Kentucky Geological Survey
UNIVERSITY OF KENTUCKY

Kentucky Is Karst Country!

What You Should Know About Sinkholes and Springs

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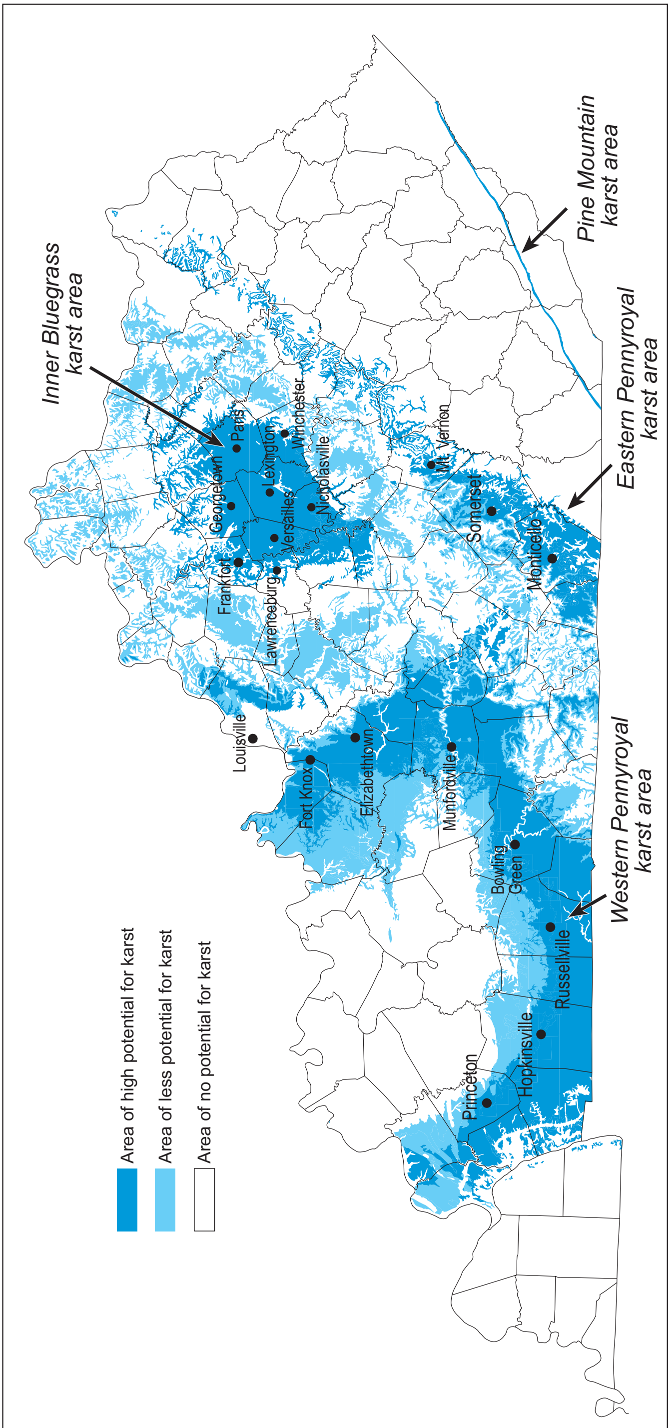
Introduction

Kentucky is one of the most famous *karst* areas in the world. What is karst? It's a landscape with *sinkholes, sinking streams,* caves, and *springs.* Much of Kentucky's beautiful scenery, particularly in the Inner Bluegrass Region, is the result of the development of karst landscape. A large amount of Kentucky's prime farmland (including its famous horse farms) is underlain by karst, and springs and wells in karst areas supply water to thousands of homes. Many of Kentucky's major cities, including Frankfort, Louisville, Lexington, Lawrenceburg, Georgetown, Winchester, Paris, Versailles, Nicholasville, Fort Knox, Bowling Green, Elizabethtown, Munfordville, Russellville, Hopkinsville, Princeton, Somerset, Monticello, and Mount Vernon, are in karst areas as well. The Daniel Boone National Forest, with its important recreational and timber resources, is largely underlain by karst. Kentucky's caves provide recreational opportunities and contain unique ecosystems. Mammoth Cave is the longest surveyed cave in the world, with over 350 miles of passages. Two other caves in the state are over 30 miles long, and nine Kentucky caves are among the 50 longest caves in the United States.

Although maps that show in detail where karst occurs in Kentucky have never been made, the areas underlain by rocks on which karst can develop have been geologically mapped, so the percentage of karst landscape in the state can be estimated. About 55 percent of Kentucky is underlain by rocks that could develop karst, given enough time. About 38 percent of the state has at least some karst development (enough to be recognized on topographic maps), and 25 percent of the state is known to have well-developed karst features.



Areas in Kentucky underlain by limestone and other carbonate rocks. The darker areas are more subject to the development of sinkholes, caves, and springs.

The karst of Kentucky occurs in five principal regions, but also in many scattered locations. The largest area is the Western Pennyroyal, which sweeps in an arc from the Ohio River, near Fort Knox, south to the state's southern border, then west past Hopkinsville and north again back to the Ohio River. Bowling Green and several other major cities are in this region. Many of the state's longest caves, and landscapes most densely pocketed with sinkholes, are in this region. The next largest expanse of karst is the Inner Bluegrass, surrounding Lexington in central Kentucky. The Eastern Pennyroyal lies along the western edge of the Cumberland Plateau in eastern Kentucky, extending from the state's northern border on the Ohio River south-southwest to the state's southern border. Somerset is in the Eastern Pennyroyal Region. The Carter Caves Region, east-northeast of Winchester, is the fourth region, but is sometimes considered part of the Eastern Pennyroyal. Although no large communities are located in the Carter Caves Region, Carter Caves State Park, an important tourist attraction, is here. The last major karst area is along the crest of Pine Mountain in southeastern Kentucky, where geological forces have thrust the limestone from deep beneath the coal field to the surface. No communities are in this karst area, but it is a significant recreational and ecological resource.

