Geohydrological and Biological Investigations Associated with a New Lead-Zinc Exploration Area near Winona, Missouri, and the Viburnum Trend of Southeastern Missouri

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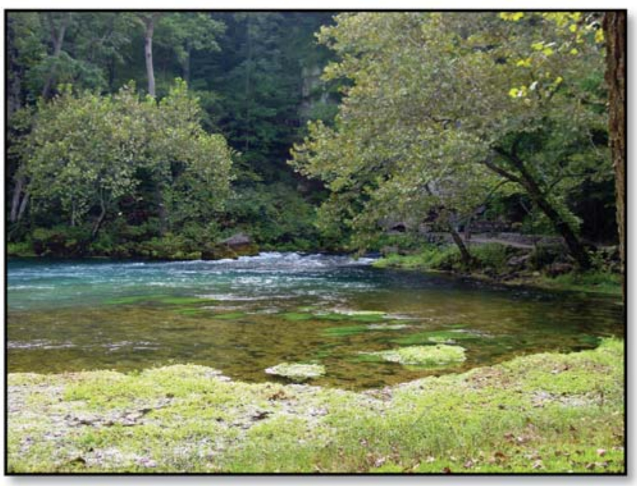
Introduction

Lead-zinc mining in the Viburnum Trend (fig. 1) began in the mid-1960s around Viburnum, Missouri. During the next 2 decades, 10 mines were opened along the south-trending ore deposit. Generally, the older mines are located in the northern part of the trend, and newer mines are located in the southern part of the trend. In response to declining economical ore reserves in the trend, mining companies began to explore for new ore bodies in an area south of Winona, Missouri, and north of the Eleven Point River (fig. 1). Mining companies have drilled more than 300 exploration boreholes in this area since the 1980s. Much of the exploration drilling is focused around a former Prospecting Permit Application Area (PPAA; fig. 1) granted in 1995 to a mining company by the U.S. Forest Service (FS) and U.S. Bureau of Land Management (BLM).



The exploration area is within a region highly valued for its scenic beauty and recreational opportunities, including two federally designated scenic rivers that more than 2 million people visit annually: the Ozark National Scenic Riverways (ONSR) administered by the National Park Service (NPS), and the Eleven Point National Scenic River (EPNSR) administered by the FS. The rugged, heavily forested region contains two large springs and numerous smaller springs, and supports a sensitive and diverse ecosystem. Big Spring, one of the largest springs in the Nation with an average annual mean discharge of 447 cubic feet per second (289,000 gallons per day; Hauck and Nagel, 2001), is located 20 mi (miles) east of the PPAA within the ONSR boundaries (fig. 1). Dye-trace investigations and ground-water level mapping have shown that the PPAA is within the recharge area of Big Spring (Imes and Kleeschulte, 1995). Another large spring, Greer Spring, has an annual mean discharge of 344 ft^3/s (cubic feet per second; 222,000 gallons per day; Hauck and Nagel, 2001) and is located about 3 mi south of the southern part of the PPAA within the EPNSR boundaries (fig. 1). The primary recharge area of Greer Spring may be about 25 mi northwest of the spring based on dye-trace studies and water-level maps (unpublished data on file at the USGS, Rolla, Missouri). Many smaller springs are present along three streams (Eleven Point River, Spring Creek, and Hurricane Creek; fig. 1) that flow through or near the PPAA. The discovery of an economically viable ore deposit in this new exploration area could potentially lead to the development of a new lead-zinc mining district. Mine dewatering in this area could substantially lower water levels and, thereby, decrease ground-water discharge to the many springs. Also, mining-related support activities could seriously degrade the quality of spring and stream water in the area and could introduce lead and other metals into stream and spring sediments where it might contaminate and threaten aquatic biota.

