Chapter 3. Science in the Watershed

This chapter discusses various scientific analyses that were used in the planning process. Several studies were carried out in conjunction with the Bonne Femme Watershed Project, while others discussed in this chapter were completed independently. It was important for the Stakeholders to understand various aspects concerning stream health and function, combined with how they might change in the future. These studies helped provide an understanding of the scientific necessity for, and impact of, their planning decisions. Various studies were given to the Stakeholders via reports and presentations. Project-related studies were carried out to give the Stakeholders scientific information that helped inform their planning process. Also, initial studies recorded baseline conditions for the watershed's streams. Each study is briefly summarized.

Details of these studies are provided in Appendix G.

3.a Karst Hydrogeology and Soils of the Bonne Femme Watershed

__General Watershed Information__

As shown in Figure 3.1, page 46, the Bonne Femme watershed is located in southern Boone County, Missouri between the cities of Columbia and Ashland (Figure 3.1, left). The watershed encompasses 93.3 square miles and consists of nine subwatersheds (Figure 3.1, upper part). For convenience, these are combined into three major subwatersheds (Figure 3.1, left): Little Bonne Femme Creek; Bonne Femme Creek; and the combination of Turkey and Bass Creeks. The upper map in Figure 3.1 shows the surface-drained subwatersheds (i.e., those subwatersheds in which most of the water stays at or near the land surface). The lower map in Figure 3.1 shows the two karst recharge areas (i.e., subwatersheds which contribute water to the two major cave systems; see the discussion below). The term karst refers to soluble bedrock (limestone and dolomite) terrain that has *sinkholes*, caves, *losing streams* and springs. A karst recharge area is the surface land area that drains to a cave system.

A mixture of land uses occurs within the Bonne Femme watershed, with agricultural activities the predominant land use, encompassing 61.5% of the watershed area (Figure 3.2, page 47). Row crop production is mainly in the eastern (higher elevation) portions of the watershed, and along flood plains in the western (lower elevation) portions of the watershed. Pasture and range lands are more widely scattered, but generally concentrated in the central and eastern portions of the watershed. Forested areas make up nearly one-third of the watershed, mainly within the central and western parts of the watershed. These forested areas also encompass most of the publicly-owned lands, including Rock Bridge Memorial State Park and Three Creeks Conservation Area. Urban areas are beginning to encroach on the watershed as the cities of Columbia and Ashland continue to grow.

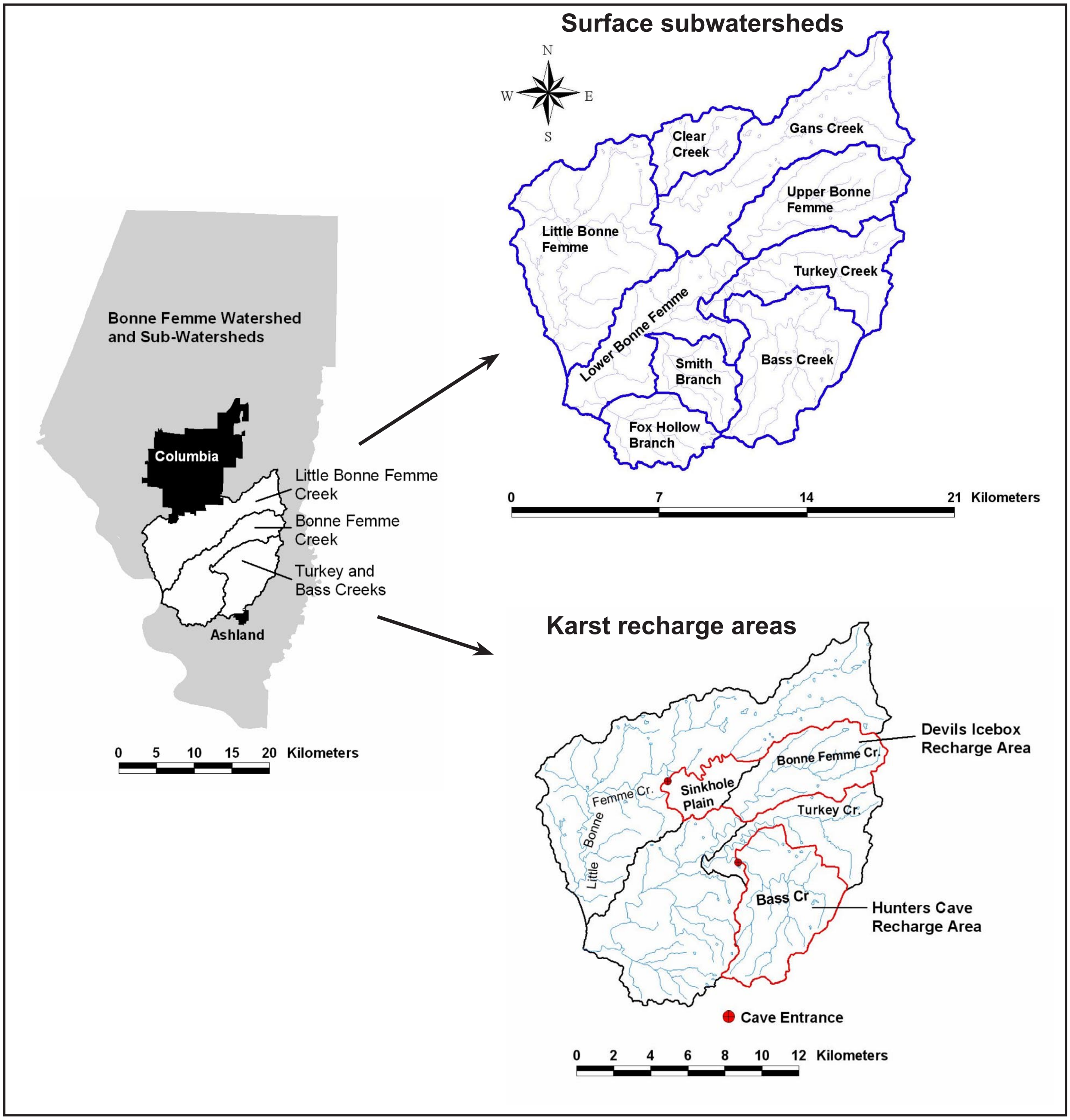

Figure 3.1 Location of Bonne Femme watershed, subwatersheds, and karst recharge areas.

Karst Recharge Areas and Implications for Water Quality

The two *karst* recharge areas that supply water to the Devil's Icebox and Hunters Cave Branches are of similar size (Devil's Icebox, 13.1 square miles and Hunters Cave, 12.9 square miles); their combined areas account for approximately 28% of the entire watershed (Lerch *et al.*, 2005). In both areas, recharge to the cave streams occurs along sinking or losing surface stream channels, in which water infiltrates through porous streambed sediments or through

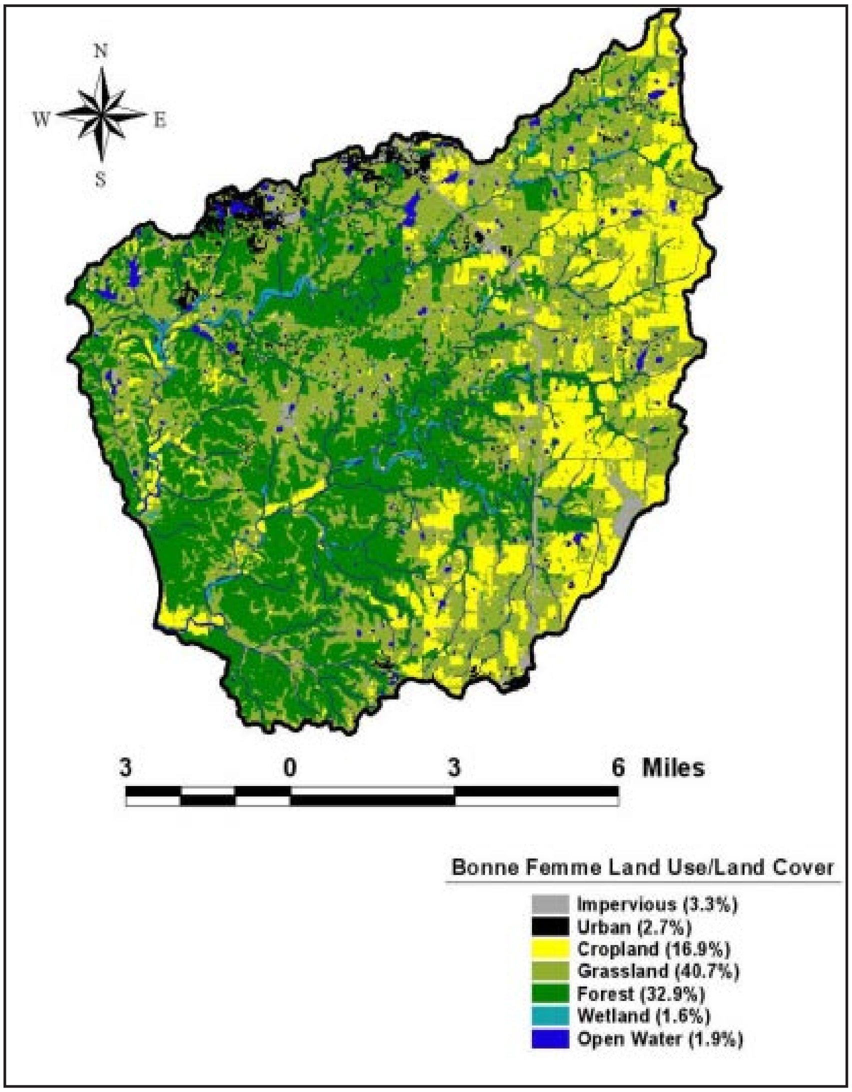

Figure 3.2 Land use/land cover for the Bonne Femme watershed.