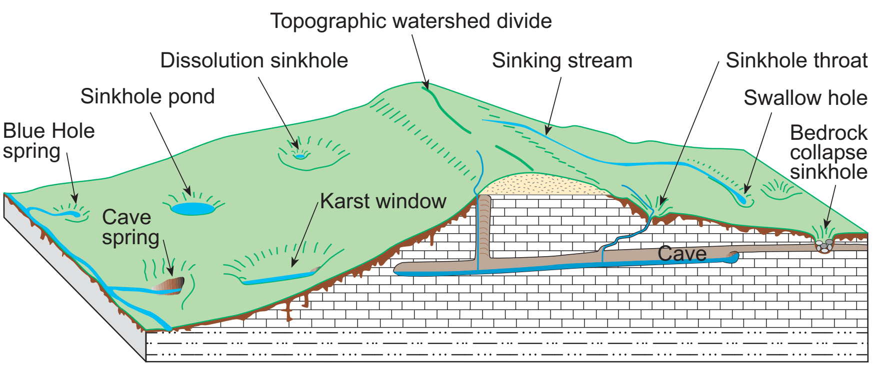
Karst affects the lives of many Kentuckians every day. Most people don't realize they're affected because the costs of karst are hidden in the form of higher taxes and increased cost of living (to pay for karst-related damages). All too often though, the consequences of living in a karst region are obvious. Of vital concern is protection of groundwater. Many communities in Kentucky were established near karst springs to take advantage of a reliable water supply. Because of pollution, most of these town springs have long since been abandoned as water supplies. Factories and homes built over filled sinkholes may be damaged as fill is transported out of the sinkhole and the *cover collapses.* And structures built in sinkholes are often vulnerable to flood damage.

This publication explains the features of karst, provides an introduction to how water flows underground in karst, describes some of the dangers to buildings in karst, and recommends ways to minimize financial losses from karst hazards. A glossary of karst terms is located at the end of this publication. Italicized words are defined in the glossary.

Features of a Karst Landscape

The term "karst" is derived from a Slavic word that means "barren, stony ground." It's also the name of a region in Slovenia near the border with Italy that is well known for its sinkholes and springs. The word has been adopted by geologists worldwide as the term for all such terrain. A karst landscape most commonly develops on limestone but can develop on several other types of rocks, such as dolomite, gypsum, and salt. The karst in Kentucky is mostly on limestone and formed over hundreds of thousands of years in a continuing process: as water moves underground, from hilltops toward a stream through tiny fractures in the limestone bedrock, the rock is slowly dissolved away by weak acids found naturally in rain and the water in soil.

An *aquifer* is any body of bedrock, or other earth material, from which useable quantities of groundwater can be produced by a well or spring. *Springs* are sites where groundwater emerges from an aquifer to become surface water. Springs occur along creeks and rivers where the *water table*, or the surface at the top of the groundwater, meets the land surface. They also occur where impermeable rocks, such as shale, underlie or have been faulted against permeable rock. The impermeable rock blocks the flow of the groundwater, forcing it to the surface. Karst springs occur where the groundwater flow has concentrated to dissolve rock and form a conduit or cave in soluble rock. The *groundwater basin* of a karst spring collects drainage from all the sinkholes and sinking streams in its drainage area. The water flowing from each



Some important karst features. Other types of karst features are not illustrated on this diagram.

sinkhole joins together underground to form ever-increasing flow in successively larger passages, which discharge at a spring. Karst springs, or "cave springs," can have large openings and discharge very large volumes of water. The soil cover, narrow fractures, small conduits, and larger cave passages collectively form a karst aquifer.

A *sinkhole* is any depression in the surface of the ground from which rainfall is drained underground. Karst sinkholes form when a fracture in the limestone bedrock becomes enlarged. Sinkholes form in two ways. In the first way, the roof of a cave becomes too thin to support the weight of the bedrock and soil above it. The cave roof then collapses, forming a collapse sinkhole. Bedrock collapse is rare and the least likely way a sinkhole can form, although it is commonly (and incorrectly) assumed to be the way all sinkholes form. The second way sinkholes form is much more common and much less dramatic. As the bedrock under a sinkhole is dissolved and carried away underground, the soil gently slumps or erodes into the sinkhole. Once the underlying conduits become large enough, insoluble soil and rock particles are carried away too. Dissolution sinkholes form gradually over long periods of time, with occasional episodes of soil or cover collapse.

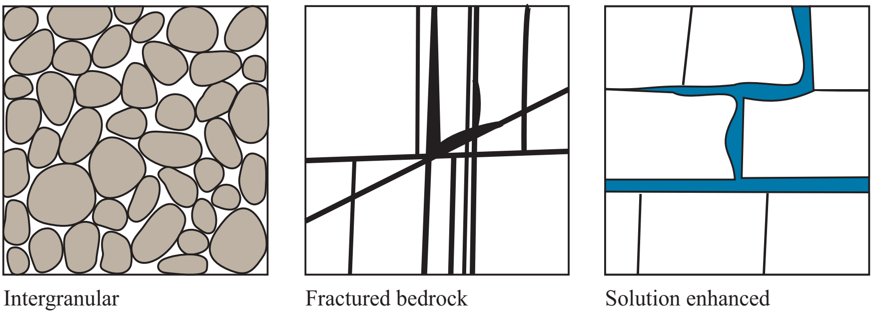
All of the dissolved limestone and soil particles eroded from the bedrock to form a sinkhole pass through the sinkhole's "throat" or outlet. The throat of a sinkhole is sometimes visible, but is commonly covered by soil and broken rock, and can be partly or completely filled with rubble. This opening can vary from a few inches in diameter to many feet. Normally, water flows out of the sinkhole throat to a conduit, which drains to a spring. When sinkhole throats are totally blocked and little water can flow out, a sinkhole pond may form; this is a common sight in the Pennyroyal regions. Sinkhole ponds are temporary features and last only as long as their throats are tightly plugged.