Because of the many environmental concerns associated with potential lead-zinc mining in the new exploration area, the FS, BLM, and U.S. Geological Survey (USGS) have supported several investigations since 1988 designed to quantify background physical and chemical characteristics of ground, surface, and spring water and sediment; to assess aquifer and confining unit hydraulic properties; to study background concentrations of trace elements in aquatic biota; and to provide geological mapping to establish a geohydrologic framework in the PPAA vicinity. These studies have provided vital information on the natural geohydrologic system of the PPAA vicinity. The USGS plans a 5-year integrated hydrologic, geologic, and biologic investigation of the possible effects of mining in the new exploration area and the Viburnum Trend (fig. 1). The Viburnum Trend offers an ideal laboratory for assessing potential environmental effects of mining in the PPAA vicinity because geologic conditions and mining practices in the Viburnum Trend are similar to the geology and likely mining practices in the exploration area. The investigation is planned to include onsite studies of stream, spring, and aquifer hydrology, additional field geologic mapping, geochemical research on trace element mobility from mined ore bodies, surveys of stream biological quality and lead accumulation by aquatic biota, and research on the toxicity of lead and other heavy metals to aquatic biota. The planned investigation would be conducted by a USGS multi-discipline scientific team.

Geohydrologic Setting

Three major geohydrologic units (fig. 2) overlie the Precambrian basement rocks in the exploration area. The deepest unit, the St. Francois aquifer, is composed of the Lamotte Sandstone and overlying predominantly carbonate Bonneterre Formation and contains most of

