

Kentucky Interagency Groundwater Monitoring Network

Annual Report

July 2012–June 2013

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October 2013

Acknowledgments

Thanks to the following, who provided the summary reports on the activities of their agencies:

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Robert J. Blair, Kentucky Division of Water, Groundwater Section

Pete Cinotto, U.S. Geological Survey, Kentucky Water Science Center

James C. Currens, Kentucky Geological Survey, Water Resources Section

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Kentucky Interagency Groundwater Monitoring Network Annual Report July 2012–June 2013 Executive Summary

Adequate supplies of clean groundwater are essential to many of Kentucky's citizens, businesses, industries, and ecosystems. Regional and temporal variations in groundwater quantity and quality are not adequately known, however. For this reason, the 1998 Kentucky General Assembly directed the Kentucky Geological Survey to establish a long-term groundwater monitoring network (KRS 151.620 and 151.625). Known as the Kentucky Interagency Groundwater Monitoring Network, this entity collects groundwater data, characterizes groundwater quality, distributes groundwater information, improves coordination between agencies that use groundwater data, and facilitates data sharing. These activities are conducted in cooperation with the Interagency Technical Advisory Committee (ITAC), composed of representatives from nine State and Federal agencies and three from the University of Kentucky. The duties and responsibilities of this committee include developing a plan to coordinate agencies for overall characterization of the state's groundwater, reviewing the data-entry process to ensure that all groundwater data collected are placed into the Kentucky Groundwater Data Repository, establishing a long-term groundwater monitoring plan for the commonwealth, recommending priorities for the state's groundwater research needs, and annually reviewing and evaluating groundwater data collection and analysis.

The Kentucky Geological Survey is also charged with annually reporting network activities to the governor's office and the Legislative Research Commission. This report summarizes activities during the 2012-13 State fiscal year.

From July 2012 through June 2013, 22 data-collection programs were under way. Groundwater information was communicated to the

scientific and regulatory communities and to the public through 17 publications and 13 presentations, as well as postings on websites. Meetings of the Interagency Technical Advisory Committee provided an opportunity to coordinate groundwater-related efforts and share information among agencies. Exchange of groundwater data, including electronic transfer of analytical results between Division of Water and Kentucky Geological Survey databases, has continued through close cooperation between the Kentucky Division of Water and the Kentucky Geological Survey.

The Kentucky Interagency Groundwater Monitoring Network has been in existence for 15 years. During this time, significant progress has been made, but important work remains to be completed. Among the ongoing critical issues facing Kentucky are:

- Determining recharge areas for sampled wells and springs so water supplies can be protected
- Establishing monitoring sites in areas that are currently not monitored or where groundwater demand is expected to increase
- Optimizing the sampling frequency to account for natural variations in groundwater flow systems throughout the state
- Monitoring the rate of intrusion of nonpoint-source contaminants into groundwater systems so that effective prevention and remediation can be implemented
- Establishing standard procedures for assessing whether compromised well integrity is allowing surface contamination to reach groundwater supplies
- Standardizing reported information about sampling methods, field measurements,

and sample-site descriptions to promote data sharing

- Developing a water-level monitoring network to track long-term land-use and climate effects on groundwater supplies
- Standardizing reporting procedures and database structures to facilitate electronic data sharing
- Providing increased public access to groundwater-quality data in order to increase awareness
- Determining sources and amounts of bacteria and other pathogens in both local and regional groundwater flow systems
- Investigating the amount of pharmaceutical and personal-care-product chemicals in water systems
- Evaluating amounts and effects of pesticide metabolites in groundwater
- Increasing the use of stable isotopes, caffeine, and other tracers to indicate contaminant sources and quantify groundwater ages and flow rates
- Quantifying how groundwater affects the quality and quantity of water in streams in terms of water-quality standards, total maximum daily loads, and designated uses.

Additional issues in the news that relate to groundwater have been discussed at recent ITAC meetings, including:

- The effect of metals in groundwater on public health
- The increase of emergent pharmaceuticals found in surface water and groundwater

and their effect on the health of both humans and animals

- The rapid increase of geothermal energy development and how this process affects aquifers
- The impacts of natural gas fracturing (“fracking”) on aquifers
- The effects of stormwater injection into karst and alluvial systems
- The growing trend of nitrate spikes in some groundwater systems
- Groundwater nutrient contributions related to total maximum daily loads
- Expanding irrigation and how it affects the drawdown on aquifers in western Kentucky.

The Kentucky Interagency Groundwater Monitoring Network will continue to address these issues. Recent advances have been the result of substantial agency commitment of State executive budget funds; one-time, competitive grants to the Kentucky Division of Water’s Groundwater Section and the Kentucky Geological Survey; and voluntary cooperation between agencies. An effective groundwater monitoring network requires sustained, recurring funding to maintain the long-term effort. As noted in previous annual reports, the availability of these funds is decreasing. Most of the activities during the reporting period were investigations of identified or suspected groundwater-quality problems and were possible only because the agencies involved were able to obtain funding from outside sources.

Introduction

Groundwater is used extensively throughout Kentucky for domestic, agricultural, commercial, and industrial purposes. Because of its connection with rivers, lakes, and wetlands, groundwater is also essential to the health of surface-water ecosystems. Determining the quality of this resource and protecting it from contamination are vital to the future of the commonwealth and its citizens. The Kentucky Interagency Groundwater Monitoring Network was established in 1998 by the Kentucky General Assembly through KRS

151.625 to increase knowledge and awareness of groundwater resources. For 15 years, the network has met its obligation of collecting and interpreting data, communicating findings, sharing data, and promoting interagency cooperation. Previous annual reports for the network are posted at www.uky.edu/KGS/water/gnet.

The 1998 legislation also established the Interagency Technical Advisory Committee to assist the Survey in the development, coordination, and implementation of a groundwater monitoring network (KRS 151.629). The following agen-

cies and organizations were asked to appoint a representative to the Interagency Technical Advisory Committee:

- Kentucky Department for Environmental Protection
- Kentucky Department for Natural Resources
- Kentucky Department of Agriculture, Division of Pesticide Regulation
- Kentucky Division of Conservation
- Kentucky Division of Forestry
- Kentucky Division of Public Health Protection and Safety
- Kentucky Division of Waste Management
- Kentucky Division of Water
- University of Kentucky, College of Agriculture
- University of Kentucky, Kentucky Geological Survey
- University of Kentucky, Kentucky Water Resources Research Institute
- U.S. Geological Survey, Kentucky Water Science Center.

Information provided by the Kentucky Division of Water indicates that more than 400,000 citizens rely on water from private wells and springs for drinking, cooking, and washing. Public water systems serving more than 1.25 million people also rely on groundwater as a source of drinking water. This dependence on groundwater resources will continue and may increase for economic reasons. Many public water-supply systems are considering switching from surface-water to groundwater sources because the required treatment and monitoring are less extensive and less expensive. Furthermore, many people who now rely on private wells or springs for domestic water supplies will remain dependent on groundwater because of the cost of extending public water-supply systems to rural areas and because groundwater supplies are more than sufficient in some areas of the commonwealth.