Swallow holes are points along streams and in sinkholes where surface flow is lost to underground conduits. Swallow holes range in diameter from a few inches to tens of feet, and some are also cave entrances. Swallow holes are often large enough to allow large objects such as tree limbs and stones to be transported underground. This also means that waste dumped into *sinking* *streams* (surface streams that disappear underground) can easily reach underground streams. It is not uncommon for discarded automobile tires and home appliances to be found deep within caves that have flowing streams and large swallow-hole entrances. Likewise, sewage, paint, motor oil, pesticides, and other pollutants are not filtered from water that enters a karst aquifer.

Karst windows are a special type of sinkhole that give us a view, or window, into the karst aquifer. A karst window has a spring on one end, a surface-flowing reach of stream across its bottom, and a swallow hole at the other end. The stream represents the top of the water table, demonstrating the relationship between surface and groundwater. Karst windows develop by both dissolution and collapse of the bedrock. Many karst windows originated as bedrock-collapse sinkholes.

Karst Hydrogeology Is Different

Many important aquifers are composed of granular materials such as loose sand and gravel or weakly cemented bedrock. Such aquifers occur in Kentucky, particularly along the Ohio River and in the Jackson Purchase Region. Groundwater flows in these aquifers between the grains of sand or gravel, or through narrow fractures in solid bedrock, and usually very slowly. How quickly water flows in a granular or fracture-flow aquifer also depends upon how interconnected the pores or fractures are. Such small openings act as a filter, physically or chemically removing most



Common types of aquifer porosity found in Kentucky: unconsolidated intergranular, fractured bedrock, and solution-enhanced limestone. Solution-enhanced porosity begins as fractured bedrock in Kentucky.

bacteria, viruses, and polluting chemicals within a few tens to hundreds of feet. In shallow granular aquifers the water table mimics the land surface, and the direction of groundwater flow can often be predicted by the slope of the land. The pattern of water movement through the fracture system of a fractured bedrock aquifer or the pore spaces of a granular aquifer is approximately evenly distributed, compared to a karst aquifer.

In contrast to the drainage patterns of granular aquifers, the drainage patterns of karst aquifers resemble the branching pattern formed by streams flowing above ground across insoluble rocks. The disrupted nature of the landscape in a karst terrain prevents us from seeing the now-abandoned, relic channels that carried water on the surface before the limestone dissolved. The sinkholes and sinking streams that drain to a large karst spring can be many miles away from the spring. Water enters karst aquifers either directly, through swallow holes and sinkholes, or indirectly, through the pores in the soil overlying the limestone bedrock. The conduit of a karst aquifer is like a roofed creek bed, and responds to rainfall in the same way that a storm sewer does. Although the soil overlying a karst aquifer provides some filtration of contaminants in the water, there is almost no filtration at sinking streams and swallow holes. For example, the amount of fecal bacteria in water collected from springs draining urban and agricultural areas can reach counts of thousands of bacteria per 100 milliliters of water, making the water unsafe for people to drink.

A groundwater basin boundary may have little relationship to surface drainage boundaries (see the block diagram, page 4). Unlike a stream flowing on the surface, a cave stream eroding upstream can extend beneath a ridge to divert flow from an adjacent groundwater basin. As a result, the actual drainage basin (catchment area) of a karst spring may be much larger, or smaller, than is apparent from topographic maps. Sinkholes and valleys shown on maps may seem to be in one watershed, yet drain to a far-away spring. Also, during high flow conditions, water from the source (headwaters) area may split and flow into two or more basins simultaneously.

Branched flow paths called conduit *distributaries* can discharge water to multiple springs and are quite common in karst systems. As the water flowing in the conduits nears a permanent surface-flowing stream into which it discharges, the water seeks the lowest available exit and is constantly creating new spring openings downstream. Frequently, flow from these springs rises from a completely water-filled conduit. The depth of the clear water in the spring pool gives the water a deep blue color; this is the origin of the term "blue hole." During higher flows the intermittently abandoned openings or "cave springs" also discharge water. Several openings may develop almost simultaneously, leading to many springs along a stream channel that drain a single groundwater basin.

Dye-tracing experiments are used to determine the routes groundwater takes in karst aquifers and the location, size, and shape of watersheds draining to specific springs. Although the concept of pouring dye into a sinking stream or swallow hole and waiting for the dye to reappear at a spring is simple, these experiments require considerable skill to complete with consistent success. It would be inefficient to stand and watch for the dye to emerge from a spring, because it could take many days to resurface, it could flow from the spring at night, the dye could be too diluted to see, or it could discharge from a different spring than expected. To monitor many springs simultaneously, and around the clock, packets of material that adsorb the dye are attached to anchors and are placed in the water at the spring mouth. A commonly used material for dye detectors, also known as *bugs*, is activated carbon charcoal. Bugs are placed in every spring the water could conceivably flow to, the dye is poured into the swallow hole, and the bugs are then changed once a week until the dye is detected. The bugs are taken to a laboratory where they can be carefully

Groundwater tracing dye (fluorescein) being poured into a swallow hole. Photograph by J.C. Currens.

examined for very low concentrations of dye. A wide variety of tracers are now used, but the most common tracers are dyes that fluoresce (glow) when exposed to ultraviolet (black) light. The U.S. Environmental Protection Agency has approved the dyes commonly used for groundwater tracing.

Water Supplies from Karst Aquifers

Obtaining a water supply from karst aquifers can be both rewarding and frustrating. Wells and springs each have advantages and disadvantages as water supplies. Springs are easily found, may have significant flow, and their quality can be determined before expending a lot of money for plumbing. But springs are commonly not near the site where the water is to be used. Also, they are difficult to protect from near-surface contamination. Wells can be located near the point of use and can be sealed from infiltrating water from the land surface immediately around them. But completing a successful well in a karst aquifer can literally be a hit or miss proposition. Most of the water in a karst aquifer is flowing in widely separated conduits, or fractures, in the rock (*bedding planes* and *joints*). Generally, conduits produce more water than fractures. Wells drilled into karst aquifers must intersect a conduit or fracture to produce water. Water flowing in a karst conduit is a relatively small target for a well to intercept, compared to water flowing in a granular aquifer.