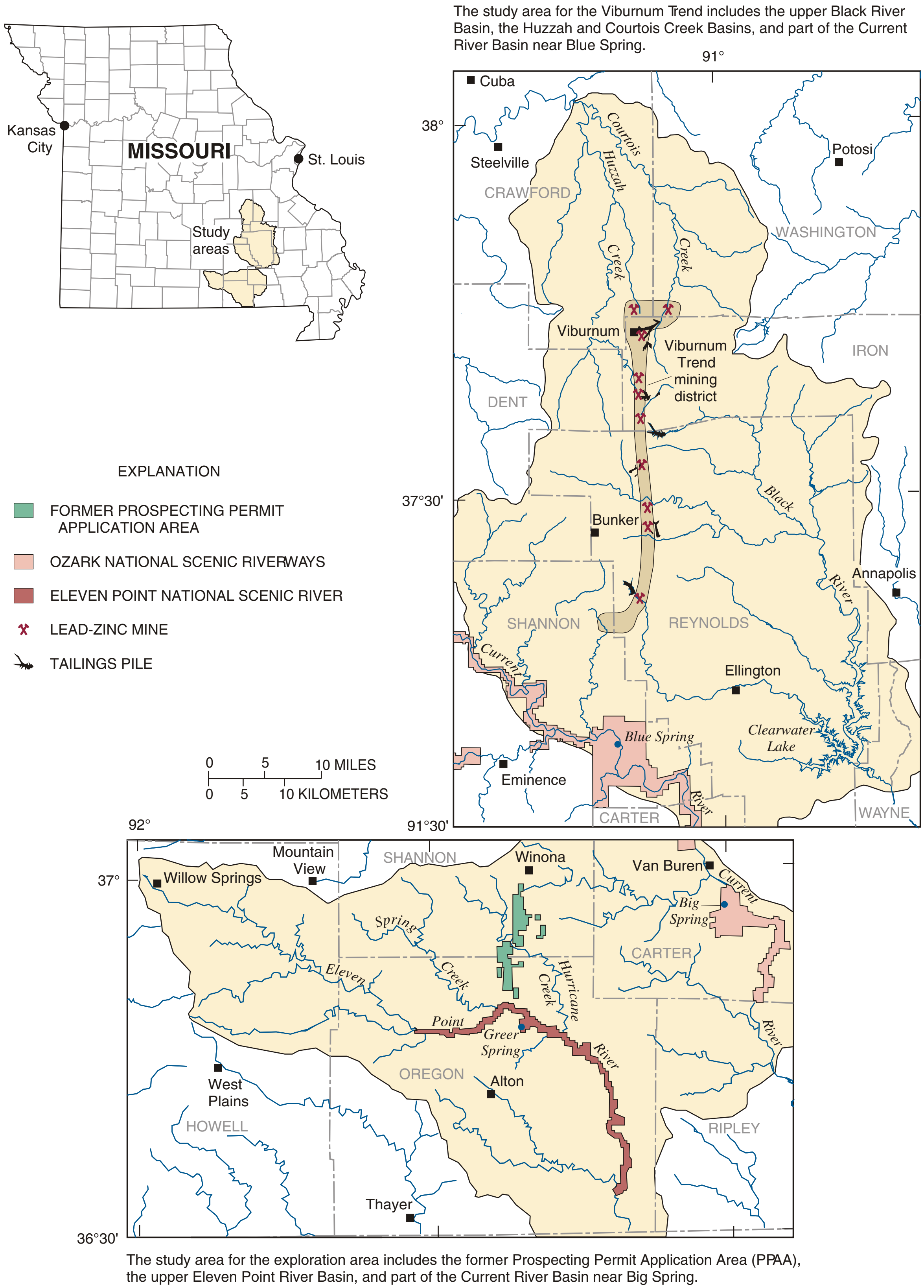


Figure 1. Study areas for investigation of effects of lead-zinc mining in the Viburnum Trend and potential effects of lead-zinc mining in the new exploration area.