Data were obtained from 30-m resolution LANDSAT data collected from 2000-2004.

cracks in the bedrock. Upper Bonne Femme Creek is the *losing stream* that supplies most of the water to the Devil's Icebox Cave Branch; Bass Creek is the main source to the Hunters Cave Branch. In addition, water can also enter the caves through sinkholes (a hole at the bottom of a depression). Each sinkhole drains a small land area and therefore contributes less water volume to the cave than the losing streams. Many *sinkholes* in the Pierpont area drain into the Devil's Icebox Cave Branch, so a considerable volume of water can enter the cave in this manner. However, the sinkhole drainage area is smaller than the upper regions of the Bonne Femme Creek drainage area, so the latter is the major contributor. Of particular interest is the underground transfer of water between two surface subwatersheds. For example, in the Devil's Icebox Cave Branch recharge area, water from upper Boone Femme Creek loses water to the Devil's Icebox Cave Branch, which eventually discharges to the Little Bonne Femme Creek.

Management Challenges

Overall, karst recharge areas are very vulnerable to groundwater contamination, because surface water rapidly enters the cave system with little or no opportunity for reducing contaminants by surface soils. In the Bonne Femme watershed, sources of pollution that are a potential threat to karst groundwater quality include unmitigated urban development, improper application of chemicals and nutrients, malfunctioning private septic systems, and animal waste. These pollution sources can impact karst aquifers through the introduction of numerous contaminants, such as oil, gasoline, antifreeze, pesticides, fertilizers, sediment, and fecal coliform bacteria (Ruhe *et al.*, 1980; Boyer and Pasquarell, 1999; Mahler *et al*., 1999; Lerch *et al.*, 2001).

A growing threat to karst groundwater in the Bonne Femme watershed is the increasing area of land surface that is impervious to water as a result of urbanization. In developments without proper handling of stormwater and removal of pollutants, *impervious surfaces* such as roads, building rooftops, sidewalks, driveways, and parking lots, will negatively impact stream hydrology, biology, and channel shape. In surface stream watersheds, impervious surfaces increase speed and amount of storm water runoff, which in turn degrades aquatic habitat and biological health of streams, increases stream bank erosion, and decreases base flow discharge (Burges *et al.*, 1998; Booth *et al.*, 2002). These hydrologic impacts have also been shown to occur in karst recharge areas (Betson, 1977; Ruhe *et al.*, 1980). Karst systems further complicate the impact of unmitigated impervious surfaces because stormwater runoff can transfer from one watershed to another through underground channels. This situation exists where water transfers from the upper reaches of Bonne Femme Creek to the Devil's Icebox Cave Branch, and hence to the Little Bonne Femme Creek. The increased runoff caused by impervious surfaces will most profoundly impact The Devil's Icebox Cave Branch, but localized increases in impervious surface could negatively impact the water quality and quantity of the Hunters Caves Branch as well.

Geology, Soils, and Land-Use

The geology and the soils of the Bonne Femme watershed are rather atypical for karst watersheds in Missouri (Figure 3.3, page 48). The difference is due to the fact that the watershed lies at the edge of glacial activity that occurred in the last two million years. The layers of bedrock within the watershed were formed during the Mississippian Age, 310-345 million years ago. The lower layers of bedrock form a unit called the Chouteau Group, which is rarely exposed at the Earth's surface. This layer is composed of limestone, dolomite, and silty dolomite with a total thickness of approximately 100 feet, but it is not conducive to cave development because of its insoluble nature (Unklesbay, 1952). The Chouteau Group serves as the base of the cave stream in the Devil's Icebox Cave. Overlying the Chouteau Group is the Burlington Limestone, a crinoid-rich limestone with abundant chert and a total thickness of approximately 160 feet (Wicks, 1997). Caves within the watershed were formed within the Burlington Limestone layers, which are exposed throughout the central portions of the watershed.

The eastern portions of the watershed are covered by clay-rich Pleistocene age glacial and loess (i.e. wind blown) deposits (Figures 3.4, page 49). These poorly drained, fertile soils

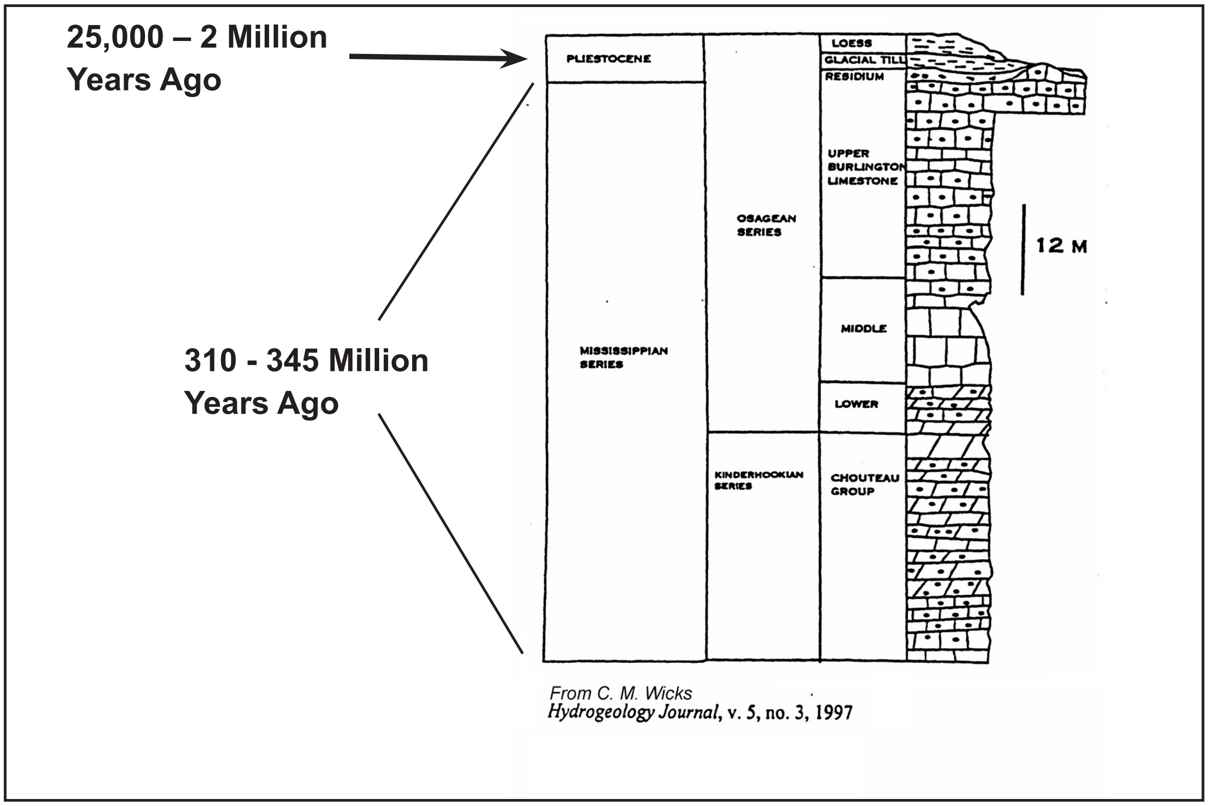

Figure 3.3 Generalized geologic stratigraphy for the Bonne Femme watershed.

are generally in the Mexico-Leonard-Armstrong soil associations (USDA-NRCS, 2001) (Figure 3.4), and they also support the most intensive row crop production within the watershed (Figure 3.2). This area was covered by glaciers, leaving *glacial till* soils. Then, as the glaciers receded, it was covered by *loess* with high clay content, leaving deep soil deposits. Topography is relatively flat and karst features are absent.

