U.S. Department of the Interior Prepared in cooperation with the Kentucky Geological Survey and U.S. Fish and Wildlife Service U.S. Geological Survey

Scientific Investigations Map 3506 Sheet 1 of 2

Abstract

Fern Cave in Jackson County, Alabama, is a 15.6-mile-long (25.1-kilometer) cave system, managed by the U.S. Fish and Wildlife Service and Southeastern Cave Conservancy, that has the second highest biodiversity of any cave in the southeastern United States. Groundwater in karst ecosystems is known to be susceptible to impacts from human-induced land-use activities in watersheds that contribute recharge to the groundwater system. To provide the U.S. Fish and Wildlife Service with necessary baseline information on the groundwater flow system in Fern Cave, the U.S. Geological Survey and the Kentucky Geological Survey conducted a series of dye traces during 2019–21 to delineate the watershed recharging the cave system. The dye traces identified two separate streams that flow through the cave and a recharge area of 1.73 square miles (4.48 square kilometers) draining to the cave system. Current land use within the recharge area is dominated by deciduous forest with minimal additional land use types, indicating a low potential for undesirable effects to the cave by anthropogenic sources.

Introduction

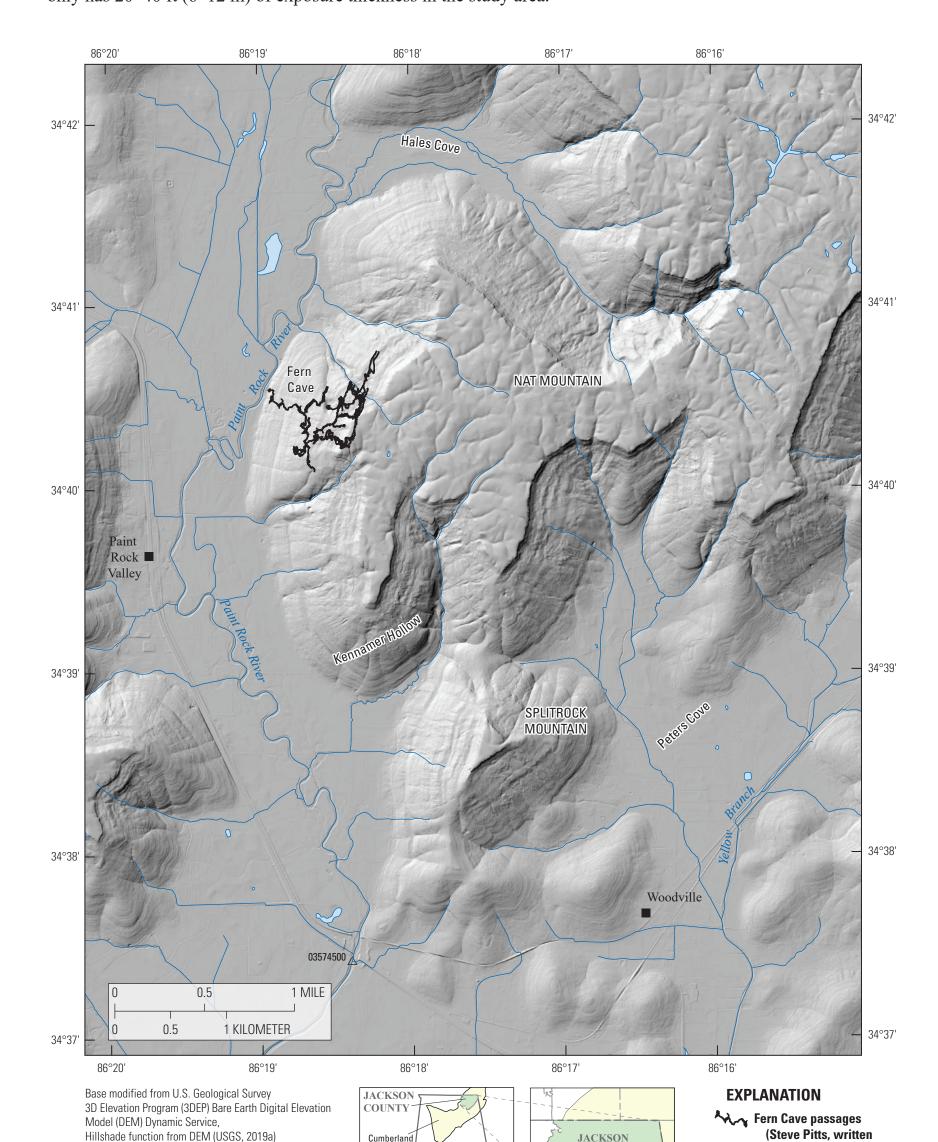
Karst aquifers have long been noted to have high hydraulic connectivity between the surface-water system and groundwater system (Palmer, 1990; Priebe and others, 2018). Matrix and fracture flow paths result in longer storage within the aquifers, whereas dissolution enhanced flow paths result in rapid recharge (Toran and others, 2007; Mudarra and others, 2019). As a result of this rapid flow, karst groundwater systems are highly susceptible to contamination from surface sources, such as human-induced impacts from land-use activities (Fields, 1993; Urich, 2002).