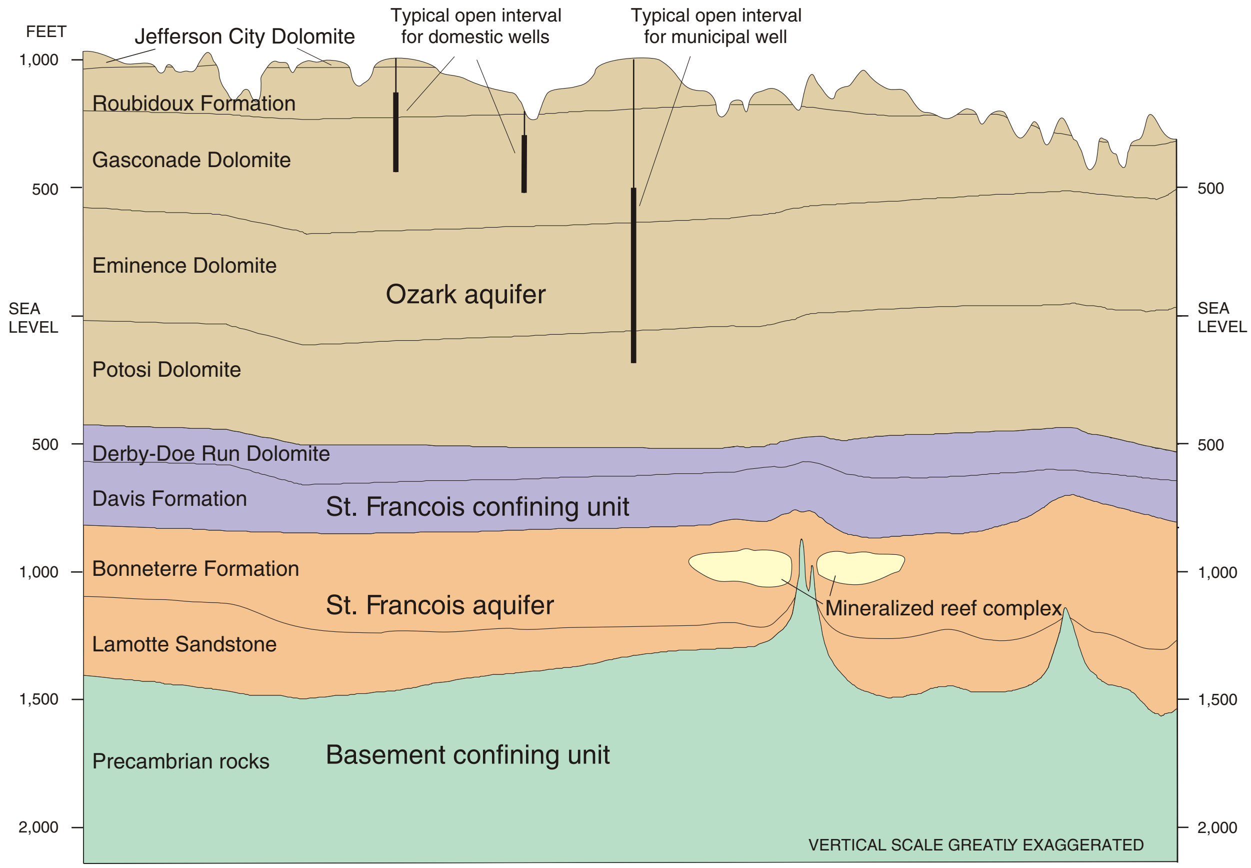


Figure 2. Generalized section of the exploration area showing Precambrian knobs, depth of primary mineralized zone, major aquifers and confining units, geologic formations, and depths of typical domestic and municipal supply wells (thinner line is cased interval; thicker line is open borehole).

the lead-zinc mineralization. The aquifer yields sufficient water for domestic and municipal use where it crops out in southeastern Missouri; however, because the top of the unit is about 1,600 ft (feet) below land surface in the vicinity of the PPAA, it is not used as a water-supply source. Lead-zinc ore usually is concentrated within the Bonneterre Formation and commonly is associated with ancient reef complexes near Precambrian igneous knobs that protrude upward into the aquifer (Leach, 1994; Goldhaber and others, 1995; Kleeschulte, 2000a).

The St. Francois confining unit overlies the St. Francois aquifer. The confining unit consists of the shaly Davis Formation and overlying Derby-Doe Run Dolomites, which contain a substantial thickness of limestone. The approximately 300-ft thick confining unit impedes the flow of ground water between the St. Francois aquifer and the surficial Ozark aquifer. The Ozark aquifer is about 1,000 ft thick and primarily is composed of (from deepest to shallowest) the Potosi Dolomite, Eminence Dolomite, Gasconade Dolomite, Roubidoux Formation, and Jefferson City Dolomite in the vicinity of the PPAA. The Ozark aquifer is karstic and supplies large quantities of water to springs and to domestic and municipal wells throughout southern Missouri. The term karst refers to a geologic terrain formed when carbonate rocks such as limestone and dolostone are dissolved by ground water. Karst terrain typically is characterized by the presence of sinkholes, caves, streams that lose water into the ground, and springs. Karst features are common throughout the exploration area and greatly increase the rate of groundwater flow through the aquifer and the potential for rapid transport of contaminants from upland areas to streams and springs and between surface-water basins.

Investigations in the New Exploration Area

The USGS began hydrologic investigations in the new exploration area in 1988 after mining companies had expressed a strong interest in the area, which was indicated by the amount of exploration activity. The first studies were directed toward the collection of background or baseline data on water flow, water quality, sediment composition, and heavy metals in stream biota. These data were collected to provide hydrologic information with which future data could be compared if mining occurs in the area. The comparison would be helpful in quantifying environmental changes induced by mining and mining-related activities.

Much of the baseline hydrologic assessment work was accomplished from October 1988 to September 1993 and published in Kleeschulte and Sutley (1995). Water samples were collected from 29 wells, 6 stream sites on the Current River, Eleven Point River, Spring Creek, and Hurricane Creek, and 7 perennial springs in these river basins to assess the quality of surface and ground water in the vicinity of the PPAA. Physical properties such as specific conductance, pH, temperature, dissolved oxygen, and alkalinity were measured when the water samples were collected. The samples were submitted to the USGS laboratory in Denver, Colorado, for determination of dissolved cations, anions, trace elements, nutrients, and total organic carbon. Stream and spring water samples also were analyzed for suspended sediment concentration. Streambed sediment samples also were collected at each spring and stream water-quality sampling site and were submitted for grain-size analysis, semi-quantitative mineralogy analysis, and quantitative elemental analysis to determine the background concentration of insoluble heavy minerals commonly associated with lead-zinc mining (Kleeschulte and Sutley, 1995).