Significant quantities of groundwater are used for commercial and industrial applications, crop irrigation, livestock watering, mining, and thermoelectric power generation. Groundwater also sustains valuable ecosystems by providing base flow to streams, lakes, and wetlands. This is

particularly important during moderate to severe droughts, such as those that occurred in 1999-2001, 2005-06, 2007-08, and 2011-12. In the absence of precipitation, groundwater base flow is the only source of water to maintain stream flow and lake levels, and to preserve riparian and wetland ecosystems.

2012-13 Activities and Accomplishments

Brief summaries of work performed by the ITAC agencies during the 2012-13 State fiscal year are presented below to show how the major goals of the network are being addressed. Additional information regarding these projects can be obtained by contacting the responsible agency.

The Interagency Technical Advisory Committee met on July 10, 2012, at the Kentucky Geological Survey in Lexington. This meeting provided an opportunity for networking and information sharing between committee members.

The Kentucky Water Resources Annual Symposium on March 18, 2013, was attended by approximately 120 participants. The program included the following groundwater presentations:

- *Herbicide Transport Within Shallow Karst Groundwater on Kentucky's Pennyroyal Plateau Beneath Row Crop Agriculture*, C. Groves, R. Lerch, J. Polk, B. Miller, and S. Vanderhoff, Hoffman Environmental Research Institute, Western Kentucky University, Bowling Green
- *Groundwater Tracing in the West Pennyrile Karst Region*, R. Blair and J. Moore, Kentucky Division of Water, Frankfort
- *Flowing Onward: Mapping New Program Directions for the Kentucky Geological Survey's Water Resources Section*, C. Taylor, Kentucky Geological Survey
- *Mapping Karst Sinkholes Using LiDAR – A Pilot Study in Floyds Fork Watershed, Central Kentucky*, P. Taylor, J. Zhu, M. Crawford, and J.C. Currens, Kentucky Geological Survey
- *Changes in the Kentucky Groundwater Data Repository Search Engines*, B. Davidson, Kentucky Geological Survey

- *Groundwater Discharge at the Kentucky Horse Park KWIS Station*, J.C. Currens and M. Farwell, Kentucky Geological Survey
- *Groundwater Phosphorus in Kentucky Relative to Karst, Groundwater Sensitivity, and Groundwater Physiographic Region*, C. Chan, Kentucky Division of Water
- *Groundwater Monitoring of Drinking Water Sources in Kentucky, 2000–2012: Comparison of Physiographic Regions*, A. Westerman, P. O'dell, and J. Blanset, Kentucky Division of Water
- *Preliminary Results for the Statewide Groundwater Pathogens Study*, S. Mallette and J. Moore, Kentucky Division of Water

Statewide and regional ambient monitoring programs evaluated groundwater that is not affected by point-source contamination and determined whether nonpoint-source chemicals such as sewage, pesticides, fertilizers, and volatile organic compounds have affected groundwater quality. These large-scale studies are conducted in basin management units (Fig. 1), which were

established by the Kentucky Division of Water (1997) and include one or more major river watersheds. Site-specific studies were conducted in smaller watersheds or other, more restricted regions. These more specific studies were designed to evaluate the effects of particular land uses or unique hydrologic conditions on the quality of unregulated water supplies, such as roadside springs, used by the public.

Groundwater Data Collection

Groundwater data are generated through many avenues. Drilling wells, collecting and analyzing water samples, measuring water levels in wells, and mapping recharge and discharge areas of karst systems provide the fundamental data needed to determine current groundwater quality, detect changes over time, and evaluate hydrogeologic hazards.

Kentucky Division of Water, Watershed Management Branch, Groundwater Section

The Groundwater Section of the Watershed Management Branch of the Kentucky Division of

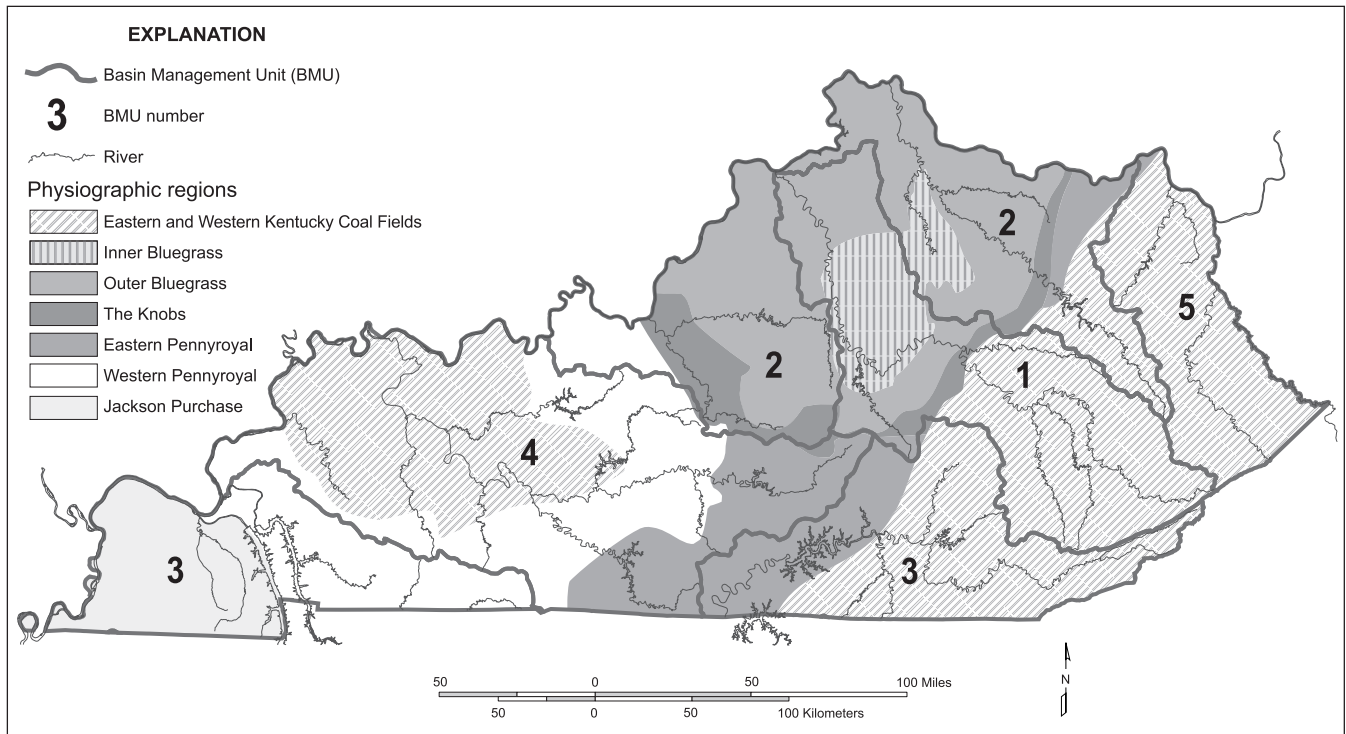


Figure 1. Major rivers, basin management units, and physiographic regions in Kentucky.

Water maintains an active groundwater sampling and analysis program. The following projects have been active during the report period.