Researchers have suggested that as habitat availability in cave systems increases, so does cave biodiversity (Christman and Culver, 2001). Recent efforts at documenting biodiversity in caves of the southeastern United States have begun to confirm both their high biodiversity and high endemism (Culver and others, 2000; Niemiller and Zigler, 2013). As a result, it is crucial to understand the recharge area of cave systems, which delivers water that can affect or negatively impact these sensitive ecosystems. In fluviokarst settings, understanding the recharge area for a cave or spring is critical to mitigate contamination potential and maintain water quality and quantity for sensitive cave biota.

A cooperative project between the U.S. Geological Survey (USGS), U.S. Fish and Wildlife Service (USFWS), and the Kentucky Geological Survey (KGS) was established in December 2019 to conduct dye traces focused on delineating a recharge area for the Fern Cave system in Jackson County, Alabama, to aid in management and preservation of these cave and karst resources. This study took place from December 2019 to May 2021. This report documents the mapping of karst groundwater flow paths and delineation of recharge areas for Fern Cave, Alabama, through the use of dye tracing.

Fern Cave is located in Nat Mountain in the Paint Rock Valley of Jackson County, Alabama (fig. 1). Nat Mountain is a highly dissected lobe of the Cumberland Plateau (Fenneman, 1938), bounded on the north and west by the Paint Rock River and bordered to the south by Yellow Branch in Peters Cove. The study area extends along the western portion of Nat Mountain from Hales Cove (to the north) to Splitrock Mountain (to the south). The base level stream for the area is the Paint Rock River, which forms the western border of the study area and has a drainage area of approximately 300 square miles (mi²; 777 square kilometers [km²]) upstream from the stream resurgences that flow from Fern Cave (U.S. Geological Survey, 2019b). The gage at the Paint Rock River at Woodville (USGS station number 03574500; U.S. Geological Survey, 2019c, 2020) had a stage range from 1.53 to 18.61 feet (ft) above datum (datum of gage is 570.95 ft above the National Geodetic Vertical Datum of 1929 [NGVD 29]), between December 2019 and May 2021, the duration of this study. Higher stage levels indicate large flood events and result in major changes in hydrologic gradients between the surface and groundwater systems (U.S. Geological Survey, 2019c, 2020). The vertical relief of Nat Mountain is approximately 1,000 ft (305 meters [m]), ranging from 590 to 1,600 ft (180–488 m) above NGVD 29 (U.S. Geological Survey, 1997). Land use on Nat Mountain is dominated by deciduous forests (Dewitz and U.S. Geological Survey, 2019).