Before choosing a site for a well, consult with a hydrogeologist (a geologist specializing in groundwater) or a well driller. They should improve your chances of obtaining an adequate water supply. New wells, and wells being reconditioned, must meet modern well-construction standards[1]. It is best to *case* (line with pipe) the entire length of the drill hole and install *screens* (slotted pipe) across the water-producing zones. It is vital to have a good seal between the bedrock and the casing. The space between the drill hole and the casing must be sealed with clay or cuttings, in order to prevent surface runoff or contaminated shallow groundwater from entering the well. A device called a "packer" is installed above conduits and caves to prevent the sealing material from falling into the conduit. Wells producing

[1] Kentucky Division of Water, 1991, Kentucky water well construction practices and standards: Natural Resources and Environmental Protection Cabinet, 25 p.

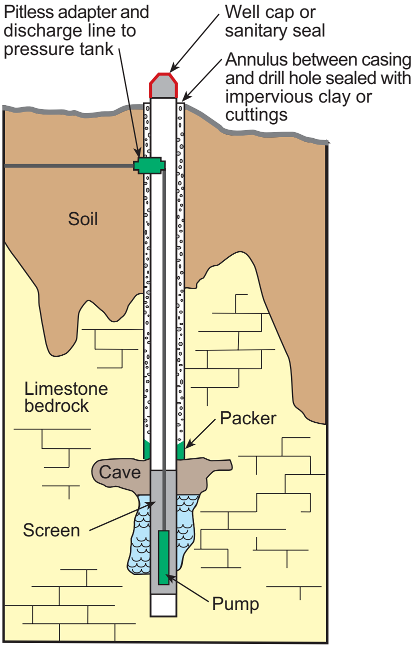


Diagram of a properly constructed domestic water well in a karst aquifer.

from conduits can benefit from a screen being installed across the conduit to limit the size of sediment deposited in the well. The top of the casing must extend above ground level and be covered with a sanitary seal or watertight cap to keep dirt, bird droppings, or small animals from falling into the well. Plumbing connections are the safest when a *pitless adapter* (see Glossary) is used to route the water discharge line out of the well casing below ground level and below the depth at which the soil freezes.

You can take several steps to decrease the possibility of contamination of your well. Most pollution seeps through the soil or along a leaking casing directly into the well. This can be avoided by grading the ground around the well to direct runoff away from the casing. When choosing a site for a new well, make sure it is at least 150 feet away from potential sources of pollution, such as fuel storage tanks, septic systems, feedlots, or chemical storage areas[1]. When mixing farm chemicals, be sure to park the chemical sprayer and other equipment as far from the well as possible. A spill containment pad is highly recommended for the area where pesticides are mixed and tanks are filled. All wells in karst aquifers should be cleaned periodically to remove clay and silt.

Because the location of a spring is already known, there is no risk of a *dry hole*, as when drilling a well. It would be wise to know the minimum flow, however, during droughts. Discharge records for springs are sometimes available, and may provide an estimate of the average flow and the minimum flow. Dye traces may have

[1] Kentucky Division of Water, 1991, Kentucky water well construction practices and standards: Natural Resources and Environmental Protection Cabinet, 25 p.

been conducted that identify some of the sources of the spring water. For more information about discharge records and past and future dye tracing, contact the Kentucky Geological Survey or the Kentucky Division of Water.

As for a well, steps should be taken to prevent runoff from contaminating a spring. A properly constructed spring house will shelter tanks and pumps from cold weather, and keep animals out, while allowing excess water to flow away. The spring house should be solidly built to withstand high discharge following storms. Water from a spring may be muddy during heavy rains, because groundwater flow velocities in caves can be several feet per second, fast enough to allow silt and clay to be carried through the conduits. Including a sediment-settling tank in the spring house will prolong pump life and make the water taste better.

Water from a well or spring should be tested for bacteria, nitrate, total volatile organic compounds, and metals whenever a significant change in odor, color, or taste is noticed. Bacteria tests should be made when a well is sealed, and again a week or two later after all of the chlorine used to sanitize the well has dissipated. Bacteria tests should also be repeated at least once a year and every time the water becomes muddy. If the sample is collected while the water is muddy, you'll have the best chance of determining if there is a contamination problem. Springs should be sampled more frequently than wells, and tested for bacteria after major storms.

All users of karst springs and wells drilled into karst aquifers should treat the water to kill microbes, remove sediment, and soften the water. Treatment for bacteria, viruses, and protozoa is very important because karst aquifers are highly vulnerable to pollution from a variety of waste sources. Sanitizing the water can only be safely omitted if the area draining to the spring or well is known and is protected from pollution and the spring house or well is properly constructed and secure. Even so, dead animals or feces can temporarily contaminate water from an otherwise pristine watershed. The systems most commonly used to sanitize household water supplies use chlorination. Ozone, ultraviolet light, and boiling are also used to sanitize water.

Sediment is the next most common quality problem in water supplies from karst aquifers. Settling tanks or filters may be required to remove sand, silt, clay, and organic material, particularly from springs. Filters alone should never be relied upon to remove microorganisms. "Hard water" is also a common problem caused by dissolved calcite (from limestone) and other minerals in the water. Hard water leaves mineral deposits in plumbing and interferes with the cleaning action of soaps and detergents. Hard water can be conditioned with a water softener: a tank containing an ion-exchange compound that replaces calcium, magnesium, and some dissolved iron with sodium. Iron and manganese are also occasional problems in karst aquifers. For help with installing a treatment and conditioning system, and maintaining it, contact your local extension agent, water treatment business, or water-well driller.