Central portions of the watershed are characterized by *residual soils* (i.e. weathered from bedrock) of the Weller-Bardley-Clinkenbeard association (USDA-NRCS, 2001). This area was never covered by glaciers. Soils are mostly the material remaining from weathered limestone bedrock (residuum), and the soils tend to be rocky and shallow. Thin loess covers some ridge tops and uplands. This central region is the karst area, with features such as sinkholes, caves (including Devil's Icebox and Hunters Caves), and springs. Topography is characterized by steep slopes, rock outcrops, and deeply dissected stream valleys. These soils support some pasture and range land, but forested areas are the most common land cover in this area of the watershed.

The western portion of the watershed is covered by *loess* (wind blown) and *fluvial* (water deposited) soils of the Menfro-Winfield-Rocheport and Keswick-Hatton-Winnegan soil associations. The deep loess deposits were derived from the Missouri River floodplain, and

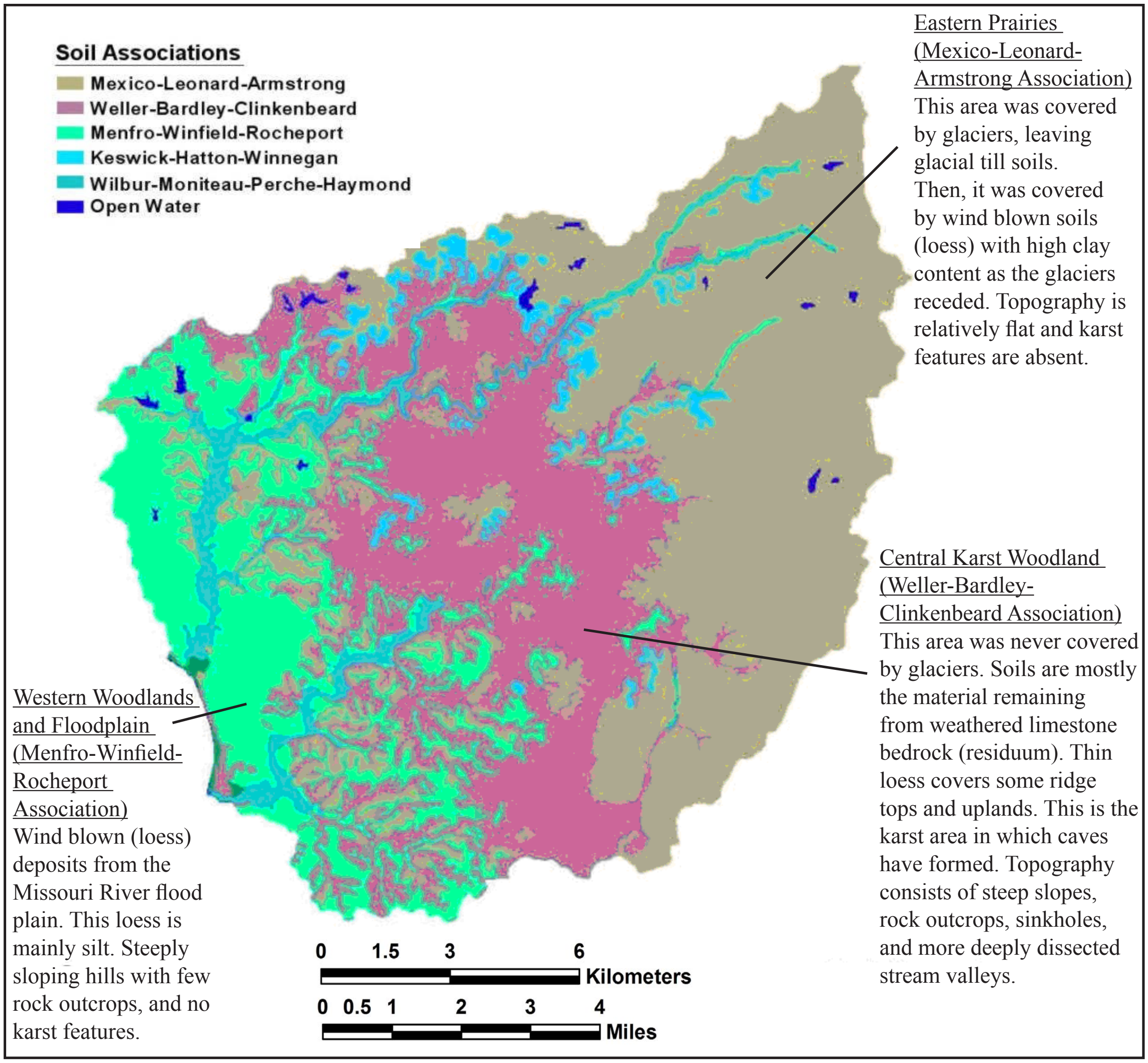

Figure 3.4 Soil Associations

they are mainly silt rather than the clay-rich loess in the eastern part of the watershed. The topography consists of steeply sloping hills with few rock outcrops and no karst features.

Soils perform some essential functions with respect to mitigation of contaminants. These functions can be divided into three categories: 1) hydrologic, 2) retention, and 3) degradation. First, soils impact watershed hydrology based on the rate that water moves into the soil (*infiltration*) and the soils' water holding capacity. In general, thicker soils will have greater water holding capacity than thinner soils; therefore, the soils in the eastern and western portions of the watershed will hold more water than those in the central area of the watershed. The karst area of the watershed not only has thin soils, but also has sinkholes in which water flow has little interaction with the soil before draining to groundwater or one of the cave streams in the watershed. In contrast, soils in the eastern portion of the watershed have high clay content, which significantly slows the rate of water infiltration, which leads to more runoff.

The second key function of soils is their ability to retain contaminants. Soils contain clays and organic matter that can chemically bind some contaminants, such as metals and pesticides, while other contaminants, such as nitrate (NO_3^-), will travel downward with percolating water and will not be retained by the soil. Although the soils in the eastern portion of the watershed have high clay contents, their ability to retain contaminants is limited by their high runoff potential. However, management factors, such as incorporating fertilizers and pesticides for crop production, do greatly improve retention of these contaminants by enhancing their interaction with soil. Soils in the central portion of the watershed are typically so thin that, regardless of their clay or organic matter content, their ability to retain contaminants is very limited. The silt loess soils in the western portion of the watershed have the best overall characteristics for retaining contaminants, but steep slopes that promote runoff may limit contaminant retention in some settings. Also, the relatively shallow water table and higher infiltration rates of these silt loess soils likely creates a high risk for leaching of poorly retained contaminants, such as nitrate, to groundwater.

The third important function of soils is their ability to biologically or chemically degrade contaminants, resulting in the formation of less- or non-toxic byproducts. Often, this function will be related to the organic matter, clay content and hydrologic characteristics of soils, since these properties determine how conducive the soil is to microbial growth and activity, and how chemically reactive the soils may be. The thin soils within the central portion of the watershed certainly have less ability than soils in the eastern and western portions of the watershed with respect to this function. Compared to the thicker clay and silt loess soils, thin soils with low organic matter will not support sufficient microbial populations to achieve significant contaminant degradation. However, short- and long-term land uses also affect the ability of a soil to degrade contaminants. For instance, the persistence of the herbicide atrazine often is related to the cropping history of the soil. Soils with even a short-term history of corn production, in which atrazine was used for weed control will degrade atrazine many times faster than areas that have never received the herbicide. Also, certain forage grasses, such as tall fescue, orchardgrass, and eastern gamagrass have the ability to stimulate microbial populations near the soil surface, resulting in enhanced degradation of some herbicides, and in reductions in nutrient leaching to ground water. Thus, the degradation potential of any soil is a complex function of soil properties and their associated plant communities.

Contributor: Robert N. Lerch, Soil Scientist, USDA-ARS.

Figure 3.5 Life Cycle
Federally endangered gray bats (left) that inhabit caves of Boone County, spend summer nights catching thousands of flying insects that in younger stages of life were aquatic. Living in streams of the watershed are mayfly nymphs (middle), one of the *EPT* insects that are sensitive to water quality. After metamorphosis, mayfly nymphs become adult flying insects (right) that are preyed upon by bats.