Ambient Groundwater Monitoring Network. Regularly scheduled sampling continued for the statewide Ambient Groundwater Monitoring Network. This fiscal year, 127 samples were collected from 57 sites (wells and springs) across the state. Groundwater-quality data were provided to numerous persons through information requests. Data were also included in statistical analyses for regional and watershed-based groundwater assessments. The monitoring sites are summarized in Table 1, and site locations are shown in Figure 2.

Pesticides Memorandum of Agreement Project. The Pest MOA with the Kentucky Department of Agriculture covers four permanent sampling sites (three springs and one well) in western Kentucky. Each site was sampled quarterly for a total of 16 samples during the fiscal year (Table 2). Pesticide data from these sites and the Ambient Groundwater Monitoring Network sites are submitted to the Department of Agriculture annually.

Complaint Sampling. The Division of Water responds to complaints about groundwater and investigates as requested by the general public. In this fiscal year, the Division collected 26 samples from 26 sites in response to complaints. The majority of these samples were collected by Groundwater Section personnel. Several other water wells and springs were inspected in response to requests from citizens for technical assistance, although analytical samples were not collected.

Nonpoint-Source Groundwater Assessments. The Division currently has four active nonpoint-source projects in various phases from final report drafting to study area reconnaissance and site selection.

Elkhorn Creek Sub-basin (BMU 5) Groundwater Study (NPS0604). This project focused on assessing groundwater quality of domestic wells along Elkhorn Creek in southeastern Pike County and northeastern Letcher County. All water-quality samples have been collected and their chemistry analyzed. In addition, each well used in this study has been sampled for total coliform and *E. coli* bacteria. Biological activity reaction tests were also conducted at each well; these tests cover iron-related, sulfate-reducing, and slime-forming bacteria. Work on the draft report is complete and it is currently in the internal review and editing process.

West Pennyryle Karst Study (NPS0704). Work on this project began in late fall of 2008. Tracer tests have been completed throughout the study area, which includes parts of Livingston, Crittenden, Caldwell, Lyon, and Trigg Counties. A total of 54 tracer tests have been recovered from 31 springs, and 18 spring basins have been partially or fully delineated. Groundwater-quality monitoring, using the integrated surface-water and groundwater approach, began in October 2012 and will be completed in September 2013. Details of the groundwater tracing results were presented at the Kentucky Water Resources Research Institute Annual Symposium. Work on the draft report has begun and it should be complete in mid 2014.

Statewide Pathogens Study (NPS0803). This project focused on the occurrence of pathogens in groundwater. Emphasis was on private water wells and springs being utilized for domestic water supplies. Approximately 200 sites across Kentucky were sampled for total coliform, *E. coli*, iron-related, sulfate-reducing, and slime-forming bacteria, and caffeine. Although this research took place throughout the state, priority was given to areas with the highest domestic groundwater use,

specifically the Eastern Kentucky Coal Field and Jackson Purchase Region. Sample collection was completed in February 2013 and preliminary results were presented at the Kentucky Water

<i>Region</i>	<i>No. Sites</i>	<i>Region</i>	<i>No. Sites</i>
Bluegrass	7	1: Kentucky River	7
Eastern Coalfield	8	2: Salt and Licking Rivers	8
Ohio River Alluvium	10	3: Four Rivers, Upper and Lower	22
Mississippian Plateau	24	4: Green and Tradewater Rivers	15
Western Coalfield	2	5: Big and Little Sandy Rivers and Tygarts Creek	5
Jackson Purchase	6		

SITE TYPE

- Spring
- Well
- County Boundary Polygons
- Eastern Coal Field
- Eastern Pennyroyal
- Inner Blue Grass
- Knobs
- Outer Blue Grass
- Purchase
- Western Coal Field
- Western Pennyroyal

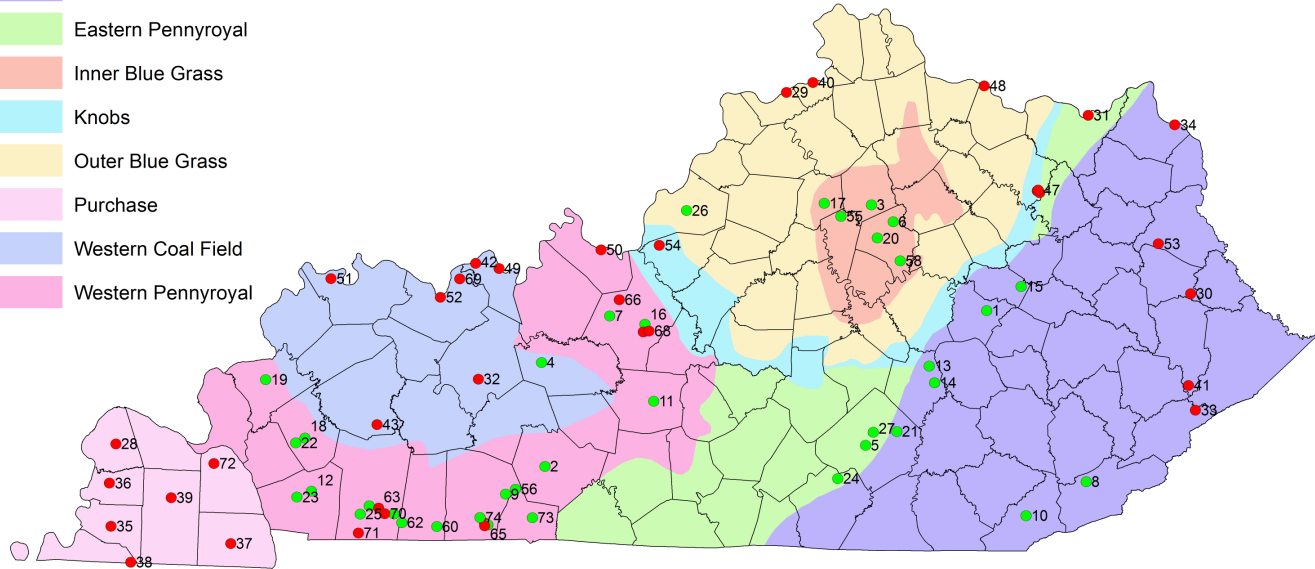


Figure 2. Kentucky Interagency Groundwater Monitoring Network sites maintained by the Kentucky Division of Water.

Resources Research Institute Annual Symposium. The draft report is currently undergoing internal review and should be completed in early 2014.

South-Central Karst Study (NPS0903). Funding for this project was made available in 2012, and work commenced with a literature and map review of the study area. This project will focus on expanding karst groundwater mapping efforts south of Lake Cumberland. The study area includes parts of Clinton, Wayne, and McCreary Counties. Work is currently focused on the hydrogeologic inventory and preparation for groundwater tracing. Monitoring sites will be chosen following completion of the tracer tests and delineation of several karst groundwater basins. This project will take an integrated surface-water and groundwater assessment approach.

Special Projects. The Division conducted 27 tracer tests for karst mapping projects and groundwater technical assistance. We also assisted eight county health departments, the Division of Mining Rec-

lamation and Enforcement, Division of Waste Management, Lexington-Fayette Urban County Government, U.S. Army Corps of Engineers, and sewer departments in Frankfort, Lexington, and Somerset with dye traces to investigate subsurface hydraulic connections. The Division also made several presentations about geology and groundwater at elementary schools in Woodford County for their annual Science Day event.