Dye-tracing investigations (Aley, 1975; data on file at the Missouri Department of Natural Resources, Division of Geology and Land Survey) have indicated that the recharge area of Big Spring includes the area of lead-zinc exploration. The USGS determined ground-water altitudes and seasonal ground-water fluctuations in the PPAA vicinity by measuring the depth to water in 57 wells during the spring of 1990, 1991, 1992, and 1993, and fall of 1991, 1992, and 1993. Additional dye-trace investigations also were conducted by the USGS. The water-level data were used in conjunction with the dye-trace data to determine ground-water flow directions in the area between the PPAA and Big Spring and to further identify areas of mature karst development where water is rapidly transported to Big Spring (Imes and Kleeschulte, 1995). Continuous water-level recorders also were installed on three deep wells during the study to assess the seasonal response of water levels in the wells.

Losing streams, a common feature in the karst terrain of southern Missouri, occur where a combination of high streambed hydraulic conductivity and low ground-water levels cause a substantial part of the stream water to flow through the streambed into the bedrock. The presence of losing streams in the potential new mining area is of concern because contaminants released during mining activities or from stored mine waste (tailings piles) potentially can migrate into the ground-water flow system. Losing stream reaches were identified and ground-water discharge to streams was measured in the Eleven Point River, Spring Creek, and Hurricane Creek (Kleeschulte, 2000b). The upstream reaches of Spring Creek and Hurricane Creek are almost entirely losing streams. Water lost by Hurricane Creek flows eastward through the ground-water flow system beneath a surface-water basin divide and eventually discharges at Big Spring.

The bedrock geology in the area between Hurricane Creek and the Current River was mapped from 1995 to 2001 as part of a USGS National Cooperative Geologic Mapping Program. The traditional mapping of bedrock formations was augmented by a concentrated effort to identify fractures (a break in the bedrock caused by stress relief, including cracks, joints, and faults), bedding planes (a rock layer surface that tends to split, break, or separate from overlying or underlying layers), and other rock features that can affect ground-water flow. The physical characteristics of each observed fracture and bedding plane were described onsite. These characteristics include length, width, and orientation of the rock opening, and evidence that the fracture or bedding-plane openings were being decreased (cementation) or enlarged (dissolution) by ground-water flow (McDowell, 2000; McDowell and others, 2000). Most of the cave systems in this area have developed along bedding planes, indicating that ground water formerly flowed preferentially along bedding planes (Orndorff and others, 2001).

Photograph courtesy of Michael J. Kleeschulte

If lead-zinc mining is permitted in the new exploration area, the upper part of the Bonneterre Formation near mine tunnels and shafts would be dewatered. There are questions regarding the potential effect of mine dewatering on the ground-water levels in the Ozark aquifer and on springs and streams in the area. The USGS is evaluating the vertical hydraulic conductivity of the St. Francois confining unit to help determine if mine dewatering in the St. Francois aquifer would be likely to lower water levels in the Ozark aquifer. The investigation includes laboratory determination of the vertical hydraulic conductivity of rock core samples from the St. Francois confining unit collected from exploration boreholes by mining companies, as well as mapping of the thickness, altitude of top, and shale content of the St. Francois confining unit (Kleeschulte and Seeger, 2000; Kleeschulte and Seeger, 2001). The estimated vertical hydraulic conductivity of 10^{-12} to 10^{-14} ft/sec (foot per second) determined for carbonate and shale rocks that form the St. Francois confining unit suggests that the unit forms an effective barrier to ground-water flow. However, the investigation did not include an assessment of the occurrence or hydraulic properties of vertical fractures that may extend through the St. Francois confining unit. A pilot study is being conducted to investigate the value of using audio magneto-telluric surveys to determine the presence of vertical fractures in the confining unit.