3.b Cave Life

Missouri is sometimes called "The Cave State" because caves are so abundant throughout Southern Missouri and the Missouri and Mississippi River border areas. The Missouri Speleological Survey has recorded locations of about 6,300 caves. Many people find caves to be fun places to explore, places to see beautiful *stalactites* of calcite, and to challenge one's fear of the dark and unknown. Adding to the mysterious surroundings are mysterious animals. Bats, with their unique insect-catching abilities of flight and *echolocation*, sleep through the winter while hanging from cave ceilings in the mild year-round temperatures. Other creatures are unlike anything seen above ground. They lack color and eyes, and manage to live quite well in an environment with no light or plants.

Many of these mysterious creatures remain undiscovered, because scientists haven't yet visited their cave — only about 1,000 (about 15%) of Missouri's caves have been inventoried for cave life. Undiscovered because some of the animals are tiny. Undiscovered in the sense that while some have been found, they haven't yet been taxonomically described and named. Undiscovered in that while some have been described and named, we understand very little about how they live and interact with other animals.

The pink planarian (Figure 3.6) existed in obscurity underground for thousands of years, before its discovery by scientists in 1956 (Hyman, 1956). Fifty years later, only a little research has been conducted (and still much is unknown about how the pink planarian lives or about the ways it could benefit humans). Other species of planarians were useful in the 1960s in memory research (Jacobson *et al.*, 1966). Planarians are one of the simplest of animals that have brains and nervous systems. The pink planarian is a flatworm approximately one inch long and approximately one-quarter inch wide. They are white or translucent, sometimes with a pink tinge. Both male and female sexual organs exist within each individual. A cocoon of eggs is produced (Kenk, 1975). In a laboratory, pink planarians ate amphipods. One of the mysteries

Figure 3.6 The Pink Planarian. Not only is the pink planarian cave adapted, it is also endemic, depending entirely upon Devil's Icebox Cave for it's habitat. It has not been found to exist anywhere else.

that remains is how pink planarians manage to catch *amphipods* in the wild. Amphipods are fast swimmers and pink planarians have no eyesight (and it's dark anyway). Another mystery is whether animals such as crayfish and salamanders prey upon pink planarians.

Notably, the pink planarian is rare. This species has been found to exist in no other cave besides Devil's Icebox Cave. This means the pink planarian is "*endemic*," being restricted to this one habitat. Endemic can refer to areas of various size, but with cave animals, usually refers to one cave. The entire population of pink planarians exists in one cave stream, making it vulnerable to extinction should Devil's Icebox Cave Branch become polluted. One would hope that if the main cave stream became polluted, that some individuals in the underground tributaries to the main stream would survive to repopulate, but to date, none have been found in the cave tributaries (Sutton, 2004).

The pink planarian is adapted to the nutrient inputs received from hundreds of sinkholes and has obviously survived agricultural practices of early Boone County that included hog lots and soil erosion. However, it's not known what effect modern chemicals, pesticides, oils, etc. may have on the pink planarian — another mystery. A 1981 ammonia pipeline break killed thousands of cavefishes, cave crayfishes, and grotto salamanders in Meramec Spring Cave, Missouri. Nonetheless, the more common types of cave pollution are less dramatic and occur over a long time period, including siltation and the input of extra nutrients.

Siltation occurs when fine silt or dirt is washed in and is deposited in between and on top of rocks on the bottom of the cave stream. A low amount is natural, but high amounts can be very harmful. If not managed well, large amounts of silt can be washed in from construction sites and other lands that lack vegetation. Pink planarians and other cave animals move through spaces under and between rocks, so if those spaces are filled, they lose habitat. In Mammoth Cave, Kentucky, siltation in the lower level pools resulted in the elimination of a previously common cave-restricted *isopod* and its predator crayfish (Lewis, 1980; Poulson, 1996). In Missouri, siltation from land clearing probably caused the severe decline of the Tumbling Creek cavesnail (Elliott *et al.*, 2005).

Caves naturally have very little food available for animals. Species adapted to caves can live in these conditions but most animals can not. Because caves are naturally poor in food supply, it is a threat when extra nutrients from fertilizers, manure, etc. are carried in from the land. Too much food supply can cause a population explosion of species of *amphipods* and *isopods* that live both above and below ground. Increased competition for space disrupts the cave ecology, and harms species that live only in caves. The result is a replacement of

Figure 3.7 Amphipods and habitat

The amphipod on the left (*Crangonyx forbesi*) lives both above and below ground, while the amphipod on the right (*Bactrurus brachycaudus*) is restricted to underground habitats. Photos taken by William R. Elliott, courtesy of the Missouri Department of Conservation.

the cave-restricted species with species that also exist on the land. For instance, in Mammoth Cave, Kentucky, a rotting staircase in one area caused an amphipod to dominate and replace the previous resident — a cave-restricted isopod (Lewis, 1987; Poulson, 1996). A severe case of sewage pollution in Hidden River Cave, Kentucky caused the disappearance of cavefish and cave crayfish (EPA, 1981; Lewis, 1989; Quinlan, 1977).

It is no mystery that each animal needs a habitat. Some animals are more restricted in what can serve as habitat for them. Cave-restricted species (also called troglobites) live their entire lives inside caves and cannot survive outside of caves. Other species (called troglophiles) can live both in caves and above ground. For example, a salamander that normally lives in leaf litter above ground can find its way into a cave and survive there as well. If a temporary toxic pollution event occurs in a cave, a *troglophile* species would lose only a small percentage of its population and could repopulate the cave when conditions improve. However, the entire population of a cave-restricted species could be eliminated from the cave with no nearby individuals available to repopulate. The only way both categories of animals can continue to exist is if cave habitats are managed primarily for the sake of cave-restricted species. The natural world is healthier when a greater number of native species (*biodiversity*) are present because each is unique and plays a role within its ecosystem. Protecting biodiversity is a goal among biologists. In part, biologists are admitting that much remains a mystery. Since we don't understand all of the intricacies of relationships among animals in an ecosystem it's prudent, as Aldo Leopold advised, to "keep all of the parts," just in case we learn that something is more important than previously realized. It's hard to get research dollars devoted to obscure little cave animals, so many are not researched. They may hold the secrets that will unlock mysteries that can benefit people, someday… if we keep all of the parts.

Missouri has 83 cave-restricted species, 68 described and 15 not yet described, (Elliott, 2007). *Troglobites* found in Missouri caves include white and blind cavefishes, the grotto Salamander, millipedes, crustaceans (crayfishes, isopods and amphipods) and planarians. Sometimes an animal is not only restricted to cave habitats, but also restricted to a single cave (*endemic*). Such is the case with the pink planarian, and with a new species of isopod that was collected by Mick Sutton in 2003. Both live in the stream inside Devil's Icebox Cave.

Because it is endemic, the pink planarian is listed as a *species of conservation concern* by the Missouri Conservation Department in categories defined as "critically imperiled" in Missouri (S1) and "globally imperiled" (G2G3) (MDC, 2006). A difficult process is involved in becoming classified as "*endangered*" by the U.S. Fish and Wildlife Service - something not yet attempted for the pink planarian.

The number of endemic and cave-restricted species recorded for a particular cave affects how the cave ranks among others in biodiversity[1]. In addition to being the seventh longest cave in Missouri with 6.25 miles of passages, Devil's Icebox Cave is ranked second in biodiversity among Missouri's 6,300 caves. The cave that is number one in Missouri is also the highest in cave biodiversity among caves west of the Mississippi River - Tumbling Creek Cave in Taney County. Missouri ranks about seventh in the United States in troglobite biodiversity. Overall, Devil's Icebox Cave would rank highly among known western US caves, while many Eastern US caves would still have higher *biodiversity* (Elliott, 2007).

The biological records for Devil's Icebox Cave include about 200 observations and collections. These records have been entered into the Missouri Cave Life Database, a project of the Missouri Department of Conservation and its partners. Devil's Icebox Cave now has about 80 species, 9 of which are cave-restricted. About 23 species are not completely identified, but this is not unusual for a large cave with a rich fauna. The cave-restricted species include a spider, an amphipod, the Tingupa cave millipede and the Missus cave springtail. Their identity is about all we know about them.

Much research has been conducted with bats. U.S. Navy sonar systems are not as sophisticated as those of bats (Simmons, 1998). Bats are able to differentiate between sounds that are only 2 to 3 millionths of a second apart, and between objects separated by only the width of a human hair (Simmons, 1998). Research for medical benefits has focused on hibernation and reproduction. Sperm is stored alive inside the female bat's body all winter prior to fertilization (Schwartz, 1981). Bats of the genus Myotis (includes gray and Indiana bats) caught 500 to 1000 mosquitoes in one hour in a laboratory study (Griffin, 1960). Each female corn earworm moth lays about 250 eggs that become caterpillars and damage our corn crops, but bats eat these moths and disrupt their reproductive behavior (Gillam, 2002).