Wellhead Protection Program. The program continues to focus on completing 5-year updates for groundwater systems throughout Kentucky. New "Water Supply Protection Area" signs have been developed and placed throughout the state. The new signs aim to raise public awareness about the importance of protecting recharge areas for drinking-water supplies throughout Kentucky. The Wellhead Protection Program is developing educational materials to raise awareness about protecting groundwater for public water supplies and the communities they serve.

Table 2. AKGWA numbers (Division of Water identification number) and sampling frequency for the network sites shown in Figure 2. AKGWA numbers can be located using the Groundwater Data Repository. Q=quarterly. M=monthly. 5Q=every fifth quarter. 2Q=every second quarter. Pest MOA=Pesticides Memorandum of Agreement; sample times vary.

Map No.	AKGWA No.	Sample Frequency	Map No.	AKGWA No.	Sample Frequency	Map No.	AKGWA No.	Sample Frequency
1	90000045	Q	26	90002934	Q	51	00040944	Q
2	90000054	Q	27	90003064	5Q	52	00065149	Q
3	90000055	M	28	00000811	5Q	53	00068511	Q
4	90000456	5Q	29	00007133	5Q	54	00066926	Q
5	90000544	5Q	30	00012311	Q	55	90001200	Pest MOA
6	90000552	Q	31	00014293	2Q	56	90000624	Pest MOA
7	90000702	Q	32	00019489	5Q	57	90001150	Pest MOA
8	90000703	Q	33	00028100	5Q	58	90001201	Pest MOA
9	90000705	M	34	00029505	2Q	59	90001460	Pest MOA
10	90000710	5Q	35	00033887	5Q	60	90001475	Pest MOA
11	90000798	M	36	00033904	5Q	61	00055953	Pest MOA
12	90000854	2Q	37	00033965	5Q	62	90001485	Pest MOA
13	90001020	Q	38	00033972	5Q	63	00011280	Pest MOA
14	90001051	5Q	39	00037330	5Q	64	90000458	Pest MOA
15	90001134	Q	40	00037376	5Q	65	00029983	Pest MOA
16	90001137	Q	41	00039374	5Q	66	00043250	Pest MOA
17	90001143	M	42	00041471	Q	67	00043253	Pest MOA
18	90001145	2Q	43	00042984	Q	68	00043258	Pest MOA
19	90001149	2Q	44	00043253	5Q	69	00047172	Pest MOA
20	90001161	Q	45	80046811	2Q	70	00047175	Pest MOA
21	90001254	5Q	46	80046812	2Q	71	00048659	Pest MOA
22	90001343	2Q	47	80046813	2Q	72	00055310	Pest MOA
23	90001344	2Q	48	00065002	Q	73	90002823	Pest MOA
24	90001822	Q	49	00061858	Q	74	90000315	Pest MOA
25	90001857	Q	50	00061854	Q			

U.S. Geological Survey

Louisville Water Co., Ohio River Alluvial Aquifer, Jefferson County. The USGS, in cooperation with the Louisville Water Co., maintains a network of 43 water-level observation wells in the north-eastern part of the Ohio River alluvium in Jefferson County. Twenty-one of the wells are equipped with continuously recording pressure transducers that measure depth to water and water temperature. Water-level measurements are taken at the other 22 observation wells on a quarterly basis. These data assist the Louisville Water Co.'s efforts to operate and maintain river-bank infiltration using a network of water-supply wells constructed to

draw and naturally filter river water through the sand and gravel aquifer near the Payne Water-Treatment Plant.

Groundwater-Level Data Collection. The USGS collects real-time continuous water-level measurements from an observation well in Graves County that is included in the USGS National Groundwater Climate Response Network – a nationwide network of long-term observation wells intended to monitor the effects of droughts and other climate variability on the nation's groundwater resources. The water-level data for this well can be accessed via the Internet at groundwaterwatch.usgs.gov or ky.water.usgs.gov. Two additional long-term ob-

ervation wells located in downtown Louisville are also maintained by the USGS and are used to collect continuous water-level data from the Ohio River alluvial aquifer. These data, historical water-level data from other observation wells, and additional information about the activities of the USGS–Kentucky Water Science Center are available on the USGS website at ky.water.usgs.gov.

Well-Integrity Survey of Abandoned Gas Wells Near West Point. Abandoned and unrecorded natural-gas wells may act as conduits for the contamination of groundwater supplies by oil- and gas-field brines and other pollutants. The casings of abandoned wells may eventually develop leaks, which, if not properly plugged, can allow pollutants to reach freshwater aquifers that supply drinking water. Such is the situation in the Fort Knox well field near West Point, Ky. Many of the drinking-water supply wells for Fort Knox have chloride concentrations in excess of secondary maximum contaminant levels of 250 mg/L, some as high as 1,900 mg/L. The USGS, working in cooperation with the U.S. Army Corps of Engineers and the Army installation at Fort Knox, is presently conducting a geophysical and hydrogeologic investigation of the Ohio River alluvial aquifer at the Fort Knox well field to identify abandoned or improperly plugged oil and gas exploration wells that may be contributing brine contamination to the freshwater aquifer and to characterize the migration and dispersion of chlorides.

Hydrogeologic Reconnaissance, Well Inventory, and Aquifer Tests to Assess the Feasibility of Stormwater Injection Wells, Northern Kentucky Sanitation District No. 1 Service Area. Hydrogeologic reconnaissance, well inventory, and site-specific aquifer test data are needed in order for Northern Kentucky Sanitation District No. 1 managers to assess whether use of stormwater injection wells is technically or economically feasible for Class V underground injection and begin the process of developing the necessary engineering-design specifications. To overcome these difficulties, the Sanitation District has requested that USGS conduct scientific activities capable of supplying the utility with the needed hydrogeologic information. USGS will complete a basic well inventory within the service area; assess, as possible, the

structural integrity of identified wells; collect basic hydrologic characteristics for the region; conduct aquifer tests on applicable wells; and document the findings via a USGS open-file report.

Kentucky Department of Agriculture

The Kentucky Department of Agriculture–Technical Support Branch continued to receive monitoring data from the Division of Water under its memorandum of agreement. The memorandum covers 16 samples yearly from four sites. It is supplemented by the Division of Water’s Ambient Groundwater Monitoring Program.

Kentucky Geological Survey, Water Resources Section

CDC Private Well Water Initiative. Water Resources Section personnel continued work on a third project with the Centers for Disease Control and Prevention in Atlanta. The CDC has initiated a nationwide project to identify and characterize private drinking-water sources, primarily wells and springs, not covered by the Safe Drinking Water Act. Funded through the Kentucky Division of Water, KGS proposed a pilot study to review and compile bacteriological data from private water wells collected by local and regional health departments in different geologic areas. At the time of this report, more than 13 health departments and two State laboratories had been visited, with as many telephone contacts made. In recent years, many Kentuckians are switching from water wells to city or county water supplies as their primary drinking-water source. Most health departments continue to sample a few private wells per month at homeowners’ requests, however. Several hundred bacteria records will be added to the Kentucky Groundwater Data Repository as a result of this project, and thereby made available for public health research.