The geology of Nat Mountain was mapped and described by the Geological Survey of Alabama (Osborne and others, 2013). Nat Mountain is capped by the Pottsville Formation of Early Pennsylvanian age, a 200-ft-thick (61-m) quartzose sandstone that is occasionally conglomeratic with interbeds of shales. Beneath the Pottsville Formation is the Pennington Formation of Late Mississippian age, a lithologically variable unit that consists of interbeds of sandstone, limestone, chert, dolomite, and shale that is approximately 300 ft (91 m) thick beneath Nat Mountain. The presence of carbonate interbeds within the Pennington Formation creates karstified intervals, which result in springs discharging from the base of the formation at its contact with the underlying Bangor Limestone. The Bangor Limestone (Upper Mississippian) is a 300-ft-thick (91 m) unit beneath Nat Mountain that may have interbeds of chert in the upper part and shale in the lower part. The Hartselle Sandstone (Upper Mississippian) underlies the Bangor Limestone; however, it is absent or so thin in the study area that it is typically unmapped. There does appear to be some hydrologic control from the Hartselle Sandstone at locations along the flanks of Nat Mountain where its presence and limited vertical permeability may create small springs that issue from the upper contact of the formation and that sink into the subsurface a short distance from the point of issuance. The Monteagle Limestone (Upper Mississippian) underlies the Hartselle Sandstone and is a 180- to 220-ft-thick (55–67 m), massively bedded limestone that is extensively karstified throughout the study area. The Tuscumbia Limestone of Middle Mississippian age underlies the Monteagle Limestone and forms the base of Nat Mountain and the valley floor of Hales Cove. The Tuscumbia Limestone contains chert nodules and stringers, and only has 20–40 ft (6–12 m) of exposure thickness in the study area.



COUNTY

commun., 2021)

USGS real-time

Figure 1. General location of study area.

Streams and waterbody data from U.S. Geological Survey

National Hydrographic Dataset (USGS, 2021)

North American Datum of 1983

Universal Transverse Mercator projection, zone 16

The Fern Cave system (fig. 2) is the longest mapped cave in Alabama, with a total surveyed length of 15.6 mi (25.1 km) and a depth of 536 ft (163 m) (Gulden, 2021). The cave is comanaged by the U.S. Fish and Wildlife Service and the Southeastern Cave Conservancy Inc. The cave has five entrances and a diversity of passage morphologies that provide a wide range of subterranean environments for native biota. The cave is known for two primary features, a 437-ft (133-m) deep, voluminous pit that is popular with recreational cavers; and the largest known Myotis grisescens (gray bat) hibernacula in the world, containing over 1.5 million bats (Martin, 2007). Much of the cave is dry; however, there are at least three distinct subsurface streams (Lower North Cave Stream, Surprise Stream, and Bottom Cave Stream) within the cave system that originate as surface streams from different areas on top of the Cumberland Plateau and that issue to springs along the east bank of the Paint Rock River. Although many of the passages in Fern Cave have floors with steep gradients, Bottom Cave and its associated stream are relatively flat-lying and contain flood debris, suggesting backwater inundation flooding from the Paint Rock River in the lower portions of the system. Because of the variety of its niche habitats, Fern Cave has recently been recognized as having the second highest troglobitic diversity of any cave in the southeastern United States, second only to that of Mammoth Cave in Kentucky (T. Inebnit, oral commun., 2021; M. Niemiller, written commun., 2022). Currently, 113 taxa, including 25 cave obligates, are known to inhabit the Fern Cave system. Species that are susceptible to impacts from water quality and of particular concern to managers are the Orconectes australis (southern cave crayfish), Typhilichthys subterraneus (southern cavefish), and the endangered Palaemonias alabamae (Alabama cave shrimp)

Methods

(Niemiller and others, 2019).

A detailed inventory of hydrologic features in the Fern Cave area was conducted at the beginning of the study to identify springs, seeps, and sink points that might be important sites for dye traces, including dye detection monitoring and injection locations (table 1). Sites selected for dye detection (fig. 3 and table 1) were monitored using weighted receptors containing activated coconut charcoal tied to a wire and placed directly in the flow of the stream or feature being monitored. These receptors were changed intermittently, at daily to weekly intervals, following dye injections to aid in determining the approximate travel time from each dye injection point to

recovery location. Once monitoring sites were identified, initial dye-injection locations were chosen with the goal of identifying flow paths into and through Fern Cave and those that flow away from the cave. Subsequent dye-injection locations were chosen on the basis of the results of the previous dye injection rounds, with each location chosen with the goal of understanding the potential boundaries of the drainage area feeding Fern Cave. Dye injections (table 2) utilized four nontoxic fluorescent dyes (fluorescein, eosine OJ, rhodamine WT, and sulphorhodamine B) that were injected into losing streams, swallets, cave streams, and one as a dry set, where dry, powdered dye was placed in a polyvinyl chloride (PVC) pipe that was staked to the streambed. The dry set was left in place for subsequent rainfall to wash the dye into the groundwater system. The dyes used in this study are commonly used in karst groundwater-tracing studies, because each dye fluoresces at a unique wavelength when exposed to light, and the fluorescence wavelength can be identified through laboratory analyses at concentrations as low as 5 parts per billion (Currens, 2013).