Devil's Icebox Cave is important as habitat for both gray and Indiana bats, which are federally-listed endangered species. Female gray bats establish a nursery colony each year in Devil's Icebox Cave from April through August. The colony currently numbers about 13,000. One mystery that remains is how the bats, who fly here in the spring from caves about 325 miles away, find the small cave entrance. Scientists are trying to determine why Indiana bat numbers continue to drop drastically, while gray bat numbers have been steadily increasing. A few hundred Indiana bats are hibernating inside Devil's Icebox Cave, despite the fact that the temperature there is warmer than what scientists thought they prefer.

1. This scoring system was developed by William R. Elliott, Missouri Department of Conservation Cave Biologist as a means of evaluating and communicating the relative biological importance of Missouri caves (Elliott, 2000a, 2007; Elliott and Ashley, 2005.)

Hundreds, if not thousands, of other bats hibernate in the 55 degree F temperatures of Devil's Icebox Cave, including the little brown, big brown, long-eared and Eastern pipistrelle species. In addition, a variety of land animals use caves occasionally to escape from predators, drought, heat and cold. These include pickerel frogs, which congregate in the water passage of Devil's Icebox Cave, sometimes in the hundreds.

Why does Devil's Icebox Cave have such a high *biodiversity* level? The answer has to do with its location within the natural divisions of Missouri, and with its watershed. Most Missouri caves are located south of the Missouri River and were not affected by glaciers. Some glaciers covered northern Missouri and stopped their southern push in the general area of what is now central Boone County. These glaciers deposited deep soils. Their melting washed silt into the Missouri River valley. That silt was picked up by winds and deposited over much of Boone County. It is theorized that the deep mud deposits inside Devil's Icebox Cave may have washed in when the glaciers melted (Weaver, 1980). Definitely, water that flows through the Devil's Icebox Cave now carries with it nutrients from the deep soils of the upper Bonne Femme Creek. In addition, leaves, sticks and other debris enter the cave through the many sinkholes of the Pierpont Karst. These inputs provide more nutrients for cave life than what is typically observed in caves of Southern Missouri. These nutrient levels are still much lower than those of surface streams, and much lower than what could easily occur if poor land management occurs in the cave's watershed. To generalize, Northern Missouri doesn't have caves and Southern Missouri's caves are lower in nutrient inputs, making caves of Boone County rather unique. The caves of Boone County do not contain the cave-restricted species of fishes and crayfishes found in Southern Missouri, but contain cave life not found in Southern Missouri caves.

Large caves of Boone County, other than Devil's Icebox Cave, include Hunter's Cave (located within Three Creeks Conservation Area, within the Bonne Femme watershed) and Rocheport (Boone) Cave (not in the Bonne Femme watershed). These have few cave-restricted animal species and no *endemic* species, so their biodiversity scores are low. The watersheds that feed water through most of the length of Hunter's Cave and through Rocheport Cave are small in size. Some water diverts from Bass Creek to flow through a short lower section of Hunter's Cave, but the land drained by Bass Creek has soils that are not as rich and deep as those of the upper Bonne Femme Creek (which feeds Devil's Icebox Cave Branch). Hunter's Cave has 33 animal species, four of which are cave-restricted. It is a minor roosting site for male gray bats during the summer months. For some maybe not-so-mysterious reason, they don't hang out with the females at the nursery site in Devil's Icebox Cave! Probably more species will be found in Hunter's Cave, but it is smaller than Devil's Icebox Cave, has fewer microhabitats and less flowing water. Consequently, it will likely not have as much biodiversity as Devil's Icebox Cave. Rocheport Cave is a relatively short cave that floods violently. Although Rocheport Cave has 32 animal species, it has no cave-restricted species. It does, however, provide an important roosting area for Indiana and gray bats because of the height and shape of cave passages and their temperatures (Elliott, 2007).

Devil's Icebox Cave and some of its life are unique. The rich soils of the cave's watershed and numerous sinkholes input more nutrients than what most caves receive and thus support a rich diversity of life. Devil's Icebox Cave is ranked second in biodiversity among Missouri's 6,300 caves. Slowly, as funds are available, scientists are revealing more about the mysterious life that resides only in caves. Since many mysteries remain, some of which may benefit people in the future, it is an important goal to protect these cave-restricted animals. The endemic, cave-restricted pink planarian lives in the stream that flows through Devil's Icebox Cave. It and other aquatic cave animals are very vulnerable to chemicals, dirt and extra nutrients that could easily wash in from the watershed.

Contributors: William R. Elliott, Cave Biologist, Missouri Department of Conservation, Resource Science Division; Roxie Campbell, Interpretive Resource Specialist, Missouri Department of Natural Resources at Rock Bridge Memorial State Park.

Figure 3.8 The semi-aquatic mink.
It obtains about half of his diet from aquatic animals such as frogs, fish and crayfish. Streams also provide wildlife with a source of drinking water. Trees and other tall plants near a stream allow wildlife to approach the stream with some amount of cover from detection by predators. These riparian corridors also serve as travel routes for wildlife that need a large habitat.

3.c Stream Ecology and Use of EPT Insects as Indicators of Water Quality

The streams of the Bonne Femme Watershed possess a diversity of animal life that is typical of this region, transitional as it is between the prairies to the north and the Ozarks to the south. Some of the streams have flowing water at all times (perennial streams), while others flow intermittently and may have only isolated pools at other times.

The community of *invertebrates* visible to the naked eye is a diverse mix, dominated by mayflies, stoneflies, caddisflies, dragonflies, beetles, true flies, crustaceans and snails. Estimates of the total richness of these streams, in terms of the numbers of different species identified in stream riffles, range from 18 in Clear Creek to 27 in Turkey Creek. The fish communities of the Bonne Femme watershed and nearby streams generally range from 11 to 17 species, represented by shiners, minnows, suckers, redhorse, sunfish, bass, darters and

Figure 3.9 Aquatic-terrestrial life connections.
Some fish species (left) need a habitat of rocky substrate free of sediment. This caddisfly larva (right) lives among the spaces between rocks. If mud fills the spaces, certain caddisflies are harmed. This caddisfly larva covered his case with sand.

stonerollers. No federally listed threatened or endangered fish species are known to exist now in these waters. The Topeka shiner, listed as federally endangered, was historically found in the watershed, but not since 1997.

Stable aquatic communities, both plants and animals, have evolved over time in harmony with their environment. Biologists refer to a stream in this condition as having "biological integrity." This term implies the capability of maintaining a balanced natural community with good diversity and resilience to minor changes (Karr and Dudley, 1981). In other words, such a stream system can withstand an assault and recover.

Stream communities are influenced by at least five interrelated factors: 1. energy source (green plants that engage in photosynthesis); 2. water quality (level of pollutants or temperature extremes); 3. habitat quality (e.g. *substrate*, appropriate water depth for certain species, etc.); 4. varying characteristics of water flow, such as volume and speed (known as "flow regime" of the stream); and 5. interactions of species within the food web. Changes in any one of these factors can so change a stream environment that the plants and animals cannot adapt. The result will be a reduction in the number of species present, the elimination of species, and an overall decrease in biodiversity in the stream environment.

Unmitigated urban and agricultural runoff are of greatest concern to the health of the streams in the Bonne Femme watershed. Examples are stream bank erosion and collapse associated with uncontrolled runoff from impervious surfaces, poor livestock management, surface soil erosion, and high levels of fecal coliform bacteria, nutrients and herbicides (Lerch, 2006). Increased urban runoff and poor land management practices in upland areas of a watershed usually have two immediate effects: an increase in the speed and volume of flowing water, and an increase in the sediment it carries. Clearing of vegetation and compacting of the soil in *riparian areas* (i.e. in direct proximity to a stream) further increase the delivery of sediment to the stream, and decrease the resistance of the stream banks and streambed to erosion (Jacobson *et. al.*, 2001). Besides affecting water quality, increased runoff of water and fine sediment can cause significant changes in the *flow regime*, as well as the energy sources in the stream,

Figure 3.10 Gans Creek.
In 2006, nearly 200 photographs were taken as one aspect of a project to document the physical condition of streams within Rock Bridge Memorial State Park. This was taken on May 4, 2006 at Gans Creek Station 31, looking upstream.