Karst Activities. The Section remained active in karst hydrogeology research, with investigations in three areas: (1) hydrology of the Cane Run karst watershed, (2) inventory of cover-collapse sinkholes, and (3) improved mapping of sinkhole occurrence using LiDAR technology.

Hydrology of the Cane Run Watershed. Water Resources Section staff and faculty in the UK College of Agriculture and the Department of Earth and Environmental Sciences have been collaborating to better quantify the discharge of water and concentrations and loads of fecal bacteria, nitrate, and suspended sediments through the Cane Run karst watershed. Cane Run, a surface stream that heads in east-central Fayette County and extends into Scott County, drains a total area of approximately 23 square miles. Near the Scott-Fayette County line, the surface flow of Cane Run is pirated by a series of swallow holes that are hydraulically connected to the main karst conduit of Royal Spring, the source of municipal water for Georgetown, Ky. KGS began monitoring flow conditions and water quality in the Royal Spring karst aquifer in May 2011, using a cluster of monitoring wells located at the Kentucky Horse Park that are drilled into the Royal Spring conduit and adjacent parts of the karst aquifer. The wells have been equipped with stage recorders, a velocity meter, a 12-volt pump to collect samples, and a water-quality testing device and data logger.

Water Resources personnel have been researching methods of accurately measuring the discharge of water and flux of potential contaminants through the Royal Spring conduit. Unlike with surface streams, conduit discharge and cross-sectional area, essential to calculating the flux of contaminants, as well as water-flow velocity distribution, are difficult to determine directly. Three methods have been used to calculate the cross section of the Royal Spring karst conduit: (1) downhole video, (2) Doppler sonar, and (3) quantitative groundwater tracing. The Doppler sonar was most useful in determining passage size. To analyze the sonar data, vector analysis was performed that showed the direction of flow, the speed of the suspended material, and the coordinates of the location of the observation. The quantitative groundwater tracing has been the most effective tool for determining discharge because the data generated by it reflect the increasing width and depth of flow as the higher and normally air-filled conduits begin to discharge. Most of the current effort is focused on collecting discharge measurements under a variety of flow conditions to develop a more precise discharge-rating curve for the Royal

Spring conduit and hence the entire Cane Run karst watershed. In addition to enabling researchers to characterize the flux of nitrate and other potential contaminants through the Cane Run watershed, we anticipate the results of this research will result in a better understanding of the role of surface water and groundwater interaction in the Inner Bluegrass karst region.

Inventory of Sinkholes and Sinkhole Occurrences. National news reports of several incidents of large sinkhole collapses in various parts of the United States, including one near Tampa, Fla., which resulted in a fatality, dramatically increased the public's awareness and concern about sinkhole occurrences in Kentucky during 2013. Water Resources staff responded to approximately 68 requests for information or field inspections of sinkholes occurring on private landowners' properties. Several interviews about karst and sinkhole occurrence were also given by Water Resources personnel to local and regional news outlets. Since 1997, the Section has collected information about the occurrence of cover-collapse sinkholes in Kentucky, maintaining an inventory of these features that describes their locations, physical characteristics, and topographic and geologic settings. A digital GIS file of sinkhole locations identified and mapped throughout the state at 1:24,000 scale was prepared in 2003 and is available for download at www.uky.edu/KGS/gis/sinkpick.htm.

Use of LiDAR Technology to Map Karst Sinkholes in Floyds Fork Watershed, Central Kentucky. To investigate new methods to improve the ease and accuracy of sinkhole identification and mapping, Section personnel have been investigating the use of digital topographic data collected using the remote sensing technology LiDAR (light detecting and ranging) to identify and map sinkholes in karst areas. They developed digital LiDAR data-processing methods and applied them to delineate sinkholes occurring in the drainage area of Floyds Fork, a surface stream draining parts of Jefferson, Oldham, Shelby, and Bullitt Counties in north-central Kentucky. Using the new LiDAR mapping method, they identified four times more probable sinkholes than could be identified using contoured depressions visible on topographic maps. A field inspection of 80 probable sinkholes located using

the LiDAR mapping method indicated that interpretation of LiDAR data was 89 percent successful in identifying and delineating sinkhole depressions actually caused by karst hydrogeologic processes.

Groundwater Contaminant Modeling at the Paducah Gaseous Diffusion Plant. Water Resources Section personnel, working in collaboration with the Kentucky Research Consortium for Energy and the Environment, developed a numerical (computer) model of groundwater flow in the aquifer system at the Paducah Gaseous Diffusion Plant, where a variety of radioactive and nonradioactive hazardous wastes were released in the past. The model will be used to help Department of Energy and other State and Federal resource managers and contractors remediate groundwater at the site by simulating the movement of contaminants. Junfeng Zhu will use the model to test potential outcomes of different groundwater remedial actions that are being considered and employed in cleanup of the Paducah site.

Cumberland Gap Tunnel Roadway Subsidence. The Water Resources staff collaborated with personnel of the Kentucky Transportation Center at the University of Kentucky to investigate why the roadbed aggregate in the Cumberland Gap Tunnel near Middlesboro, Ky., is dissolving and subsiding. In a previous project completed in 2012, groundwater and roadbed drainage samples were collected and analyzed to characterize water chemistry; limestone aggregate was suspended in 2-inch-diameter stainless-steel baskets in four test borings in the northbound tunnel and monitored to better understand and quantify the processes involved in the roadbed subsidence. Geochemical modeling was used to analyze water chemistry and dissolution data, which indicated that water draining through the tunnels is corrosive to limestone. In some areas of the tunnel bores, the aggregate may be totally dissolved by groundwater in 15 years. These findings have prompted Transportation Center and Federal highway engineers to initiate remedial measures to replace the existing limestone roadway aggregate with insoluble granite aggregate. Changes in the chemistry of water in the roadbed aggregate will be monitored before, during, and after the remedial highway construction. At present, water-level recorders in the tunnel

are being maintained to help monitor groundwater inflow and quantify drainage through the existing roadbed aggregate.

Distribution of Groundwater Information

One of the most important functions of the Groundwater Monitoring Network is translating analytical data from water-level measurements and groundwater analyses into readily available, useful information and presenting it to the public. During the 2012-13 fiscal year, groundwater information was communicated via short reports, oral and poster presentations at meetings and conferences, and posting on websites. Major reports and presentations are listed below.