Following retrieval of the dye receptors, processing and analysis were conducted at the Kentucky Geological Survey Water Laboratory in Lexington, Kentucky, on a Cary Eclipse fluorescence spectrometer using established protocols (Currens, 2013). Once positive traces were confirmed, results were plotted in a geographic information system (GIS) spatial framework to begin delineating the recharge area of the cave. Additional information related to methods used for the study is included as part of the metadata within a separate USGS data release of the dyetracing data for this study (Miller and others, 2023).

From these dye traces, a recharge area, also known as a groundwater basin for Fern Cave was delineated by following topographic divides between the injection points for positive traces in Fern Cave and positive traces that were detected at monitoring locations outside of the cave system. When dye from an injection was not detected in Fern Cave but was detected at an adjacent monitored discharge feature, then that point was used as a groundwater basin divide. Following delineation of a recharge area, boundaries were drawn with both defined and interpreted boundaries. Defined boundaries surround areas underlain by relatively insoluble strata (sandstone or shale) and indicate areas unlikely to be karstified, thus the boundaries follow topographic boundaries. Interpreted boundaries lie along portions of the recharge area boundary underlain by soluble bedrock (limestone) and where groundwater recharge may not follow topographic boundaries because of karstification of the underlying bedrock. Although dye tracing is a proven method for delineating groundwater basins in karst terrain, this method may be limited by hydrologic conditions that occur during tracing, such as precipitation heterogeneity and changes in groundwater or stream levels that can cause basin divides to shift laterally depending on ambient conditions.

In addition to the work focused on delineating the groundwater basin(s), a round of dye injections was conducted in May 2021 to identify the connection between streams within Fern Cave. For these injections, dye was injected directly into the Surprise Stream and Lower North Stream, and cave streams downstream from the injection sites were monitored throughout the cave system (table 2). Some subsurface flow paths were able to be accurately represented using cave survey data provided by the Fern Cave Project (Steve Pitts, written commun., 2021). The Fern Cave Project had conducted surveys of the cave system using handheld instruments, fiberglass tapes, and had manually collected data related to passage dimensions and speleological features present at the time of survey. These data were then used by this project to determine cave stream pathways and accurately gain elevational data for the monitoring sites established in the cave. At the time of publication, these data were not

