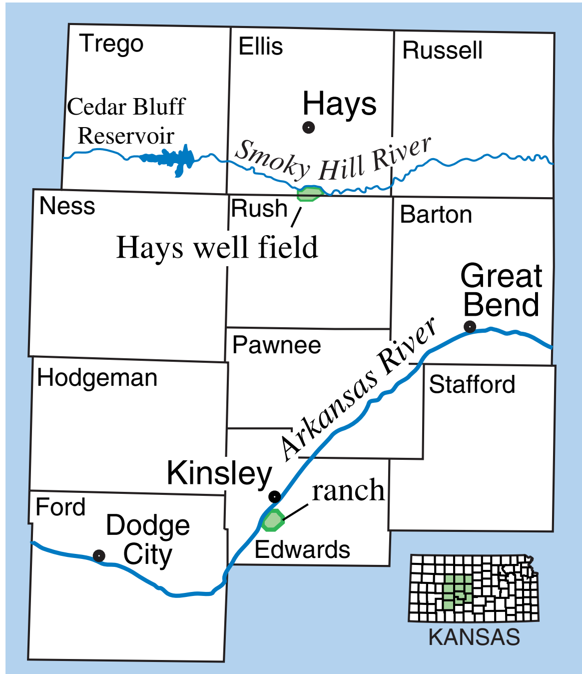


Figure 2. Stream-aquifer interaction. A) Under natural conditions (prior to development by wells), aquifers are in a state of balance; inflow (recharge) equals outflow (discharge). B) Pumping may lower the water table, causing springs, streams, and wetlands to dry up; in this instance, recharge equals pumping.

alteration of one part affects all of the system. Surface and groundwater are not separate components, and development of either water resource must be based on an understanding of the whole system.



A Failure to Recognize Stream-Aquifer Interconnections: Unexpected Things Can Happen!

Sometimes a decision about one aspect of a water system in Kansas has an impact on a variety of systems, impacts not necessarily intended or even recognized when the original decision was made.

In 1951, the Bureau of Reclamation constructed Cedar Bluff Dam on the upper reaches of the Smoky Hill River in Trego County in west-central Kansas. Cedar Bluff captures drainage from the Smoky Hill and two of its major tributaries. The dam was intended to provide flood control, water for irrigation and municipal use, and water for a fish hatchery. Shortly after the dam was completed, heavy spring and summer rains in 1951 and 1957 filled the reservoir. In the mid-1960s, however, inflow into the reservoir slowed substantially. Decreased inflow to Cedar Bluff was attributed to a lessening of streamflow related to lower water tables and the increased use of conservation practices in agriculture, such as terracing and building of farm ponds, that dramatically decreased runoff. Because of this lack of inflow, the contents of Cedar Bluff Reservoir averaged only about 13% of the designed level from 1980 to 1987 (Ratzlaff, 1987). Releases of water from Cedar Bluff to entities with water rights were curtailed in 1979.

Hays, Kansas, a city of about 18,000 people, is about 22 miles (35 km) downstream from Cedar Bluff Reservoir and about 10 miles (16 km) north of the Smoky Hill River. One of the city's primary water sources is a well field in the alluvial aquifer of the Smoky Hill River, which produced about 2,500 acre-feet of water annually. Lessened streamflows in the Smoky Hill — caused by the lower water tables, decreased runoff, and the lack of discharge from the reservoir — meant that considerably less water was available in the Smoky Hill to recharge the alluvial aquifer. Yields in the Hays well field dropped to about 1,000 acre-feet annually. Because of dwindling water supplies, Hays began a number of conservation efforts, resulting in a substantial reduction in per capita water use. The city also began aggressively seeking additional water sources and eventually purchased land and water rights to a ranch in Edwards County, Kansas, about 85 miles (136 km) away, with plans of transferring water for municipal use in Hays, in spite of considerable opposition to the plan in Edwards County.

In short, then, lessened streamflow in the Smoky Hill River had the domino effect of lessening supplies in Hays, leading to the possible transfer of water away from the Arkansas River drainage basin, more than 100 miles (160 km) away from Cedar Bluff. The reservoir's construction, along with other factors, had a variety of consequences — related to agricultural, municipal, and irrigation water supply, as well as streamflow — that reverberated far beyond the simple building of a dam in Trego County.