Publications

- Beck, E.G., and Dinger, J.S., 2013, Protection of domestic well water from nitrate contamination: Kentucky Senate Bill 271 revised contract reports (1998–2000): Kentucky Geological Survey, ser. 12, Contract Report 56, 11 p.
- Beck, E.G., Dinger, J.S., Grove, J.H., and Pena-Yewtukhiw, E.M., 2013, Assessment of potential nitrate contamination to shallow groundwater systems in the Western Kentucky Coal Field and Jackson Purchase Area: Kentucky Senate Bill 271 revised contract reports (2000–2006): Kentucky Geological Survey, ser. 12, Contract Report 51, 53 p.
- Beck, E.G., Dinger, J.S., Grove, J.H., and Pena-Yewtukhiw, E.M., 2013, Assessment of nitrate and pesticide impacts to bedrock aquifers in upland agricultural settings of the Western Kentucky Coal Field: Kentucky Senate Bill 271 revised contract reports (1995–2000): Kentucky Geological Survey, ser. 12, Contract Report 4, 54 p.
- Blair, R.J. and Ray, J.A., 2012, Groundwater assessment for nonpoint source pollution impacts and spring basin delineations within sub-watersheds of the Salt River Basin: Beargrass Creek and Sinking Creek: Kentucky Division of Water, 77 p.
- Currens, J.C., and Farwell, M., 2013, Groundwater discharge at the Kentucky Horse Park KWIS

- station [abs.]: Kentucky Water Resources Annual Symposium, Abstracts with Programs, p. 17.
- Currens, J.C., Paylor, R.L., Beck, E.G., and Davidson, B., 2012, A method to determine cover-collapse frequency in the Western Pennyroyal karst of Kentucky: *Journal of Karst and Cave Studies*, v. 74, no. 3, p. 292-299.
- D'Angelo, E., Grove, J., Beck, G., Zeigler, G., and Sikora, F., 2012, Arsenic species in Broiler (*Gallus gallus domesticus*) litter, soils, maize (*Zea mays* L.), and groundwater from litter-amended fields: *Science of the Total Environment*, v. 438, p. 286-292.
- Davidson, B., 2012, Enhancing the capacity for environmental and public health surveillance of unregulated drinking water in Kentucky through digitization of selected groundwater data: Final report for Centers for Disease Control Private Drinking Water Initiative: Kentucky project 2011-2012: Kentucky Geological Survey, ser. 12, Contract Report 2, 6 p.
- Davidson, B., 2012, Kentucky Interagency Groundwater Monitoring Network annual report, July 2011-June 2012: Kentucky Geological Survey, 22 p.
- Davidson, B., 2013, Changes in the Kentucky Groundwater Data Repository search engines [abs.]: Kentucky Water Resources Annual Symposium, p. 15.
- Finley, R., 2012, Sequestration and enhanced oil recovery: Sugar Creek Oil Field test site, Hopkins County, Kentucky: U.S. Department of Energy Final Report, 260 p.
- Frailey, S.M., Parris, T.M., Damico, J.R., Okwen, R.T., and McKaskle, R.W., 2012, CO₂ storage and enhanced oil recovery: Sugar Creek Oil Field test site, Hopkins County, Kentucky: Illinois State Geological Survey, Open-File Series 2012-4, 234 p.
- Parris, T.M., Beck, E.G., Frailey, S., Takacs, K., Krapac, I., Damico, J., Locke, R., Iranmanesh, A., and Wimmer, B., 2012, Summary of CO₂ injection pilot project, Sugar Creek Field, Hopkins County, Kentucky [abs.]: American Association of Petroleum Geologists-Eastern Section, 41st Annual Conference, Proceedings and Abstracts, p. 51-52.
- Taylor, C.J., 2013, Flowing onward: Mapping new program directions for the Kentucky Geological Survey's Water Resources Section [abs.]: Kentucky Water Resources Annual Symposium, Abstracts with Programs, p. 9.
- Taylor, T.P., Zhu, J., Crawford, M., and Currens, J., 2013, Mapping karst sinkholes using LiDAR—A pilot study in Floyds Fork watershed, central Kentucky [abs.]: Kentucky Water Resources Annual Symposium, Abstracts with Programs, p. 13.
- Zhu, J., and Hampson, S., 2012, Predicting groundwater contaminant plume migration at the Paducah Gaseous Diffusion Plant, Kentucky [abs.]: Proceedings, 57th Annual Midwest Ground Water Conference, p. 52.
- Zhu, J., and Hampson, S., 2013, Paducah Gaseous Diffusion Plant groundwater modeling support activities: Phase 1 summary report: Kentucky Geological Survey, ser. 12, Contract Report 52, 13 p.

Presentations

- Beck, E.G., 2012, Groundwater for pivot irrigation: Governor's Office of Agriculture Policy meeting, Frankfort, Ky., August 31, 2012.
- Beck, E.G., 2013, Potential groundwater sources for irrigation wells: Muhlenberg County Cooperative Extension Service Row Crop Producers meeting, Greenville, Ky., March 4, 2013.
- Beck, E.G., 2013, Potential groundwater sources for livestock wells: Muhlenberg County Master Cattlemen's meeting, Greenville, Ky., March 4, 2013.
- Blair, R.J., and Moore, J.E., 2013, Groundwater tracing in the West Pennyryle karst region of Kentucky: Kentucky Water Resources Annual Symposium, Lexington, Ky., March 18, 2013.
- Davidson, B., 2012, The Kentucky Groundwater Data Repository: A review: Governor's Office of Agricultural Policy Groundwater Resources meeting, Kentucky Division of Conservation, Frankfort, Ky., August 31, 2012.
- Davidson, B., 2013, Changes in the Kentucky Groundwater Data Repository search engines: Kentucky Water Resources Annual Symposium, Lexington, Ky., March 18, 2013.
- Davidson, B., 2013, Using the Kentucky Groundwater Data Repository: Knowing your site

before drilling a well: Kentucky Groundwater Association drillers' workshop, Louisville, Ky., March 1, 2013.

Davidson, B., 2013, Using the Kentucky Groundwater Data Repository search engines: Summit Engineering groundwater workshop, Lexington, Ky., April 23, 2013.

Mallette, S.L., and Moore, J.E., 2013, Preliminary results for the statewide groundwater pathogens study: Kentucky Water Resources Annual Symposium, Lexington, Ky., March 18, 2013.

Taylor, C.J., 2013, Flowing onward: Mapping new program directions for the Kentucky Geological Survey's Water Resources Section: Kentucky Water Resources Annual Symposium, Lexington, Ky., March 18, 2013.

Taylor, C.J., 2013, Karst drainage characteristics and flooding in the Lost River Basin, Orange County, Indiana: Kentucky Geological Survey internal seminar, Lexington, Ky., April 5, 2013.

Taylor, C.J., 2013, Karst hazards: Kentucky Society of Professional Engineers spring seminar, Paducah, Ky., June 18, 2013.

Westerman, A.L., O'dell, P.W., and Blanset, J.M., 2013, Groundwater monitoring of drinking water sources in Kentucky, 2000–2012: Comparison of physiographic regions: Kentucky Water Resources Annual Symposium, Lexington, Ky., March 18, 2013.

Website Information

The Kentucky Geological Survey provides online access to information about water wells and springs at kgs.uky.edu/kgsweb/DataSearching/Water/WaterWellSearch.asp. These data are useful to the public, well drillers, consultants, and researchers. KGS also maintains a website for the Kentucky Interagency Groundwater Monitoring Network (www.uky.edu/kgs/water/gnet), which contains links to current and previous annual reports of the network and to the websites of the ITAC agencies and organizations.

KGS has compiled information about hydrology, geology, topography, water supply, and water quality from maps, reports, and data collected from 1940 to the present at www.uky.edu/kgs/water.