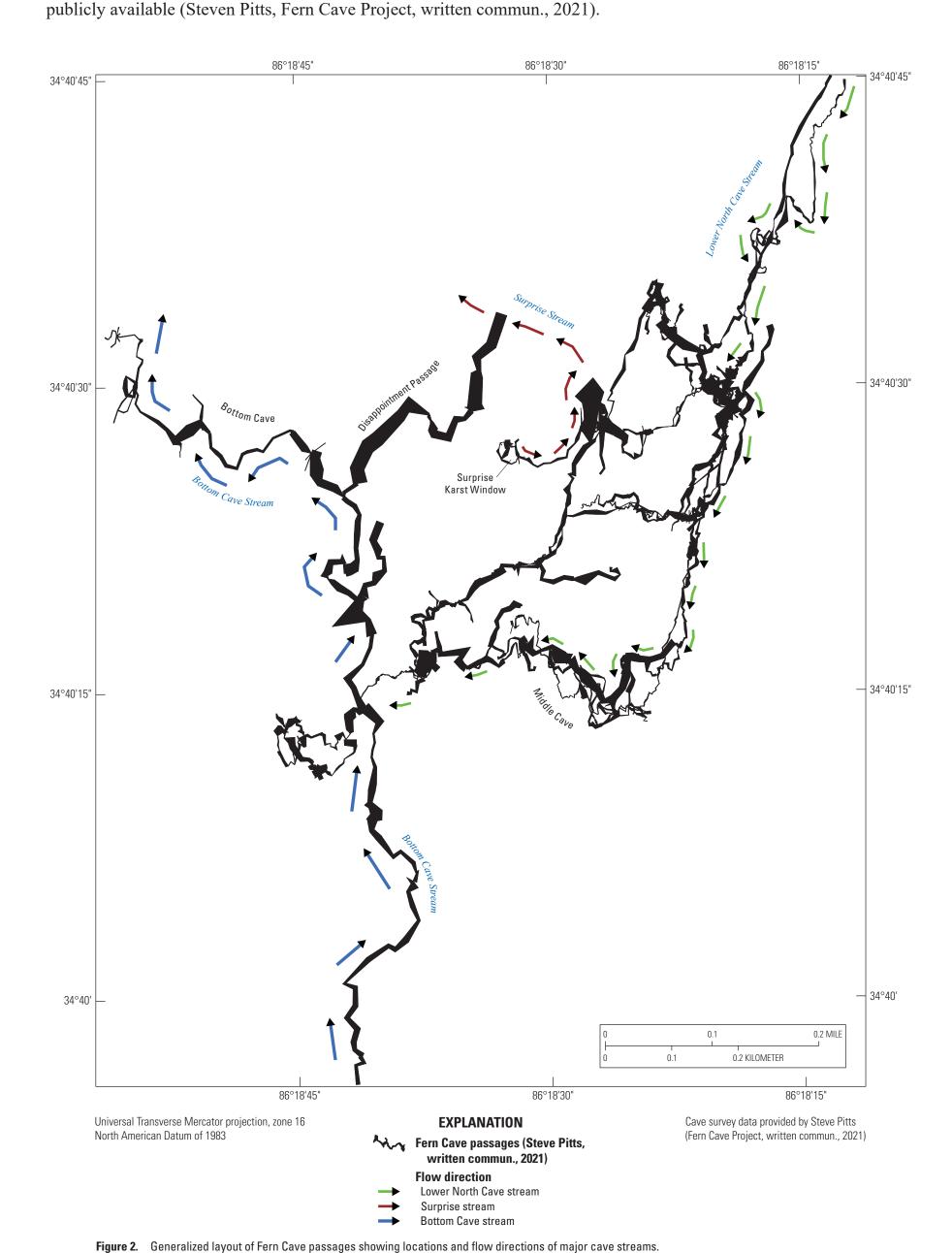


Table 1. Monitoring sites (Miller and others, 2023).

[Elevations are referenced to the National Geodetic Vertical Datum of 1929. CV, cave stream; SP; spring; ST, surface stream, Hwy, highway; ft, foot]

Site number	Site name	Site type	Elevation (ft)	
001	Haley Spring	SP	585	
002	Lower North Cave stream at base of 155 pit	CV	857	
003	Lower North Cave site 2, at small infeeder, mid-site	CV	843	
004	Lower North Cave stream above cascades	CV	840	
005	Bottom Cave main stream at reed torches	CV	604	
006	Bottom Cave main stream at station PU12	CV	600	
007	Bottom Cave side tributary stream at PU19	CV	600	
008	Paint Rock River at Paint Rock Canoe and Kayak take out	ST	580	
009	Paint Rock River near streamgage 03574500	ST	575	
010	Kennamer Spring	SP	615	
011	Roadside Spring	SP	600	
012	Big Spring	SP	605	
013	Boiling Spring	SP	595	
014	Paint Rock River at Jones Bridge	ST	595	
015	Hales Cove failsafe	ST	590	
016	Paint Rock River downstream of Hales Cove	ST	590	
017	Paint Rock River due west of Nolton Point	ST	588	
018	Lower North/Bottom Cave Spring	SP	585	
019	Paint Rock River at Log Jam Island	ST	583	
020	Surprise Karst Window spring	SP	1,140	
021	Bottom Cave stream downstream from last tributary	CV	591	
022	Bottom Cave main stream, mid-site	CV	591	
023	Bottom Cave tributary. Waterfall Dome Route & North Cave streams	CV	595	
024	Unnamed stream dropping into 100 ft pit in Jericho Passage	CV	717	
025	Dripping dome in Jericho Pit, West Room	CV	752	
026	Kennamer Hollow upstream from Kennamer Spring	ST	615	
027	Small spring with dam near Kennamer Spring	SP	612	
028	Waterfall stream near Kennamer Spring	ST	630	
029	Kennamer Hollow, downstream of road	ST	610	
030	Nat Overflow Spring	SP	600	
031	Unnamed wet weather stream downstream from road	ST	600	
032	Paint Rock River downstream from Fern Overflow Springs	ST	585	
033	Paint Rock River upstream from Fern Overflow Springs	ST	585	
034	Paint Rock River downstream from Haley Spring, upstream from 018	ST	585	
035	Paint Rock River upstream from Haley Spring	ST	585	
036	Paint Rock River downstream from 017	ST	585	
037	Northern perched spring near Nolton Point	SP	860	
038	Central perched spring near Nolton Point	SP	840	
039	Southern perched spring near Nolton Point	SP	840	
040	West branch of Kennamer Hollow	ST	1,180	
041	East branch of Kennamer Hollow	ST	1,140	
042	Fern Overflow Spring 1	SP	590	
043	Fern Overflow Spring 2	SP	595	
044	Bottom Cave main stream, 500 ft upstream from Reed Torches	CV	618	
045	Disappointment Passage, Bottom Cave side	CV	578	
046	Bottom Cave main stream, 1,500 ft upstream from Reed Torches	CV	527	
047	Bottom Cave main stream upstream from 023	CV	595	
048	Bottom Cave main stream downstream from datalogger	CV	595	
049	Bottom Cave main stream at entrance to large side passage on right	CV	598	
050	Unnamed left side tributary to Bottom Cave main stream	CV	604	
051	Unnamed right side tributary to Bottom Cave main stream	CV	591	
052	Surprise Stream at climbdown past Earthquake Room	CV	578	
053	Wilson Dome stream	CV	616	