The Importance of Protecting Karst Resources

To many people, sinkholes are bottomless pits into which waste will disappear forever. To others they are a nuisance and nonproductive land that must be filled up and covered. More-informed people know not to put household garbage, paint, junk cars, and chemicals into a sinkhole, but may consider natural debris acceptable. But any kind of waste, including grass clippings and tree limbs, can have an adverse effect. Organic matter, such as lawn waste, animal waste, and sewage, lower the oxygen content of the water, killing cave-dwelling aquatic animals and promoting the transport of other contaminants such as metals. If a sinkhole is filled up with trash and covered with soil, any structure built over the fill would be in danger of subsid-

View of a sinkhole dump from underground. Garbage and trash dumped into a sinkhole don't go away; they just disappear from view above ground. Photograph by J.C. Currens.

ence damage as the waste decays and is transported into the underground system. Wells drilled into karst aquifers frequently become polluted because of waste dumped into sinkholes. Now illegal, the practice of discharging septic waste into sinkholes is particularly dangerous because organisms that cause disease can be transported long distances and pollute a well or spring used by other people. A hepatitis outbreak in southwestern Kentucky in 1967 sickened 74 people who visited a restaurant and consumed soft drinks made with well water from a karst aquifer[1]. The well had been polluted by the septic system of the restaurant. In 1992 organic waste from a mulching operation dumped into a sinkhole was shown to be responsible for a fish kill downstream from the spring to which it flowed. In 1997 the Kentucky Division of Water received a complaint that the water from a well in the Inner Bluegrass was turning a peculiar blue color: dye tracing revealed that the toilets in a nearby building were being discharged into a *dry well* (a hole drilled into a sinkhole, or crevice in the limestone), which then drained to this water well[2]. Although this "plumbing connection" had been in use for many years, the coloring agent, which was toilet bowl cleaner, had only recently begun to be used! Other similar stories are common from across the karst areas of Kentucky.

Sinkhole filled with trash and lawn debris. Photo by J.C. Currens.

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[1] Nitzkin, J.L., and Henry, M.H., 1971, Infectious hepatitis in Logan County, Kentucky; a probable common source outbreak: Journal of the Kentucky Medical Association, v. 69, p. 349–353.

[2] Leo, D.A., 1997, Kentucky Division of Water, personal communication.

Royal Spring in Scott County is the largest karst spring in the Inner Bluegrass and drains an area of over 25 square miles. The spring is the water supply for the city of Georgetown. Photograph by J.C. Currens.

Even if every Kentucky citizen living in a karst region were provided with public water service, protecting groundwater would still be necessary. Water treatment plants in karst areas must get their supply from either a stream or lake fed by karst springs, or directly from a karst spring. The flow of some streams used as sources of public water supplies is maintained almost entirely by karst springs. The city of Georgetown uses a large karst spring, Royal Spring, as its supply. The city lost this water supply during the winter of 1988–89 when gasoline was detected in the spring. The gasoline leaked into the ground from a storage tank somewhere in the watershed of the spring. Georgetown water customers had to be issued bottled water for several weeks until a new water-treatment system could be installed.

The general health of the environment also depends on clean water, not just for the cave animals, but for the fish, birds, and mammals that use streams and lakes fed by karst springs. The species found in caves and karst aquifers also provide unique insights into the functioning of ecosystems. There may be strictly practical benefits to society from karst-related resources as well. For example, bacteria found naturally only in some caves are being investigated as sources of cancer-fighting drugs[1].

[1] Cole, J., 1999, Treasures in a pristine cave: Geotimes, v. 44, no. 10, p. 6–7.

How to Protect Karst Groundwater

The best way to protect a karst aquifer from pollution is to control the human activities in the groundwater basin of the aquifer. This is fairly easy when the groundwater basin of the spring is small and is included within the spring user's property. It is difficult when the drainage basin is large and many landowners are involved. Talk to your neighbors about the impact of waste disposal in sinkholes and the impact land use has on groundwater in karst settings. Let them know you think pure drinking water is important and that disposal of waste in a sinkhole may ruin a neighbor's well or spring, or their own groundwater supply, or a city's water supply. If you are a rural resident, inquire about trash pickup and programs to refurbish domestic sewage disposal systems. If you are a farmer, get involved in U.S. Department of Agriculture cost-share programs and other government-sponsored programs to promote soil conservation and groundwater protection. Many best management practices (BMP's) are now available for protecting sinkholes from polluted runoff. BMP's have also been devised for construction sites, timber harvesting, and urban areas.

Hundreds of pesticide containers, some of them still full, were illegally dumped into this sinkhole. Photograph by J.C. Currens.