Stream Team Monitoring and Rock Bridge Project

Stream Teams are composed of concerned citizens who conduct litter pickups, monitor water quality, conduct bank stabilization, and become stewards for their adopted stream. The Volunteer Water Quality Monitoring Program is an activity of the Stream Team Program that teaches volunteers to monitor stream water quality on their adopted sections of streams. Eight Stream Teams have entered data on sections of eight streams within the Bonne Femme watershed. The Stream Team Program, managed jointly by the Missouri Department of Conservation and Missouri Department of Natural Resources, provides training, testing equipment and data management. Four levels of training are available. Level 2 training/monitoring indicates that the trained volunteer has attended 3 workshops (32 hours) and passed a quality assurance test of their monitoring procedures and equipment. While Stream Team data is not expected to be as exact as that of professionals and laboratories, it does indicate conditions in the watershed. When problems have been detected, professional data have consistently confirmed Stream Team findings. Stream Team monitoring includes conducting a visual survey; chemical testing for dissolved oxygen, Ph, temperature, conductivity and nitrates; measuring water depth and velocity; and collecting and identifying *macroinvertebrates*. (For online information, see www.mostreamteam.org.)

In the spring of 2006, a project was conducted to document the physical condition of streams within Rock Bridge Memorial State Park (RBMSP). UMC Intern Austin DeVoe conducted the study under the direction of Park Naturalist Roxie Campbell. Protocols were established and followed that enable the study to be duplicated in the future. Where applicable, Stream Team protocols were used. GPS coordinates were recorded for stations that were established every 100 to 200 meters on Devil's Icebox Spring Branch, Clear and Gans Creeks. Four photos were taken at each station (see Figure 3.10, above). Other data collected included stream channel width and depth, water width and depth, water velocity and embeddedness. The data are available at www.CaveWatershed.org.

its suitability as habitat for living creatures, and the interactions among those living creatures within the stream. Thereby, aquatic life suffers further harm.

An increase in fine sediment in stream riffles and pools may result in the alteration or elimination of preferred habitats for some stream species because of changes in the stability or composition of the streambed or stream bank (*substrate*). Other possible effects include interference with the respiratory function or nesting behavior of the stream organisms, or interference with their feeding activities by reducing the concentration or value of food (Lemly, 1982; Graham, 1990). Increased penetration of light into a stream by removal of streamside vegetation can result in higher water temperatures and quantity of plants and bacteria that live on rocks in the stream, known as *periphyton biomass*.

Unmitigated urban runoff is widely believed to adversely affect aquatic communities in adjacent streams by increasing pollution and modifying stream channels. Impervious surfaces, without adequate stormwater treatment, that cover 8% to 15% of a watershed are known to negatively affect stream health by funneling pollutants and excessive quantities of water into streams from streets, parking lots, driveways, roofs, patios and sidewalks (Schueler, 1994; Center for Watershed Protection, 2003). While pollutants have a direct effect on living organisms, increased peak flows and total volumes of water are believed to have indirect, yet more deleterious, effects through stream bank erosion, streambed sedimentation, and disruption of pool and *riffle* sequence (Center for Watershed Protection, 2003). In a study of land use relationship to fish health in Wisconsin streams, the health of fish communities was negatively related to the amount of upstream urban development as well as the amount of agricultural land (Wang *et.al*., 1997). The health of fish populations was positively related to the amount of upstream forest in the watershed (Ibid).

Maintaining a good streamside or *riparian* vegetative buffer, consisting of a mixture of grasses, bushes and trees, is essential to the protection of the stream. The riparian buffer reduces stream bank collapse and its attendant excess sediment load delivered to the stream, mediates stream water temperatures, and provides a variety of organic food sources to maintain a productive stream environment (Hubbard and Lowrance, 1994). A vegetative buffer of twice the width of the stream on each side is usually considered sufficient (Rabeni, personal communication, 2006).

In an effort to determine baseline conditions within the streams of the Bonne Femme Watershed, a biological monitoring program was started in the Spring of 2006. Invertebrate species visible to the naked eye, rather than microscopic species, were used as biological measures of water quality. These "*macroinvertebrates*" were studied following guidelines established by the MDNR, to determine how many "taxa," or groups of distinct but related organisms, are present in each of three "Orders," or larger categories of generally pollution-sensitive creatures. These larger categories are the mayflies (Ephemeroptera), stoneflies (Plecoptera) and caddisflies (Trichoptera). The measure used is called "EPT richness." This measurement is useful because of the expectation that impairment of water quality will result in a decrease in numbers of pollution-sensitive macroinvertebrate species. EPT richness has been shown to detect most of the potential problems that may affect the Bonne Femme Watershed, including organic pollution, acidity and metals, fine sediment and insecticides. Collections made in the spring of 2006 indicated that all the sampled streams were at least "partially biologically supporting" of macroinvertebrate species, based on EPT richness scores provided by MDNR for this area (Doisy, 2006; full report is located in Appendix G).

Contributors: Charles Rabeni, Leader, and Kathy Doisy, Research Biologist, Missouri Cooperative Fish and Wildlife Research Unit, Department of Fisheries and Wildlife Sciences, University of Missouri, Columbia.

Devil's Icebox Cave Branch Biomonitoring

While looking for EPT insects is widely used to monitor the health of surface streams and is sometimes used to monitor streams fed by spring water, the best biomonitoring approach for evaluating the health of Devil's Icebox Cave Branch is to enter the cave, identify and count the cave animals that live in the cave stream. A scientific protocol (set of procedures) was developed in 2004 that standardized the methods so that one year's data can be compared to the data of other years (Sutton, 2004). Certain marked sections of cave stream are searched for pink planarians (that often cling to the bottom of rocks) and other aquatic animals such as isopods and amphipods. This biomonitoring tells us three things: 1) whether the water quality is good enough to continue to support the pink planarians; 2) whether pink planarian numbers are trending upward or downward (important since all of the world's pink planarians depend upon this one cave stream for survival); and 3) whether there is an increase in surface species that compete with cave species (this occurs when nutrient levels are increased beyond normal cave levels). Research is lacking on how sensitive pink planarians are to water quality, but if their numbers drop, some aspect of their aquatic habitat has changed for the worse. Current numbers appear to be modest. The three survey plots of preferred habitat have yielded an average of 27 pink planarians during fall counts and an average of 12 during Spring counts.

Refer to Appendix G for more information.

Contributors: Roxie Campbell, Interpretive Resource Specialist, Missouri Department of Natural Resources at Rock Bridge Memorial State Park; Priscilla Stotts, Environmental Specialist who works with stream monitoring, Missouri Department of Natural Resources; Tim Rielly, Biologist, Missouri Department of Conservation; Doug Novenger, Stream Ecologist, Missouri Department of Conservation.

3.d Water Quality Monitoring, 2001-2006

Water quality monitoring in the Bonne Femme watershed has been ongoing since 1999, when studies were initiated at Hunters and Devil's Icebox Spring Branches (Lerch *et al*., 2001; Lerch *et al*., 2005). In 2001, the monitoring was expanded to include six surface subwatersheds in addition to the two caves, and with the initiation of the Bonne Femme Watershed Project in 2003, an additional two surface sites were added, the total number of monitoring

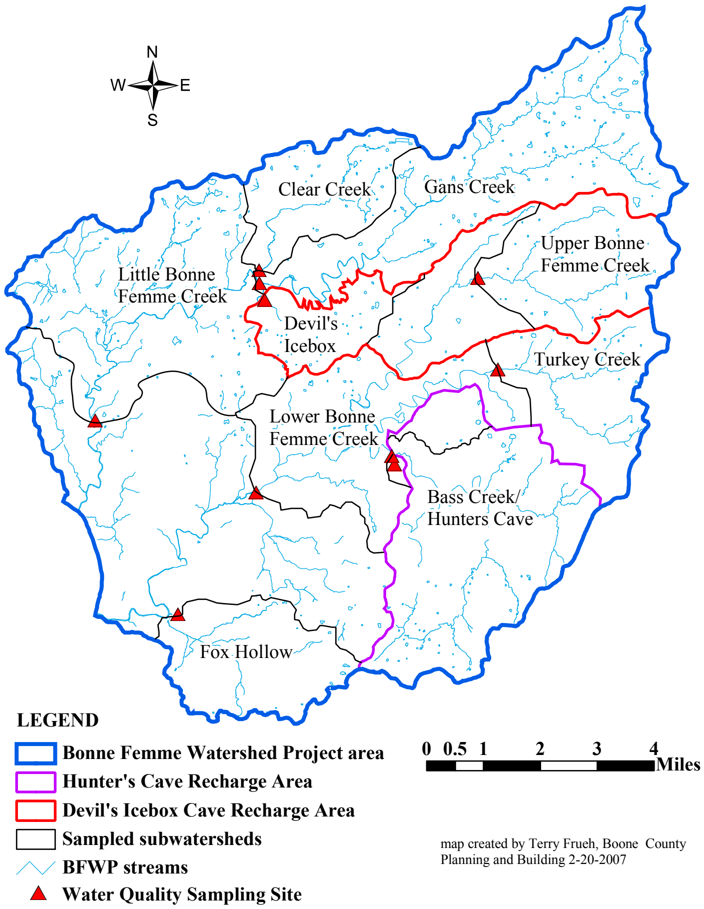

Figure 3.11 Bonne Femme watershed monitoring sites.