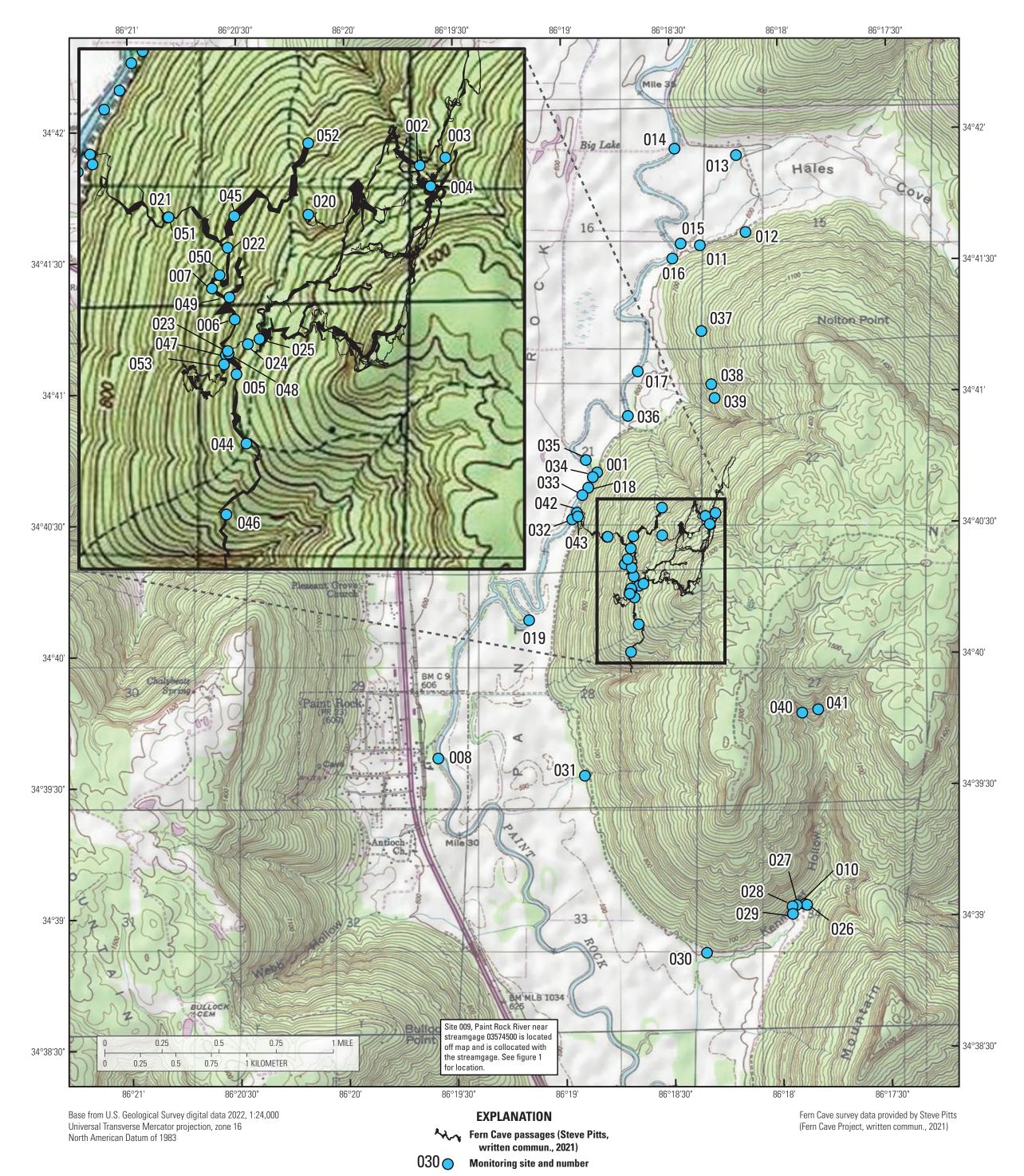


Figure 3. Locations of monitoring sites utilized for this study. Site numbers correspond to those listed in table 1.

Table 2. Dye injections and positive traces (Miller and others, 2023).
[Elevations are referenced to the National Geodetic Vertical Datum of 1929. Dates are shown in month, day, year format. lb, pound; kg, kilogram; ft, foot; m, meter; us, upstream; ds, downstream; nr, near; h, hour; min., minute; >, greater than;, not applicable]

Round number	Injection ID	Injection setting	Elevation (ft)	Elevation (m)	Strata	Injection date	Flowing water present	Dye injected	Amount injected (Ib)	Amount injected (kg)	Recovery sites (site numbers)	Elevation (ft)	Elevation (m)	Strata	Date recovered	Dye concentration
1	I-1	Streambed, small seep, sinking immediately	1,200	365.8	Pennington Formation	12/9/2019	Yes	Sulphorhodamine B	2	0.9	Bottom Cave sites (005,022), Fern Cave Overflow Spring 2 (043)	604–591	184–180	Pennington - Tuscumbia	2/16/2020	>10x background intensity
1	I-2	Streambed, flowing, sinking 50 ft ds	1,400	426.7	Pennington Formation	12/9/2019	Yes	Eosine OJ	2	0.9	Surprise Karst Window Spring (020), Haley Spring (001)	1,140–585	347–178	Pennington - Tuscumbia	12/16/2019	>10x background intensity
1	I-3	Streambed, flowing, sinking 100+ ft ds	1,060	323.1	Bangor Limestone	12/10/2019	Yes	Rhodamine WT	2	0.9	Lower North Cave Stream (004), Lower North/Bottom Cave Spring (018)	840–585	259–178	Bangor - Tuscumbia	2/18/2020	>10x background intensity
2	I-4	Streambed, seep, us from open swallet/cave	1,100	335.3	Bangor Limestone	3/14/2020	Yes	Eosine OJ	3	1.35	Northern Perched Spring (037), Central Perched Spring (038), Haley Spring (001)	850–585	259–178	Monteagle - Tuscumbia	3/15/2020	>10x background intensity, visual confirmation at 001
2	I-5	Cave stream, dropped 20+ ft in elevation down crack	1,050	320.0	Bangor Limestone	3/14/2020	Yes	Sulphorhodamine B	2	0.9	Central Perched Spring (038), Southern Perched Spring (039), Haley Spring (001)	850–585	259–178	Monteagle - Tuscumbia	4/28/2020	>10x background intensity, visual confirmation at 001