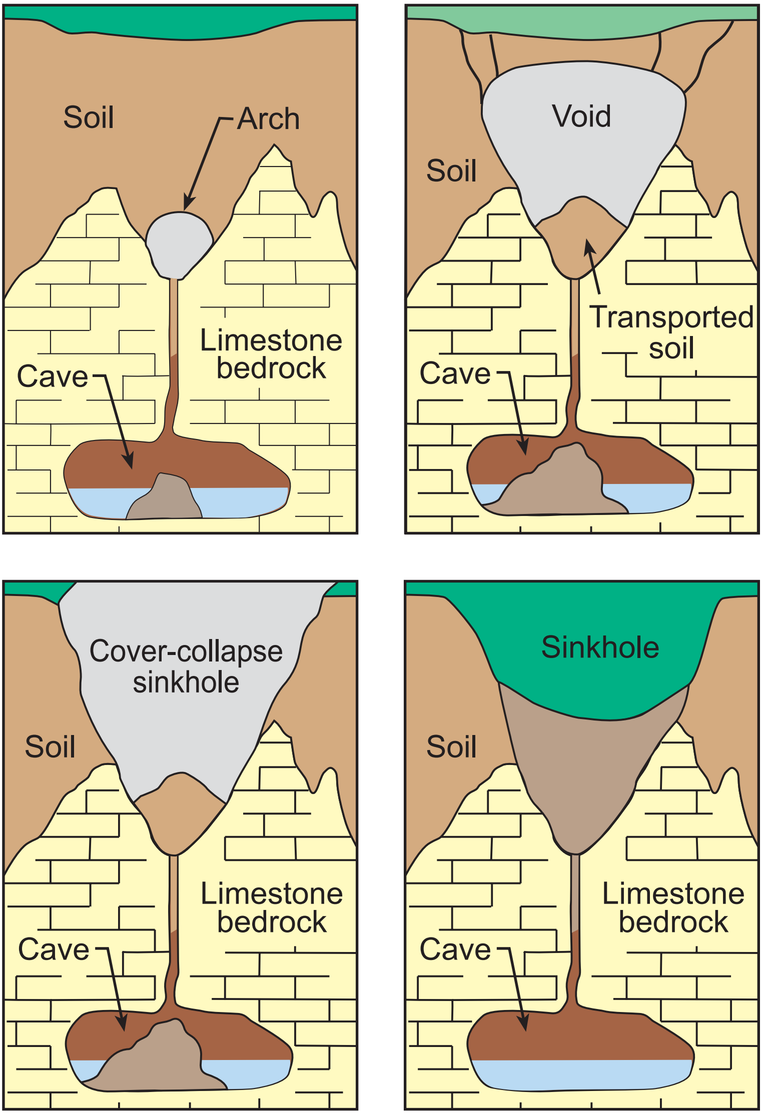
Many older homes in both urban and suburban areas have sewage discharge pipes that empty directly into sinkholes, resulting in health hazards and environmental damage. The most effective practice in urban areas is to be certain domestic sewage is disposed of in a properly operating septic system or into a sanitary sewer. Another important practice is to retain parking-lot and street runoff until solids settle and grease and oil can be filtered. Apply pesticides and fertilizer cautiously on turfgrass in suburban areas, to limit their runoff into storm sewers, which commonly flow to sinkholes and hence to the groundwater. In rural areas manure, fertilizer, pesticides, and eroded soil are the most common pollutants. Grass buffer strips around sinkholes may effectively trap soil, bacteria, and agricultural chemicals in runoff from farm fields. Livestock should be kept out of sinking streams and karst windows. Extra precautions should be taken to make sure holding lagoons for animal manure do not leak. Use agricultural chemicals judiciously. Use conservation tillage practices and cover crops. Detailed information on BMP's can be obtained from your local University of Kentucky agriculture extension agent or Natural Resources Conservation Service office.

Geologic Hazards in Karst

A geologic hazard is a naturally occurring geologic condition that may result in economic loss or may be a threat to the safety of people. There are two common karst-related geologic hazards: cover-collapse sinkholes and sinkhole flooding.

Cover-collapse sinkholes are sinkholes that occur in the soil or other loose material overlying bedrock. When the overlying soil is repeatedly wetted and dried, small amounts of soil are dislodged and carried away by the cave conduit draining the sinkhole. The collapse occurs only in the overlying soil cover, not in the limestone bedrock.

Cover-collapse sinkholes can vary in size from 1 or 2 feet deep and wide, to tens of feet deep and wide. The thickness and cohesiveness of the soil cover determine the size of a cover-collapse sinkhole. In Kentucky the thickness of soil, sand or clay, and bedrock fragments over limestone bedrock is typically less than 25 feet, so cover-collapse sinkholes more than 20 feet in diameter are uncommon. Unlike in Florida, where the cover over the limestone is very thick, in Kentucky cover-collapse sinkholes are unlikely to swallow entire houses or businesses. But cover-collapse sinkholes do severely damage buildings, drain farm ponds, damage roads, and wreck farming equipment in Kentucky.



The development of a cover-collapse sinkhole.

The most effective way to avoid cover-collapse sinkhole damage is to avoid buying or building a structure on a sinkhole that has been filled. Ask the seller if any sinkholes have been filled, and if so, where, how, and by whom. Look for previous damage to foundations and check door frames and windows for squareness. Check the surrounding lot for shallow depressions and arch-shaped cracks in the soil. Should a cover-collapse sink-

A cover-collapse sinkhole caused more than $40,000 in damage to this home near Louisville. Photograph by J.C. Currens.

hole develop under a building, the foundation of the building should be shored up as quickly as possible to avoid major foundation damage. The sinkhole can then be filled using a *graded-filter* technique[1], the foundation can be reinforced, and the ground can be graded at a less urgent pace. Always consult a professional geologist with experience in identifying karst subsidence and an engineer experienced in sinkhole remediation when dealing with a building threatened by a cover-collapse sinkhole.

Sinkhole flooding occurs when there is more precipitation than the conduits and caves can handle. Unlike a normal stream channel, the conduit has a fixed cross-sectional area and cannot expand as flow increases. There are two types of sinkhole flooding. In the first type, the throat of the sinkhole may be constricted and thus unable to carry away water as fast as it flows in. Frequently, the throat of the sinkhole is clogged by trash and junk,

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[1] Reitz, H.M., and Eskridge, D.S., 1977, Construction methods which recognize the mechanics of sinkhole development, *in* Dilamarter, R.R., and Csallany, S.C., eds., Hydrologic problems in karst regions: Western Kentucky University, Department of Geology and Geography, p. 432–438.

soil eroded from fields and construction sites, and sometimes by natural rock fall within the conduit. Occasionally the conduit itself is too small in diameter because it has recently (in a geologic sense) diverted part of an adjacent drainage basin. The second type of sinkhole flooding is caused by discharge capacity being limited farther downstream. This can be caused by caves blocked with trash or rock fall, limited conduit size, or backflooding from other sinkholes. Some sinkholes, which drain normally during modest storms, may actually become springs and discharge water from their throats during intense storms. This situation is analogous to when the waste pipe draining a double kitchen sink is clogged at the trap: when the water is let out of the full side of the sink it backs up into the empty side of the sink.