sites increasing to ten (Figure 3.11). The current monitoring program includes eight surface subwatersheds (Clear Creek, Gans Creek, Upper Bonne Femme Creek (at US 63), Turkey Creek, Bass Creek, Lower Bonne Femme Creek (at Nashville Church Rd.), Little Bonne Femme Creek, and Fox Hollow) and the two karst recharge areas (Devil's Icebox and Hunters cave branches). This monitoring scheme covers about 80% of the entire watershed. Samples were collected at all sites once per quarter, since fourth quarter 2003. General stream water properties analyzed were turbidity, pH, dissolved oxygen, specific conductivity, and temperature. Nutrient analyses included total nitrogen and phosphorus, and dissolved nitrate (NO_3^-), ammonium (NH_4^+), and orthophosphate (PO_4^{3-}). Herbicides were analyzed only for the second quarter samples. The following herbicides were measured: atrazine, deethylatrazine (*metabolite*), deisopropylatrazine (metabolite), metolachlor, acetochlor, alachlor, and metribuzin. Sampling for fecal bacteria was conducted for four weeks each quarter, with samples collected at weekly intervals. Bacterial analyses included fecal *coliforms* (FC), generic *E. Coli* (EC), and qualitative analyses for specific pathogenic bacteria – *E. Coli* O157:H7, *Salmonella*, and *Shigella*. FC analyses have been conducted at eight of ten sites since 2001; EC analyses have been conducted since fourth quarter 2004; and pathogen specific analyses have been conducted since fourth quarter 2005. If there was no stream flow, samples were not collected from stagnant pools. All laboratory methods and the sampling scheme were detailed in the Quality Assurance Project Plan (Lerch, 2004).

Chapter 3

Water Quality Monitoring Conclusions

The following general conclusions can be reached from the monitoring study:

- General stream water properties indicate no acute contamination, with all five properties measured falling within typical ranges for carbonate bedrock streams, and dissolved oxygen levels above the State minimum standard of 5 mg/L;
- Nutrient levels were similar to or less than streams in other agricultural watersheds of northern Missouri. There was no evidence of acute contamination at any site;
- The combination of dissolved oxygen, turbidity, nutrient levels, and field observations indicated that all sites have some level of nuisance algal growth and presumed loss of macroinvertebrate diversity, but *eutrophication* (the process by which a body of water becomes over-enriched in dissolved nutrients from fertilizers or sewage, thereby encouraging the growth and decomposition of oxygen-depleting plant life and resulting in harm to other organisms) conditions have not occurred at any site;
- At least one herbicide or metabolite was detected in every sample at all sites, but typically at low levels. Atrazine and its metabolites had the highest average concentrations at all sites;
- Fecal bacterial contamination was widespread with significant differences observed across sites and over seasons. Concentrations of fecal bacteria were highest in spring and summer;
- Whole body contact standards for fecal bacteria were commonly exceeded. Seven of 10 sites exceeded the State fecal coliform standard 40% of the time. Eight of 10 sites exceeded the Federal *E. Coli* standard 50% of the time;
- Frequency of detection of specific pathogens was in the following order: *E. Coli* O157:H7 > *Salmonella* > *Shigella*. The pattern of *E. Coli* O157:H7 detections indicated that cattle were the probable source;
- Of the general stream water properties measured, concentrations of fecal bacteria were significantly correlated only to turbidity and stream discharge (based only on the two cave sites);
- Land cover classes did not significantly correlate to the concentrations of fecal bacteria;
- Multiple sources apparently were the cause of fecal contamination in most subwatersheds while site specific sources of fecal bacteria appear to be responsible for the high levels observed at Devil's Icebox Spring Branch (most likely from septic systems) and Fox Hollow (most likely from nearby cattle herds).

Note that some of these conclusions may require further studies to confirm them. For more detailed information about the water quality sampling, see Appendix G.

Contributor: Robert N. Lerch, Soil Scientist, USDA-ARS

3.e Bonne Femme Dye Traces

Groundwater recharge in karst systems is highly vulnerable to pollution since there is little to no filtering of surface water as it enters subterranean conduits. *Nonpoint source (NPS)* pollutants are transported to streams dissolved in water and bound to sediments suspended in surface runoff. This pollution poses a special threat to karst systems, in part because it is spread throughout a watershed and therefore is harder to control, and in part because aquatic life in karst systems tend to be especially vulnerable to pollution. Thus, it is important to know the recharge area (the land area that contributes water to a cave) of a cave branch in order to determine the sources of water and their associated land uses. This delineation of the *recharge area* of a cave system provides the basic information required to protect organisms living in its water. Dye tracing is a method frequently used to determine hydrogeological flow characteristics of an area, and it is the primary tool available for delineating recharge areas.

Two dye trace experiments were performed by the Bonne Femme Watershed Project. The first dye trace, carried out during winter 2003-2004, confirmed that the reach of Bonne Femme Creek downstream of Highway 163 *loses* water to the Devil's Icebox Cave Branch. This approximately one-mile long reach was previously determined to be losing continuously along the reach (St. Ivany, 1988), and thus is presumed to lose flow to Devil's Icebox Cave Branch down to the point where elevation precludes transmission of water to the cave (estimated to be 700 feet above sea level). The results of this dye trace allowed us to add approximately 2.0 square miles to the previously known Devil's Icebox Cave Branch recharge area. The second dye trace, carried out in the summer of 2004, indicated that Gans Creek does not lose any water out of the stream channel during low flow to any springs, although further study is needed to confirm these results. However, it is important to note that St. Ivany (1988) found that Gans did lose a portion of its water during normal flows to a spring located in the Gans Creek floodplain, but Gans Creek did not lose water to the Devil's Icebox Cave Branch under low and normal flow conditions.

The drainage area that contributes to the losing section of Bonne Femme Creek confirmed in this trace is approximately 2.0 square miles (Figure 3.12, area C). Two recharge areas, the Pierpont Sinkhole Plain (Fig. 3.12, area A) and the upper Bonne Femme Creek subwatershed (Fig. 3.12, area B), were confirmed to be losing to Devil's Icebox Cave Branch in previous studies (King and Hargrove, 1973; St. Ivany, 1988). These have areas of 3.6 square miles and 7.5 square miles, respectively. The total identified recharge area for Devil's Icebox Cave Branch is approximately 13.1 square miles. It contains portions of the recently-formed village of Pierpont, unincorporated parts of Boone County, University of Missouri's Bradford Research Farm, Rock Bridge Memorial State Park and Three Creeks Conservation Area.

For more detailed information on the dye traces, see Appendix G.

Contributor: W. Terry Frueh, Watershed Conservationist, Bonne Femme Watershed Project.