There is concern that lead-zinc mining in the new exploration area could adversely affect the flow and quality of water at Big Spring and Greer Spring. This concern stems from dye-trace data that indicate the recharge area of Big Spring encompasses much of the exploration area and from the fact that Greer Spring is only a few miles south of the PPAA (fig. 1). Big Spring and Greer Spring are being studied by the USGS to determine the physical (extent of recharge area, discharge rates, storage capacity, turbidity, rock matrix dissolution rates, and ground-water residence time) and chemical (natural and anthropogenic compounds and isotopes) characteristics of the springs. The methods of investigation include dye-tracing, water-level mapping, measuring stage, water velocity, and turbidity in the spring branches and using automatic and manual samplers to collect water samples for chemical analysis. The information will be useful for evaluating the potential for spring degradation by lead-zinc mining and other human activities.

Investigations in the Viburnum Trend

Ground-water levels in observation, domestic, and public water-supply wells were measured during 2000 in a 17-mi by 33-mi area surrounding the Viburnum Trend and compared with historical ground-water level data (mostly pre-1960 data from the same area) to assess the effect of mine dewatering on water levels in the surficial Ozark aquifer (Kleeschulte, 2000b). Because of the geologic similarity between the Viburnum Trend and the new exploration area, the comparison provided an indication of the possible effects of mine dewatering in the exploration area. Analysis of digital interpolations of the two water-level data sets on 0.5-mi centers indicated that the differences between historical and recent water levels are small and are within the accuracy of the data. The study concluded that no large cones of depression have formed in the surficial Ozark aquifer along the Viburnum Trend as a result of the dewatering of mines in the upper St. Francois aquifer. Localized drawdown may be present near shafts, ventholes, and inadequately plugged exploration holes that completely penetrate the St. Francois confining unit.

Tailings piles are large accumulations (tens to hundreds of acres) of finely ground rock (a by-product of the mechanical and chemical separation of lead-zinc ore from the rock matrix) that typically are placed in dammed headwater valleys. The rock is piped to the disposal site as a slurry, and compacts as the slurry water evaporates or infiltrates into the pile and subjacent bedrock. Tailings can be a source of sediment load to streams, and trace-element contamination to ground water and streams. Ground-water levels and flow directions may be altered beneath the tailings piles. A hydrologic investigation of tailings piles in the Viburnum Trend is planned to more fully understand the effect of these piles on the environment. The investigation would include drilling monitoring wells around tailings piles to collect water-level and water-quality data; an analysis of tailings material, tailings water, ground water, and surface water to assess the presence and mobility of trace elements; and an estimation of a water budget for a tailings pile.

Lead-zinc sulfide minerals and associated iron sulfide in the Viburnum Trend are far below the ground surface in an oxygen deficient environment (Lee and Goldhaber, 2001a). Natural chemical reactions between the ore-bearing rock and ground water in unmined areas can cause slightly elevated background concentrations of toxic trace elements, including heavy metals in ground and surface waters (Lee, 2000). When an ore body is mined, lead-zinc sulfides are crushed, and oxygen-rich air is brought into contact with the minerals. Compounds that were stable and immobile in an oxygen deficient environment can be mobilized by the introduction of oxygen-bearing water during mining. This process can increase the concentrations of trace-element compounds in ground water and stream water above natural background concentrations (Lee and Goldhaber, 2001b). A study of regional variations in ore mineralization and ground-water chemistry in the Viburnum Trend is planned to determine the natural background concentrations of trace elements of concern. This study also would include collection of water samples from seeps in the mine tunnels, discharged mine water, tailing ponds, and ground and surface waters from mined areas to determine post-mining concentrations of major cations and anions, trace elements, and organic compounds used in the mines. Geochemical reaction calculations would be used to evaluate the processes that control the release of trace elements during the mining process.