Once a structure has been built in a sinkhole or *karst valley* (see Glossary) prone to flooding, little can be done to prevent future flood damage, except move the structure. Because many sinkholes are too large to view all at once, a builder may not recognize that the building site is in a closed depression. If you're buying real estate in a karst area, you should pay close attention to the *topography*. Consult topographic maps, inspect the area sur-

This house was built in a large karst valley that has flooded repeatedly since 1989. The karst valley cannot be recognized as a closed basin without using a topographic map or having personal knowledge of the area. Photograph by J.C. Currens.

rounding the property to determine its relative elevation, look for previous signs of water damage to buildings, and ask neighbors if the property has ever been flooded. Once a building has been erected, it's usually too late to make any cost-effective corrections. Rarely, the topography and geology will allow the construction of an overland ditch to prevent flooding. But these types of engineering solutions are only partly successful and typically cost more than the value of the property to be protected.

Some Easily Accessible Places to See Examples of Karst Features

Some good places to look at Kentucky karst are on public land and some are on private property, which has been made accessible to visitors.

General Karst Landscape

Many scenic views and karst features can be seen in Mammoth Cave National Park and Carter Caves State Park. On private property, but accessible to the public, is the Park Mammoth Resort Lodge overlooking the *sinkhole plain.* Areas of Meade and Breckinridge Counties in the vicinity of Irvington and Brandenburg have extensive karst topography that can be viewed from roadways. The Inner Bluegrass karst can be viewed while driving between Frankfort and Versailles and between Versailles and Lexington. A pleasant automobile tour can be taken from McConnell Springs Park in Lexington, north via New Circle Road to Leestown Pike, west on Leestown Pike (U.S. 421) to the junction with U.S. 60 in Frankfort, then south to the bypass around Versailles, and west returning to Lexington on U.S. 60.

Springs

Large springs can be found in any karst area by looking along major streams. Echo River Spring, Styx River Spring, and many other springs can be found along the Green River in Mammoth Cave National Park. Big Spring in Princeton (Caldwell County) is in a small city park. Town Spring in Scottsville (Allen County) is also accessible to the public. Saunders Springs Nature Preserve is located on Ky. 447 just west of Radcliff on the Fort

Knox military reservation (see www.ltadd.org/radcliff/saunders.html for more information). Many large springs occur west of Fort Knox in Meade and Breckinridge Counties. There are caves and springs at Otter Creek Park in Meade County. Buttermilk Falls in Brandenburg was used as a water source by hauling companies, but its use as a water supply was discontinued when someone contracted hepatitis from the water. The Abraham Lincoln Birthplace National Historic Site in Hardin County includes a small karst spring named Sinking Spring. At the Mill Spring Civil War battle site in Wayne County, the U.S. Army Corps of Engineers has reconstructed an operating grist mill (complete with 40-foot-high overshot wheel) that is powered by flow from a large karst spring. It's located off of Ky. 90, east of Monticello. Also in the area is Trinity Spring at Somerset, located in a small park. In central Kentucky, Royal Spring, the water supply for the city of Georgetown in Scott County, is also a city park and is open to the public.

Caves

Although there are numerous undeveloped caves in Kentucky, the best way for the first-time visitor to see a cave is to visit one that is commercially shown. In addition to the commercial caves at Carter Caves State Park (606.286.4411; www.state.ky.us/agencies/parks/ekyframes/cartcave body.htm) and Mammoth Cave (270.758.2328; www.nps.gov/maca), there are several privately owned caves in Kentucky. The American Cave Museum & Hidden River Cave in Horse Cave (270.786.1466; www.cavern.org) is an excellent facility for learning about the consequences of groundwater pollution, and how the problems it causes can sometimes be corrected. Kentucky Caverns at Kentucky Down Under is also in Horse Cave (800.762.2869; www.kycaverns.com). Crystal Onyx Cave is in Cave City (270.773.2359) and Diamond Caverns is in Park City (270.749.2891; www.diamondcaverns.com). Lost River Cave is in Bowling Green, just a few miles south of the Mammoth Cave area (phone 270.393.0077 for operating hours). Additional information about caves nationwide and the hobby of cave exploring can be found through the National Speleological Society (2813 Cave Ave., Huntsville, AL 35810-4413; 256.852.1300; www.caves.org).

Sinkholes

Driving the public highways in either the Inner Bluegrass or the Eastern or Western Pennyroyal Regions is a good way to see sinkholes. Numerous sinkholes can be seen from country roads between Park City in Barren County and Smiths Grove in Warren County. Of particular interest is the area along Ky. 422, south from U.S. 31W. A sinkhole prone to flooding, and in which houses were subject to repeated damage, is in Versailles. When traveling south from Frankfort, turn right off U.S. 60 Bypass onto Douglas Avenue and cross the abandoned railroad track. The sinkhole is on the left, behind the few remaining houses. Big Sink Pike, directly across U.S. 60 from Douglas Avenue, also leads to a large sinkhole that frequently floods.

Losing Streams

Many intermittent Kentucky creeks go underground to reemerge farther down their course. They may lose their flow all at once into a large swallow hole, but more commonly flow gradually diminishes downstream, having seeped through the gravel bed of the channel. Losing streams are not very scenic, and unless you catch the optimum water conditions for a particular stream, you can’t tell that the stream is losing. Examples include Sinking Creek in Jessamine County, Sinking Valley in Pulaski County, and Little Sinking Creek at the Barren-Warren County line. A culvert or bridge over a stream bed that is dry during normal flow conditions is a sure sign there is a sinking or losing stream somewhere up-drainage.

Natural Bridges and Tunnels

The best example of a karst *natural bridge* in Kentucky is Smokey Bridge in Carter Caves State Park. Another example in Russell County is Rock House Natural Bridge on Ky. 379, about 2 miles west of Creelsboro. The karst natural bridge there has *pirated* flow from Jims Creek directly to the Cumberland River. There are other examples, including those in Cave Hollow, Elliott County, but they are not easily accessible.

Karst Windows

McConnell Springs, in a city park located off Old Frankfort Pike in Lexington, is actually a large karst window. A blue hole can be seen at the east end of the karst window and a swallow hole at the west end. In Versailles (Woodford County), a spring in Big Spring Park is actually the head of a large karst window. The swallow hole at the west end of the park can be reached via a foot path. Short Creek is a scenic karst window on privately owned property open to the public in eastern Pulaski County. Cedar Sink in Mammoth Cave National Park is a large, deep karst window.