Sustainable Development of Water Resources

Sustainable development is broadly defined as development of a resource that meets the needs of the present without compromising the ability of future generations to meet their own needs. In this circular, sustainable development of water resources refers to a holistic approach to development, conservation, and management of water resources, an approach that considers all components of the hydrologic system. This concept requires that, in the long term, a balance must exist between the amount of water entering and the amount leaving the system. In other words, discharge to streams, springs, and wetlands (and pumping) must equal recharge, and groundwater and surface water must be considered together.

To protect groundwater supplies from overdevelopment, some state and local agencies have enacted regulations and laws based on the concept of safe yield. Safe yield is defined as the attainment and maintenance of a long-term balance between the amount of groundwater withdrawn (pumped) annually and the annual amount of recharge (Sophocleous, 1997). Safe yield is a management concept that allows water users to pump only the amount of groundwater that is replenished naturally through precipitation and surface-water seepage (recharge). As defined, safe yield ignores natural discharge from the system.

As stated earlier, under natural conditions, recharge to an aquifer is balanced by discharge. Consequently, if pumping is allowed to equal recharge, the streams, marshes, and springs will eventually dry up, because pumping removes the water that would otherwise be discharged naturally. Clearly, limiting water use to the amount of natural recharge is not enough. Nonetheless, this so-called safe yield concept is still mistakenly viewed as sustainable management.

Water-Resource Management in Kansas

Groundwater pumping in the last 50 years has depleted parts of the **High Plains aquifer** especially in southwestern Kansas, where water levels have dropped as much as 200 feet (61 m) in some places. These declines in the **saturated thickness** of the aquifer (fig. 3), especially in western Kansas, prompted the Kansas Legislature to pass the Kansas Groundwater Act in 1972, authorizing the formation of local groundwater management districts (GMDs) to help direct the development and use of groundwater resources. Since passage of the act, five districts have been formed (fig. 4).

The three western districts (GMDs 1, 3, and 4) overlie all or parts of the Ogallala aquifer and have the greatest number of large-capacity wells and the highest rate of water-level declines, while having the least precipitation and groundwater recharge. Each of these districts has adopted a plan that will allow a portion of the unappropriated aquifer to be depleted (no more than 40%) over a period of 20 to 25 years (planned depletion policy), implying that the Ogallala is not a renewable resource, at least within a human generation. This plan applies only to appropriations that were established since the policy was adopted in the late 1970s. By 1990, GMD 4 had switched to a zero depletion policy, for new wells only. Under zero depletion, an established average water level is maintained, regardless of the recharge rate.

In the late 1970s and early 1980s, GMDs 2 and 5 in central Kansas, which receive more precipitation (and thus more groundwater recharge), initially adopted the traditional safe-yield approach to groundwater management. According to this policy,

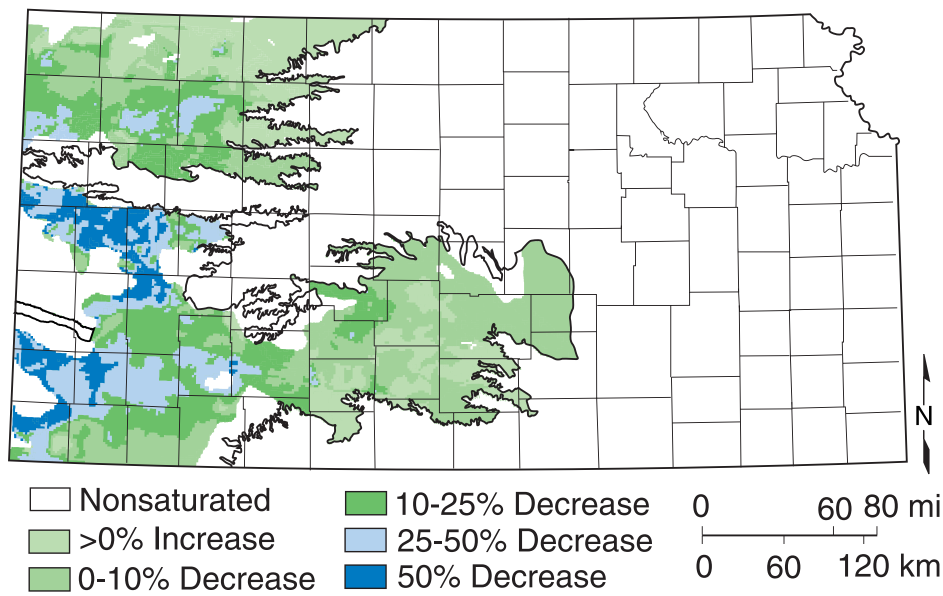


Figure 3. Percent change in saturated thickness (predevelopment through 1996) of the High Plains aquifer in western and central Kansas (adapted from Sophocleous, 1997).