2	I-6	Streambed, flowing,	1,400	426.7	Pennington Formation	3/14/2020	Yes	Rhodamine WT	1.5	0.675	Kennamer Spring (010), Nat Overflow Spring (030)	615–600	187–183	Pennington - Tuscumbia	4/28/2020	>10x background intensity
2	I-7	Streambed, flowing, sinking immediately	1,160	353.6	Pennington Formation	3/14/2020	Yes	Fluorescein	1	0.45	Not detected at any monitoring sites					
3	I-8	Dry streambed, dry set utilized	1,100	335.3	Bangor Limestone	7/28/2020	No	Fluorescein	1	0.45	Not detected at any monitoring sites					
3	I-9	Swallet, no flow, 20 ft deep	1,040	317.0	Bangor Limestone	7/28/2020	No	Rhodamine WT	2	0.9	Big Spring (012), Roadside Spring (011)	605–600	184–183	Bangor - Tuscumbia	9/24/2020	>10x background intensity
3	I-10	Streambed, nonflowing pool	1,140	347.5	Pennington Formation	7/28/2020	No	Eosine OJ	3	1.35	Bottom Cave sites (005,021,022)	604–591	184–180	Monteagle - Tuscumbia	8/8/2020	>10x background intensity
3	I-11	Streambed, nonflowing pool	1,090	332.2	Bangor Limestone	7/28/2020	No	Sulphorhodamine B	2	0.9	Bottom Cave sites (005,021,022)	604–591	184–180	Bangor - Tuscumbia	8/8/2020	>10x background intensity
4	I-12	Cave stream, Lower North Cave Stream nr Cascades	840	256.0	Bangor Limestone	5/18/2021	Yes	Rhodamine WT	2	0.9	Bottom Cave sites (021,022, 047, 049), Fern Cave Overflow Spring 1 (042), Low- er North/Bottom Cave Spring (018)	598–585	182–178	Monteagle - Tuscumbia	5/19/2021	>10x background intensity, Visual confirmation at 042, 047
4	I-13	Spring that immediately sinks into swallet	1,140	347.5	Pennington-Bangor	5/19/2021	Yes	Fluorescein	0.5	0.225	Disappointment Passage stream (052), Haley Spring (001)	585	178	Monteagle - Tuscumbia	5/19/2021, 2 h 47 min ¹	>10x background intensity, Visual confirmation at 001, 052
4	I-14	Small karst window, spring flows 40 ft into swallet	1,140	347.5	Bangor Limestone	5/22/2021	Yes	Eosine OJ	2	0.9	Bottom Cave sites (005,021,022,023,046), Nat Cave (030), Waterfall Stream (027),	630–591	192–180	Monteagle - Tuscumbia	6/23/2021	>10x background intensity