Additional Information

The Kentucky Natural Resources and Environmental Protection Cabinet administers State water-pollution regulations. The Groundwater Branch of the Kentucky Division of Water deals with groundwater-related problems and is a good source of information on maintaining a well or spring-fed water supply. These agencies can also direct you to certified water-well drillers. To report a water-pollution incident, contact the Kentucky Division of Water in Frankfort (502.564.3410; water.nr.state.ky.us/dow/dwhome.htm).

The Kentucky Geological Survey (859.257.5500; www.uky.edu/kgs) can provide information about the general geology, wells, springs, and other karst features known to be in your area. KGS hydrogeologists have detailed knowledge about the karst in central Kentucky. They can also make recommendations about how to correct specific problems.

The American Cave Conservation Association (Box 409, Horse Cave, KY 42749; 502.786.1466; www.cavern.org) has brochures and other educational resources that describe karst hydrogeology, cave life, and environmentally friendly ways to live in karst areas.

The regional office of the U.S. Geological Survey is located in Louisville (502.635.8009; info.er.usgs.gov). The USGS can provide information about general geology and karst features. They also have detailed knowledge about the karst in Jefferson and Hardin Counties.

The region 4 office of the U.S. Environmental Protection Agency is in Atlanta, Ga. (800.421.1754). The EPA headquarters is at 401 M St. SW, Washington, DC 20460 (202.260.2090; www.epa.gov). The EPA is both a source of information about environmental issues and the lead Federal agency in regulating pollution sources.

Agencies such as the University of Kentucky College of Agriculture's Cooperative Extension Service, the U.S. Environmental Protection Agency, and the U.S. Department of Agriculture's Natural Resources and Conservation Service (NRCS) jointly sponsor the Kentucky Assessment System (KY-A-Syst), which offers nonregulatory and voluntary programs to help farmers and other rural residents prevent pollution and develop safe water supplies. Contact your county agriculture extension agent or local office of the NRCS for information on best management practices and cost-sharing programs for controlling agriculture-related pollution (www.ca.uky.edu).

The National Ground Water Association (601 Dempsey Rd., Westerville, OH 43081; 614.898.7791; www.ngwa.org) has general information on well construction, how to word contracts and request bids for well construction, and many books and pamphlets on groundwater and groundwater protection.

Glossary[1]

annulus. The space between the borehole wall and the casing in a well.

aquifer. A formation, group of formations, or part of a formation that contains enough saturated permeable material to yield significant quantities of water to wells and springs.

base level. Lowest level (elevation) of erosion by a stream or karst conduit.

bedding plane. A primary depositional lamination in sedimentary rocks separating two strata of differing characteristics.

bugs. Packets of material placed in springs to adsorb groundwater tracing dyes.

captured flow. *See* pirated flow.

casing. Permanent, pipe-like liner of a well. Older wells may have masonry casings; newer wells have steel or plastic casing.

cover collapse. The collapse of unconsolidated cover (such as soil) into the underlying cavernous bedrock.

distributary. Branching of a stream into multiple channels as flow approaches its local base level. Karst conduits frequently divide to discharge at multiple springs, at nearly the same elevation, located along the stream to which the springs discharge.

dry hole. A well drilled for a water supply, but producing no water.

dry well. A well drilled into the bottom of a sinkhole into which runoff within the sinkhole is directed, in order to minimize flooding of the sinkhole area.

graded filter. A method for filling sinkholes in which the sinkhole's throat in the bedrock is covered with large pieces of stone. The layer of large stones is covered with a second layer of stones that are large enough to bridge the openings between the underlying stones. Layers of stone are laid down in courses until

[1]Modified from Field, M.S., 1999, A lexicon of cave and karst terminology with special reference to environmental karst hydrology: U.S. Environmental Protection Agency, national Center for Environmental Assessment, EPA/600/R-99/006, 201 p.

a final layer of fine gravel can be covered with soil and the surface can be graded.

grike. A vertical or subvertical fissure in a limestone bedrock developed by solution along a joint.

groundwater basin. The area throughout which groundwater drains toward the same point. It can be larger than the associated surface-water drainage basin if permeable layers extend outside of the topographical divide.

joint. A break of geological origin in the continuity of a body of rock, but without any visible movement parallel to the surface of the discontinuity.

karst. A geologic setting, generally underlain by limestone or dolomite, formed chiefly by the dissolving of rock, and characterized by sinkholes, sinking streams, other closed depressions, sinking streams, subterranean drainage, and caves.

karst valley. A compound sinkhole, sinking valley, or other large karst depression from a few hundred meters to kilometers in size.

karst window. An unroofed section of a subterranean stream; a sinkhole at the bottom of which can be seen a subterranean stream.

natural bridge. An intact segment of an otherwise collapsed cave.

pirated (basin, watershed, flow). The process by which one stream or cave enlarges its drainage basin area by expanding into a neighboring drainage basin.

pitless adapter. Plumbing fitting installed inside the casing of a water well that couples the vertical riser pipe from the pump, below ground level, to the horizontal pipe leading to the storage tank.

screen. Slotted well casing that is positioned within the producing horizon to prevent detrital particles from getting into a well while still allowing the inflow of water.

sinkhole. A basin- or funnel-shaped hollow in limestone, ranging in diameter from a few meters up to a kilometer and in depth from a few to several hundred meters.

sinkhole plain. Topographic plain on which most of the local relief is due to sinkholes and nearly all drainage is underground.

sinking stream. A surface-flowing stream that disappears underground.

spring. Any natural discharge of water from rock or soil onto the surface of the land or into a body of surface water.

swallow hole. A place where water disappears underground into a hole in a stream bed or sinkhole.

topography. The physical features of a landscape; hills, valleys, rivers, etc.

topographic divide. The boundary between two surface watersheds.

water table. The surface at the top of the groundwater, below which water completely fills the pore spaces of the rock.

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