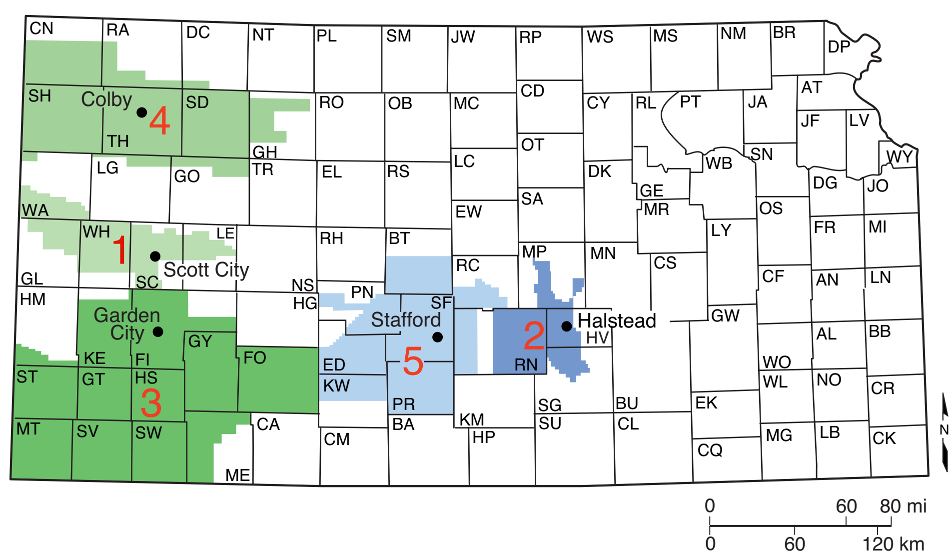


Figure 4. Groundwater management districts in Kansas.

the total amount of water that could be appropriated was limited to the long-term annual recharge, implying a renewable groundwater resource. This was the first endeavor in the state to manage groundwater as a renewable resource.

Because of declines in groundwater levels, streamflows in western and central Kansas have been decreasing, especially since the mid-1970s. In response to these streamflow declines, the Kansas Legislature passed the minimum instream flow law in 1982, which requires that minimum desirable streamflows be maintained in different streams in Kansas. Although the establishment of minimum desirable streamflows was a major step toward conservation of riverine habitat within the state, streamflows have continued to decline (Ferrington, 1993). Maps comparing the perennial streams in Kansas in the 1960s to those of the 1990s show a marked decrease in miles of streamflow in the western third of the state (fig. 5).

As a result of continued declines in groundwater levels and streamflow in parts of GMDs 2 and 5 during the 1980s, both GMDs re-evaluated their safe-yield policies and regulations in the early 1990s. Beginning in 1994, these GMDs changed to **conjunctive management** of stream-aquifer systems by enhancing their existing safe-yield policies to include the natural groundwater discharge to streams (baseflow) when evaluating a groundwater permit application. The new regulations moved towards a sustainable-yield approach, but for regulatory and name-recognition purposes, GMD 2 continues to refer to them as safe yield, whereas GMD 5 changed theirs to sustainable yield. Both districts are monitoring the effect of the enhancements.

Policymakers, water regulators, and water users have come to realize that ground water and surface water are closely interrelated systems. Groundwater feeds springs and streams, and surface water recharges aquifers. The interactions of ground and surface water affect quality as well as quantity. Groundwater can be contaminated by polluted surface water, and surface water can be degraded by discharge of saline or other low-quality groundwater. Streams and their alluvial aquifers are so closely linked in terms of water supply and water quality that neither can be properly understood or managed by itself, and therefore the combined stream-aquifer system must be considered.

The Division of Water Resources, Kansas Department of Agriculture, is attempting to develop a comprehensive management program in areas of Kansas with significant water problems. Working within the framework of existing state laws, this program intends to develop proactive, long-term solutions, which take into account surface-water depletions, groundwater declines, and deterioration of the water quality. This holistic approach (referred to as the watershed-ecosystem approach) recognizes that streams are the products of their drainage basins or **watersheds** and their associated aquifers, not simply water flowing through a channel, and that to understand such stream-aquifer interactions, it is necessary to understand the surface- and ground-water watersheds associated with the stream. Close consultation and cooperation with the local GMDs, irrigators' associations, and other interested parties are integral parts of this program.