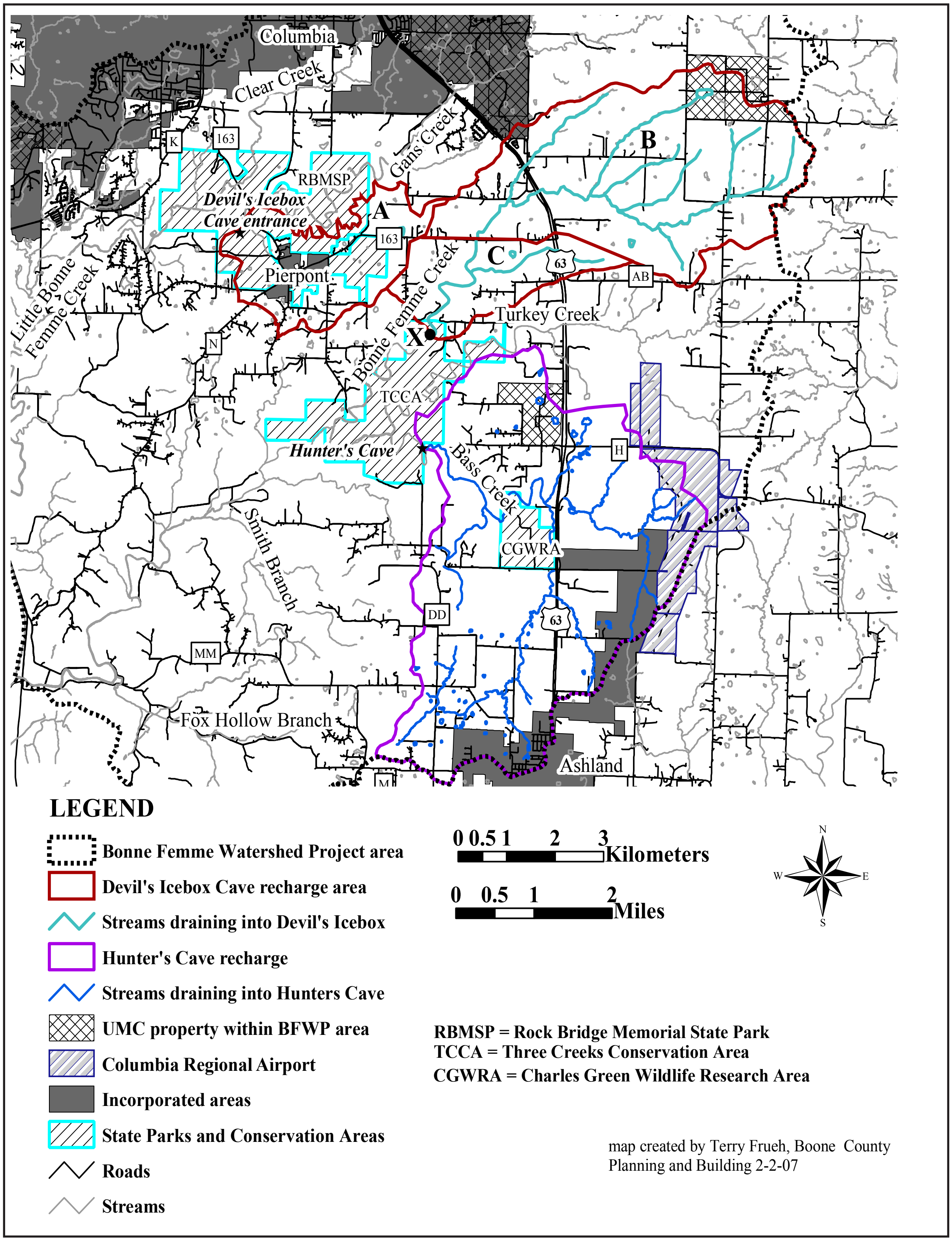

Figure 3.12 Devil's Icebox Recharge area.

3.f Subwatershed Sensitivity Analysis, a Planning Tool

The Steering Committee wanted to have an independent, scientifically-based decision-support tool created to help the Stakeholders in their planning effort. It was decided to hire a consultant with experience doing hydrologic analysis, who could use the latest technologies to create GIS data layers, and who could create an interactive model for forecasting future stream conditions.

A group of technical experts, formed by the Steering Committee, wrote a Request for Proposals (RFP) to complete a Subwatershed Sensitivity Analysis of the Bonne Femme Watershed that would serve as a decision-support tool for the Stakeholder Committee. Writing the RFP was challenging because the group had never seen an analysis completed at a similar scale and depth of study that combined hydrological modeling and a natural resource assessment. Therefore, they could not precisely state how the goals of the RFP were to be met. Thus, the RFP requested a creative approach to analyzing the streams within the watershed. Three consultants responded to the RFP, of which Applied Ecological Services (AES) was selected. Following is a brief description of the Subwatershed Sensitivity Analysis AES completed.

In this analysis, a variety of techniques were used to obtain a more comprehensive assessment of the watershed. Three different models were used to assess stream conditions.

The report lists the following conclusions from the models:

1. In the upper reaches of the watershed, the conversion of native prairie to agricultural uses without appropriate BMPs in place has resulted in increased stormwater runoff and decreased soil stability. As a result, streams in the upper reaches are downcut and eroding. Increased flows in the upper reaches also have led to stream degradation in the lowest reaches of the watershed.

2. In the lower reaches of the watershed, the conversion of floodplain bottomland forest to agricultural uses without appropriate BMPs in place has also led to increased runoff and decreased soil stability. Most of the streams in the lower reaches are entrenched, shear, unstable and disconnected from the floodplain during channel forming (one to two year storm events) storm events. These conditions become exacerbated as flows continue to increase with projected development.

3. Most of the groundwater recharge to Devils Ice Box and Hunters Cave occurs in the upper reaches of the watershed. Streams within the recharge zones occur on highly erosive loess and sandy soils, making the recharge zones highly vulnerable to erosion, streambank degradation, reduced water quality, and sedimentation impacts to sensitive cave systems.

4. Karst topography plays a major role in hydrology of the watershed. The two largest caves are mapped and their recharge areas are fairly well delineated. While the scientific community understands how karst topography affects hydrology, generally more education is needed for the lay public, especially since they have the greatest influence on how land is managed.

5. Channel instability issues appear to be migrating upstream, especially in the Northern Little Bonne Femme subwatershed. This is a common and expected phenomenon in downcutting streams as the stream seeks a flatter, more stable grade.

6. Subwatersheds most vulnerable to degradation based on the impervious cover and field indicators are clustered around Columbia and Ashland. Upper Bonne Femme and subwatersheds downstream from Upper Bonne Femme are the next most vulnerable group of subwatersheds. Most of the recharge for Devils Ice Box occurs in Upper Bonne Femme, a "moderately" vulnerable subwatershed. Most of the recharge for Hunters Cave occurs in the Bass Creek subwatershed, which is ranked as "vulnerable."

7. All subwatersheds are considered restorable, though the greatest restoration challenges will occur, in order of difficulty, in the North Branch Little Bonne Femme, Clear Creek and Bass Creek subwatersheds.

8. When assessed collectively, the three models indicate that there are regions within the watershed that should be prioritized for protection and remediation, namely the urbanizing regions around Columbia and Ashland, and the agricultural headwater region in the eastern portion of the watershed.

The Subwatershed Sensitivity Analysis report makes a series of recommendations. Their inclusion here is for informational purposes only and does not necessarily reflect the opinion of the Stakeholder Committee. Following are the main points of the Subwatershed Sensitivity Analysis report policy recommendations.

It is recommended that Boone County and the cities of Ashland, Columbia, and Pierpont (hereafter, the Watershed's local governments) take the following actions to improve stormwater and groundwater management for protection of water resources and restoration of degraded areas. At a minimum, Boone County and its municipalities could adopt the latest version of

American Public Works Association (APWA) Section 5600 stormwater design criteria and BMP Manual (APWA, 2003). These manuals were written specifically for the Kansas City metro region, and therefore would be easy to adapt to conditions in Boone County. Other recommendations build on these documents, including public education, incentive programs, and water resource protection and restoration recommendations.

1. Adopt APWA 5600 Storm Drainage Systems and Facilities stormwater design criteria.
APWA 5600 specifies application and design criteria for stormwater management, conveyance, detention, and natural stream protection. In particular, APWA 5600 includes guidance that will address problems noted in Boone County.

2. Adopt the APWA Manual of Best Management Practices for Stormwater Quality (BMP Manual).
The BMP Manual would provide the Watershed's local governments with the tools to prevent future flooding and protect water quality, including a flexible framework for developers to estimate potential water quality impacts and increased runoff from development plans. The BMP Manual would also design a comprehensive stormwater management system that includes site design and dispersed, structural and non-structural best management practices (BMPs) for residential, commercial, and industrial developments. The "Level of Service Method" can be used to maintain or reduce predevelopment runoff volumes and pollutant loads.

3. Adopt Additional Stormwater Management and Development Policies
APWA Section 5600 criteria may not be sufficient in all circumstances to stabilize stream channels and manage water quality, rates, and volumes entering streams and other water bodies.
AES recommends the Watershed's local governments adopt additional guidelines for stormwater management in all developments.

4. Public Education and Incentives
Public education and incentive programs could build support for new policies and help landowners and developers meet their obligations under the policies.
AES recommends pursuing additional education efforts and incentive programs.

5. Habitat and Biodiversity Preservation
Finally, many of the measures described above would preserve or restore scarce habitat as well as protect streams.

AES recommends that the Watershed's local governments take additional measures that would further enhance habitat protection and biodiversity in the County.

For more detailed information about the Subwatershed Sensitivity Analysis report, please see Appendix G.

Contributor: W. Terry Frueh, Watershed Conservationist, Bonne Femme Watershed Project.