Statewide groundwater data in the Kentucky Groundwater Data Repository can be accessed at kgs.uky.edu/kgsweb/DataSearching/watersearch.asp. The database covers water wells and springs and groundwater-quality data. Several alternatives are available for viewing groundwater information on both interactive and static maps, and for creating graphical representations of groundwater-quality data.

The Kentucky water-well and spring search engine was accessed by the public 6,341 times during fiscal year 2012-13, and 542 downloads were made. It remains the second most popular search engine on the KGS website, after the one for oil and gas records. Users can search for wells or springs by county, 7.5-minute quadrangle, or a radius from a user-provided latitude/longitude location. Resulting data can be displayed on maps or downloaded for use in GIS packages.

The Kentucky groundwater-quality data search engine was accessed by the public more than 1,146 times during fiscal year 2012-13, and 130 downloads were made. Users can select from hundreds of parameters in 14 major categories, some of which are herbicides, pesticides, inorganics, metals, nutrients, volatile organic compounds, and petroleum hydrocarbons. Resulting data can be downloaded, displayed on maps, or used to generate graphs comparing groundwater-quality data by physiographic region or watershed basin.

For more information on groundwater-quality or water-well and spring data, contact the Survey at (859) 323-0524.

Interagency Coordination

Cooperation among agencies and research organizations that collect, analyze, and use groundwater data reduces monitoring costs, improves program efficiency, and promotes data sharing. The Kentucky Interagency Technical Advisory Committee on Groundwater provides a forum for participating organizations to meet on a quarterly basis and discuss groundwater issues.

Many programs benefit from the Division of Water's willingness to collect and analyze groundwater samples to support various projects. The Division of Water also samples groundwater and surface water for nonpoint-source constituents in support of projects for the Division of Pes-

ticide Regulation. The Division of Water and the Kentucky Geological Survey regularly answer inquiries from the public and communicate with staff of the Kentucky Rural Water Association. KGS staff has been meeting with County Extension Service agents and Area Development District personnel throughout the commonwealth to promote awareness of hydrogeologic issues. Some ITAC agencies are also members of the Kentucky Agricultural Water Quality Authority or cooperate with the authority and participate in their meetings. Members of both the Division of Water and the Kentucky Geological Survey regularly participate in meetings of State and Federal agencies and citizens' groups that have interests in groundwater resources.

Groundwater Data Sharing

Sharing data is an essential function of the Interagency Groundwater Monitoring Network. Data transfers between agencies provide each group access to a larger database than any agency could develop independently, thereby improving evaluations of groundwater quality and suitability for various uses, threats to groundwater quality, and the effects of mining, logging, agricultural practices, urbanization, waste disposal, and oil and gas production. Sharing data also reduces the overall expense and increases the efficiency of monitoring efforts.

Data have been transferred electronically between the Division of Water groundwater database and the Kentucky Groundwater Data Repository and between the Kentucky Geological Survey analytical laboratory and the Division of Water's Groundwater Section since 1992. There has also been a high level of collaboration and data sharing between KGS and the Groundwater Section during the reporting period, as the agencies are jointly reporting on groundwater quality throughout the state. During 2012-13, electronic data files of water-well, spring, and groundwater-quality data were transferred from the Division of Water to the Kentucky Geological Survey on a quarterly basis, and uploaded to the Kentucky Groundwater Data Repository, thereby allowing end-users to access the most recent well and spring data available.

Other Activities

ITAC agencies are involved in many activities concerning surface-water quality and public education about water resources. Although these projects do not directly address issues raised by the 1998 Kentucky General Assembly, they are important contributions because of the close interconnection of groundwater and surface-water systems in Kentucky. Some of these activities are listed below.

University of Kentucky Environmental and Natural Resource Issues Task Force

The Kentucky Well Education Website. This website (www2.ca.uky.edu/enri/downwell) is a joint project between ENRI and the Kentucky Geological Survey. The website contains information on well types and well construction, along with simplified descriptions of Kentucky Division of Water regulations regarding general well construction and specific types of wells. The website provides video and photographic examples of problems that may occur in wells and gives advice on solutions. This site is maintained by ENRI.

ENRI Website. The ENRI website (www2.ca.uky.edu/enri) contains information (e.g., publications, radio scripts, activities) on groundwater. In addition, the site includes information on watersheds, stormwater, nutrient management, the Kentucky Agriculture Water Quality Act, and the Kentucky Water Awareness Month packet. The site is maintained by Ashley Osborne, ENRI extension associate.

"See Blue Go Green" Website. This website (www2.ca.uky.edu/gogreen) contains information for all Kentuckians regarding "green" topics (e.g., drinking water, stormwater, wastewater, water quality, etc.). The site includes publications, fact sheets, radio scripts, displays, lesson plans, activities, and links. It is maintained by Ashley Osborne, ENRI extension associate.

ENRI Quarterly E-News. The ENRI E-News (www2.ca.uky.edu/enri/newsletter.php) is distributed to County Extension agents and other natural-resource professionals throughout Kentucky. E-News includes information about current

research, resources (e.g., new publications, training, etc.), and events, and is coordinated by Ashley Osborne, ENRI extension associate.

Kentucky Rain Garden Program. The ENRI Task Force and UK Horticulture Department installed 31 rain gardens at various locations throughout the state (e.g., County Extension offices, 4-H camping facilities, local parks, schools). At each installation, workshops were offered to more than 300 County Extension agents, master gardeners, and local citizens. At the conclusion of each workshop, attendees rated their level of understanding regarding rain gardens prior to and after the presentation. The feedback indicated that attendees' knowledge of rain gardens increased substantially after they attended a workshop. The evaluations also indicated a high level of potential that one or more stormwater/water-quality best management practices would be adopted.

40 Gallon Challenge. The ENRI Task Force received funding from the Southern Region Water Program to administer the 40 Gallon Challenge Water Conservation Program in Kentucky. Visit www.40gallonchallenge.org to see the total number of pledges and gallons of water saved daily.

Kentucky Water Awareness Month Packet. Each May, citizens across Kentucky celebrate Water Awareness Month. This program began in 1996 as an educational tool of the University of Kentucky Cooperative Extension Service. Each year, program materials are developed at the state level, and distributed via listserv to each of the 120 County Extension offices. Counties across the commonwealth celebrate Kentucky Water Awareness Month by participating in activities such as after-school programs, environmental day camps, and home-maker club meetings. The 2013 Kentucky Water Awareness Month materials are available online at www2.ca.uky.edu/enri/kwam2013.php. The packet is coordinated by Ashley Osborne, ENRI extension associate.

4-H₂O Ambassador Program. The 4-H₂O Ambassador Program addresses concepts related to watershed education. Each of the four curriculum units focuses on a specific question about water quality and watersheds, and includes hands-on activities (e.g., chemical, physical, and biological

water analysis). Curriculum is available online at www2.ca.uky.edu/enri/4H2O.htm. The program received the Outstanding Special Project Award at the fall 2011 Southern Regional Water Program Conference.

Cane Run Watershed Project. The University of Kentucky has led watershed-based planning, monitoring, and educational efforts as part of the Cane Run Watershed Assessment and Restoration Project. This project is coordinated by Steve Higgins and Amanda Gumbert.