Management of the groundwater and surface water of a watershed or drainage basin using the ecosystem approach is beginning to take hold in Kansas. The evolution of Kansas water-management policy away from the traditional notion of safe yield is an important first step toward the sustainable development of water resources in Kansas.

Further Reading

More information about the issues surrounding safe yield and sustainable development of water resources is available in a publication by the Kansas Geological Survey titled "Perspectives on Sustainable Development of Water Resources in Kansas" (Sophocleous, 1998).

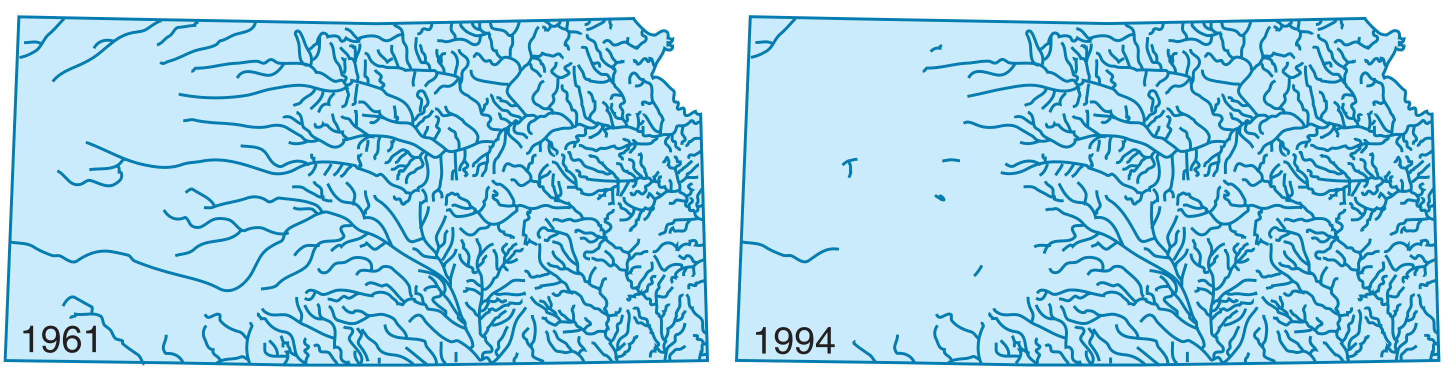


Figure 5. Major perennial streams in Kansas in 1961 and 1994 (adapted from Angelo, 1994).

Written primarily for water users, policymakers, and water regulators, this semitechnical volume provides background information about hydrologic systems and water-resource management in Kansas and discusses the concepts of safe yield, stream-aquifer systems, and sustainability. Other chapters address safe yield and confined aquifers, water chemistry, surface waters, and impacts of agriculture, climate change, and the complexity of hydrologic systems. The purpose of this publication is to educate Kansans about water-resources sustainability issues, to promote a better understanding of water resources in Kansas, and to encourage proactive and holistic management of these resources.

Glossary

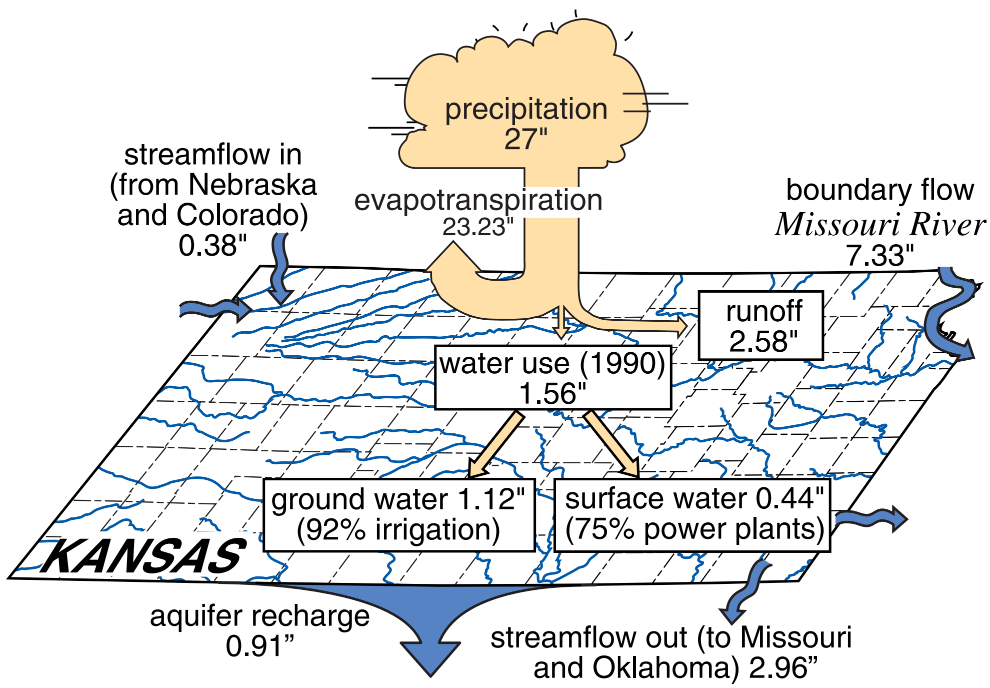
Conjunctive management: An approach to the management of ground and surface waters that maximizes the net benefits from both resources over time.