Small Spring with Dam (028)

¹U.S. Geological Survey

²Kentucky Geological Survey, University of Kentucky

¹Time period for dye trace was short enough to require the use of hours and minute

For sale by U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225, 1-888-ASK-USGS Digital files available at https://doi.org/10.3133/sim3506 Suggested citation: Miller, B.V., and Tobin, B., Mapping karst groundwater flow paths and delineating recharge areas for Fern Cave, Alabama, through the use of dye tracing: U.S. Geological Survey Scientific Investigations Map 3506, 2 sheets, https://doi.org/10.3133/sim3506 Associated data for this publication: Dewitz, J., and U.S. Geological Survey, 202 National Land Cover Database (NLCD) 2019 Products (ver. 2.0, June 2021): U.S. Miller, B.V., Tobin, B.W., and Hourigan, A.M., 2023, Mapping karst groundwater flow paths and delineating recharge areas for Fern Cave, Alabama through the use of dye tracing: U.S. Geological Survey data release, https://doi.org/10.5066/P9AE0LQ U.S. Geological Survey, 2019, USGS water-year summary 2019—03574500 Paint Rock River near Woodville, AL, in USGS water data for the Nation: U.S. Geologica

Survey National Water Information System database, https://doi.org/10.5066/ F7P55KJN. [Site information directly accessible at https://nwis.waterdata.usgs.go nwis/wys rpt?dv ts ids=&2629&adr begin date=2018-10-01&adr end date=2019-

U.S. Geological Survey, 2020, USGS water-year summary 2020—03574500 Paint

Rock River near Woodville, AL, in USGS water data for the Nation: U.S. Geological Survey National Water Information System database, https://doi.org/10.5066/ F7P55KJN. [Site information directly accessible at https://nwis.waterdata.usgs.go

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Mapping Karst Groundwater Flow Paths and Delineating Recharge Areas for Fern Cave, Alabama, Through the Use of Dye Tracing