Tailings piles contain an abundance of heavy metals (mostly as metal sulfides) that can be released into the aquatic environment under certain conditions. Particles of nearly insoluble heavy-metal sulfides can be transported directly into stream sediments by runoff. Metal sulfides also can be made more soluble by the action of bacteria (biotic processes) or by the surface oxidation of sulfides to sulfates (abiotic processes) and leach into water moving through the tailings piles into the streams. When solubilized metals enter the stream environment, they can become re-associated with particulates by forming insoluble carbonate precipitates, sorption to particle surfaces, or complexation with stream organic matter. Depending on the hardness, pH, and other water-quality conditions, both particulate and dissolved metals are available to differing degrees for uptake by aquatic organisms. A study by Schmitt and others (1993) showed that fish from several streams in the Viburnum Trend contained elevated concentrations of lead and other mining-derived metals and decreased levels of an enzyme involved in hemoglobin synthesis. Fish from reference sites in the new exploration area (Hurricane Creek) and Big Spring contained low concentrations of lead and normal enzyme levels.

Future biologic investigations planned by the USGS include additional synoptic sampling and analysis of stream biota in mining-affected areas to quantify heavy-metal concentrations in the stream ecosystem and identify metal exposure pathways in stream food webs. Metal exposure in grazing and predator fish would be characterized using biochemical indicators. The distribution of contamination in fine-grained bed sediments at riffle and depositional stream habitats and in Clearwater Lake (fig. 1) would be determined. Seasonal sampling of different stream-reach habitats would be used to identify habitat-specific responses of biological communities to heavy metals. Fresh-water mussels would be used to monitor differences in metal bioavailability among streams affected by mining activities. Data previously collected in the Viburnum Trend by the USGS as part of the National Water-Quality Assessment Program (Petersen and others, 1998) also would be analyzed to assess the composition of aquatic communities and concentrations of pesticides, metals, and other anthropogenic compounds in streams. The ecological quality of stream biota in the new exploration area would be similarly assessed and compared with data collected in the Viburnum Trend. The reference data set also would be invaluable, should mining occur in the new exploration area, to establish pre-mining background conditions.

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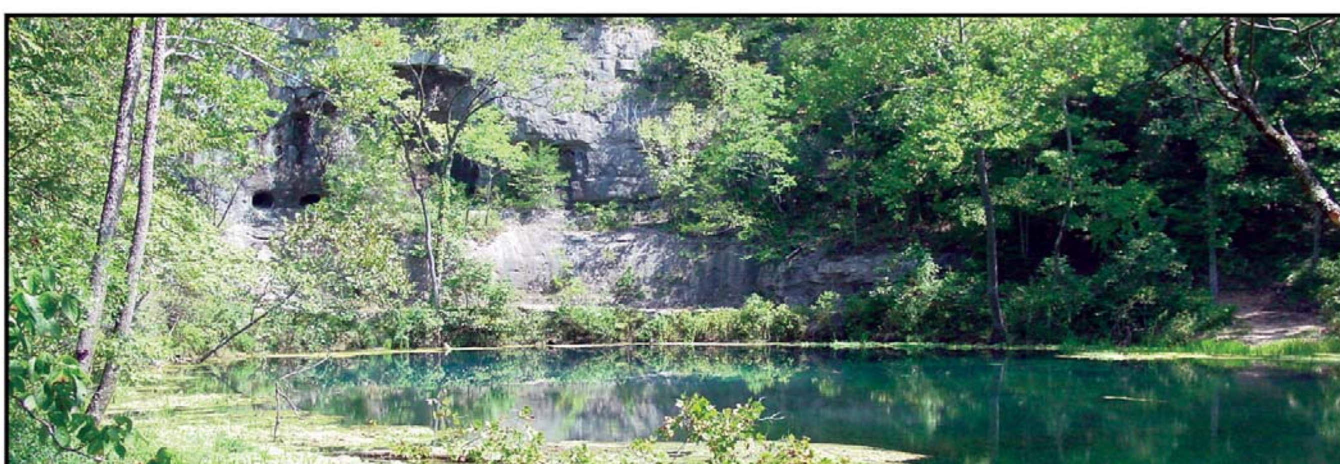

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