Discharge: The movement of groundwater to the land surface, surface water, or atmosphere.

Evapotranspiration: A collective term for water that moves into the atmosphere from evaporation from land or water and from transpiration from plants.

High Plains aquifer: In Kansas, three hydraulically connected but distinct aquifers: the Ogallala, Great Bend Prairie, and Equus Beds aquifers. In general, the Ogallala Formation is made up of unconsolidated sand, gravel, silt, and clay deposited by streams that flowed east from the Rocky Mountains during the Pliocene Epoch. The Great Bend

Water Budget of Kansas



Like a household budget, the state's water budget is based on credits and expenditures. Most water enters the state as precipitation and leaves the state in streams and through evaporation and transpiration. Studying the state's water budget allows us to see where water expenditures are going and determine whether additional water is available for use or whether its use should be restricted.

It is easier to visualize the state's water budget if we think in terms of inches of water, averaging the amounts to cover the entire state. More than 98% of the water available for use enters Kansas as precipitation. The statewide average annual precipitation is about 27 inches (69 cm). Evapotranspiration returns about 23.23 inches (60 cm) back to the atmosphere. Aquifer recharge uses approximately 0.91 inches (2.3 cm). Runoff to rivers that originate within the state represents 2.58 inches (6.6 cm), and when combined with streamflow into the state from Nebraska and Colorado (equivalent to 0.38 inches, 1 cm), surface-water outflows to Missouri and Oklahoma account for about 2.96 inches (7.5 cm). Approximately 1.56 inches (4 cm) of water are used by Kansans annually. Groundwater use represents 1.12 inches (2.8 cm) of that total (92% is used for irrigation), and surface-water use equals 0.44 inches (1.1 cm) (75% is used by power plants). The equivalent of 7.33 inches (18.6 cm) flows by the northeast corner of the state in the Missouri River, but little of this water is used in Kansas (data from Sophocleous, 1998).

Although the precipitation, evapotranspiration, and other factors in the water budget vary widely from year to year, the averages over several decades remain nearly constant. The main water supply for Kansas — precipitation that falls on the state — has changed little in the last 150 years. What has changed is how water is used.

Prairie and Equus Beds aquifers are also composed of silt, clay, sand, and gravel deposits left by streams flowing through central Kansas, but these deposits are generally younger (Pleistocene and Holocene) than the Ogallala. In some areas, these aquifers are in contact with each other and thus form one continuous aquifer.

Hydrologic cycle: The constant circulation of water from Earth's surface, through the atmosphere, to Earth's surface, and back to the atmosphere through transpiration and evaporation.

Hydrology: The study of the characteristics and occurrence of water and the hydrologic cycle. Hydrology concerns the science of surface and ground waters, whereas hydrogeology principally focuses on groundwater.

Recharge: The replenishment of water to an aquifer.

Saturated thickness: The vertical thickness of an aquifer that is full of water. The upper surface is the water table.

Watershed: The area of land drained by a single stream or river.

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KANSAS GEOLOGICAL SURVEY
The University of Kansas

The Kansas Geological Survey (KGS) is a research and service division of the University of Kansas that investigates and provides information about the state's natural resources. KGS scientists pursue research related to surface and subsurface geology, energy resources, groundwater, and environmental hazards. They develop innovative tools and techniques, monitor earthquakes and groundwater levels, investigate water-quality concerns, and map the state's surface geology.

The KGS has no regulatory authority and does not take positions on natural resource issues. The main headquarters of the KGS is in Lawrence in the West District of the University of Kansas, and the Kansas Geologic Sample Repository of the KGS is in Wichita.

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