Activities in the Cane Run watershed are:

- Continued to facilitate the Cane Run Watershed Council
- Led tours of the Cane Run watershed for UK Natural Resources Conservation and Management program courses, watershed professional development training for teachers, and State, Federal, and local agencies
- Acquired additional funding for stream-buffer and water-quality research in the Cane Run watershed, as well as additional funding for student and community education efforts
- Began implementation of water-quality best management practices at the Kentucky Horse Park and UK North Farm as recommended in the Cane Run Watershed Based Plan.

Kentucky Division of Forestry

Forested land provides important benefits to both groundwater and surface water in rural and urban landscapes. Forests absorb rain, trap and filter pollutants, recharge groundwater, slow storm runoff, sustain late-season flows, reduce flooding, maintain watershed stability and resilience, and provide critical habitat for fish and wildlife. Studies show that the percentage of forested land in a source-water area is one of the most important factors in determining water quality. The more forested land in a source area, the better the water quality and lower the treatment costs. Watersheds with less forested land have higher water temperatures and also higher levels of fecal coliform bacteria, turbidity, and nutrients.

Reduction of forest cover increases water yield, whereas establishment of forest cover de-

creases water yield. Water yield is the amount of surface water and groundwater leaving a watershed. On average, removal of 10 percent of forest cover was found to increase water yield by 40 mm in conifers, 25 mm in deciduous hardwoods, and 10 mm in brush and grasslands. Although simply removing forest increases the water yield, placing an impervious barrier such as pavement, roofing, or exposed rocks from mining further increases these yields.

The Kentucky Statewide Assessment of Forest Resources and Strategy, known as the Kentucky Forest Action Plan, released in June 2010 by the Kentucky Division of Forestry, revealed that water quality/quantity was the second most important concern of the citizens of the commonwealth, highlighted in a statewide survey of the most important issues facing the state's forest resources. The Division, along with stakeholder input, delineated seven major forest priority areas across the commonwealth to focus a collaborative strategy in maintaining sustainable forests and as a basis for improving water quality and quantity (Fig. 3).

The primary objective of the Division's Timber Harvest Compliance Program is to ensure that commercial timber harvesting operations use best management practices to protect water from nonpoint-source pollution. This program enforces the minimum performance standards of BMP's

mandated by the Kentucky Agriculture Water Quality Plan.

For the state fiscal year of July 1, 2012–June 30, 2013, a total of 4,372 harvest inspections were performed, resulting in 336 enforcement actions. A BMP monitoring study from a recent statewide survey indicated that 68 percent of the applicable BMP's were implemented on the sites examined.

The Division's Forestry Stewardship Program is also proactively involved with mitigating water-quality concerns by providing technical assistance in practice plans for riparian buffer development under the auspices of the U.S. Department of Agriculture–Natural Resources Conservation Service's Conservation Reserve Program.

The Division also addresses water quality by promoting the agroforestry concept of strategically incorporating trees into the agricultural landscape in order to protect water resources and meet landowner objectives. This integrated watershed approach is very effective in promoting water quality and many times has proved economical to landowners when implemented.

Mitigating stormwater issues is a component of the Division's Urban Forestry Program. The Division's urban forestry specialists are educating community leaders about the many benefits of trees in the urban setting, one of which is phytoremediation, or the use of trees to decontaminate soils or water. Urban forestry specialists and foresters

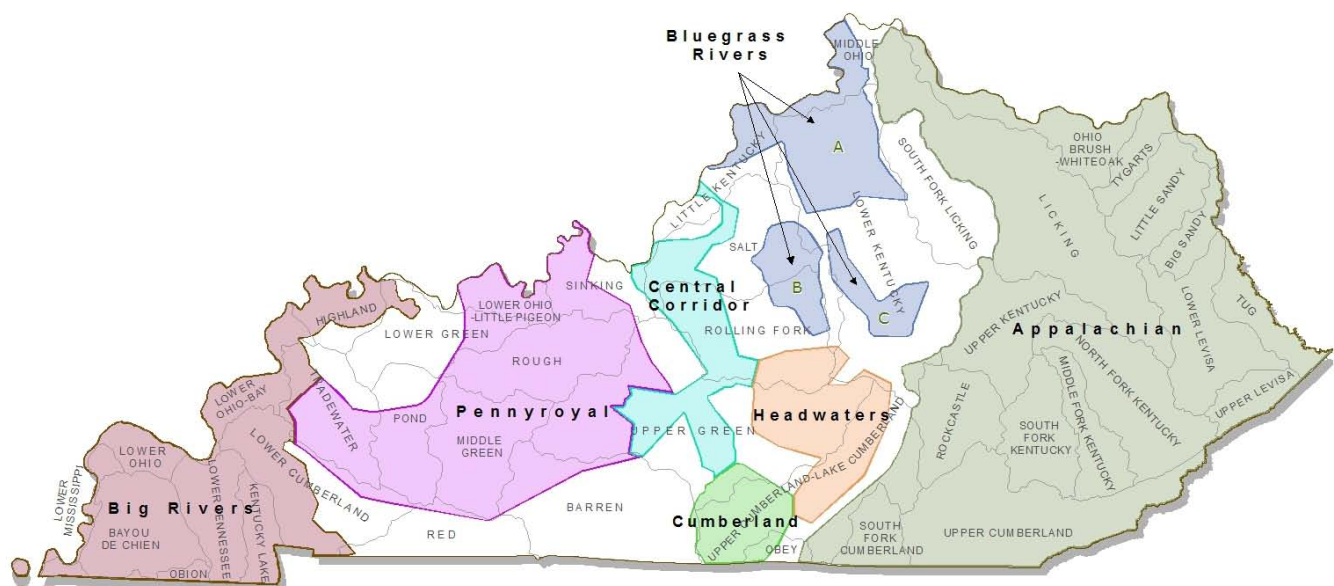


Figure 3. Kentucky forest priority areas and watersheds.

at the Division are also involved in the Cane Run Watershed Council, addressing water-quality concerns in the Lexington and Georgetown urban interface.

Watershed restoration projects initiated this year in which Division of Forestry personnel have provided technical assistance:

- Targeted bottomland hardwood management plans and educational outreach for landowners in the lower Green River area of western Kentucky
- Worked on the Red Bird River Restoration project led by the U.S. Forest Service and the Kentucky Waterways Alliance in southeastern Kentucky.

Kentucky Division of Mine Reclamation and Enforcement

The Field Support Section of the Division of Mine Reclamation and Enforcement investigates groundwater at the request of citizens of the commonwealth. The investigations may be a result of diminished water-well quality or quantity. In

addition, the Division also investigates surface water, including diminished quality, stream loss, or flooding. Investigations are also conducted as a result of landslides, methane migration, or other problems related to coal mining in the Eastern and Western Kentucky Coal Fields.

During the 2012-13 fiscal year, the Division received 72 new requests for inspections. Sixty-two inspections were also completed; of these, nine concluded that mining activity had had an adverse impact on a citizen's well or property. Of the nine adverse impact determinations, one was the result of diminished well-water quality, one was the result of loss of well-water quantity, six were related to seeps or landslides (or both), and one was caused by various issues related to surface water.

References Cited

Kentucky Division of Water, 1997, Kentucky watershed management framework: Kentucky Division of Water, 53 p.