

Water Availability and Use Science Program

Prepared in cooperation with the National Park Service

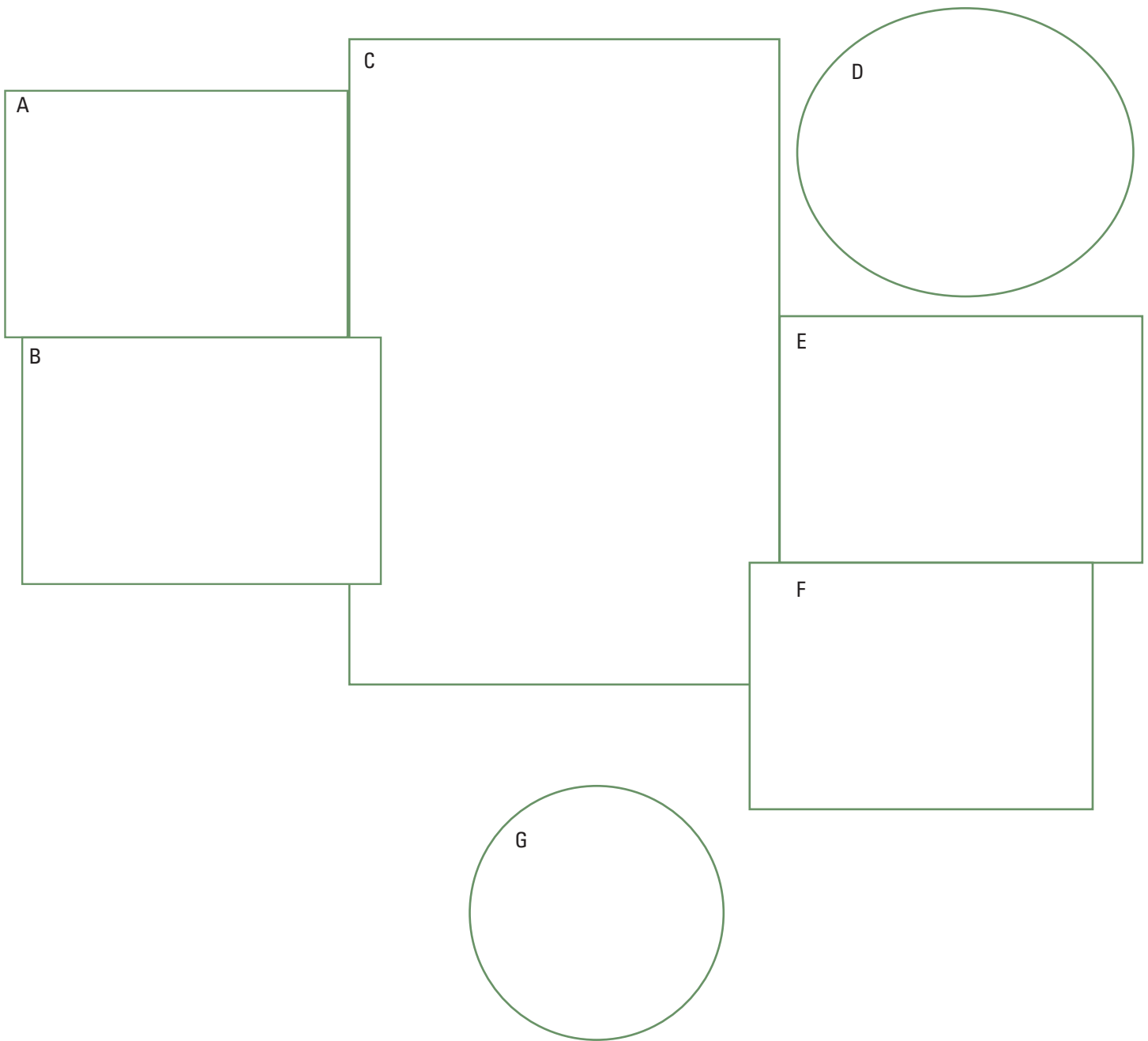
Groundwater Tracing Used to Delineate Recharge Areas and Map Karst Groundwater Pathways for Subterranean Streams at Oregon Caves National Monument and Preserve



Scientific Investigations Report 2025–5084

**U.S. Department of the Interior
U.S. Geological Survey**





Cover.

A. Looking up at the speleothems at Paradise Lost within Oregon Caves, November 2, 2022. Photograph by Ivan Ekblom, National Park Service.

B. Calcite crystals within a small pool in Oregon Caves, November 1, 2022. Photograph by Ivan Ekblom, National Park Service.

C. National Park Service employee changes charcoal packets at a site while wearing nitrile gloves, April 24, 2021. Photograph by Ivan Ekblom, National Park Service.

D. *Ascaphus truei* (coastal tailed frog), which breeds in the waters of the River Styx that flows through Oregon Caves, May 18, 2022. Photograph by Ivan Ekblom, National Park Service.

E. Faulting in the ceiling of the Ghost Room as evidenced in offset in a dike that cuts through the marble, May 14, 2021. Photograph by Ivan Ekblom, National Park Service.

F. Dye injection of sulphorhodamine b in upper Cave Creek, May 6, 2024. Photograph by Ivan Ekblom, National Park Service.

G. *Onychiurus oregonensis*, a troglotic springtail on the surface of an in-cave pool within Oregon Caves, November 1, 2022. Photograph by Ivan Ekblom, National Park Service.

Groundwater Tracing Used to Delineate Recharge Areas and Map Karst Groundwater Pathways for Subterranean Streams at Oregon Caves National Monument and Preserve

By Benjamin V. Miller

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
Length		
inch	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
acre	4,047	square meter (m²)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm²)
acre	0.004047	square kilometer (km²)
square mile (mi²)	259.0	hectare (ha)
square mile (mi²)	2.590	square kilometer (km²)
Flow rate		
cubic foot per second (ft³/s)	0.02832	cubic meter per second (m³/s)
Mass		
pound, avoirdupois (lb)	0.4536	kilogram (kg)

Datums

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29) and the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the vertical datum.

Abbreviations

ADV	acoustic Doppler velocimeter
GIS	geographic information system
NPS	National Park Service
ORCA	Oregon Caves National Monument and Preserve
USGS	U.S. Geological Survey

Groundwater Tracing Used to Delineate Recharge Areas and Map Karst Groundwater Pathways for Subterranean Streams at Oregon Caves National Monument and Preserve

By Benjamin V. Miller

Abstract

Oregon Caves National Monument and Preserve in southwestern Oregon is a 4,554-acre area managed by the National Park Service that is home to several cave systems, including Oregon Caves, which is the longest cave in Oregon, with 3.03 miles of mapped passages. Because of the interconnected nature of karst hydrologic systems, it is critical to understand the areas that can influence water quality and quantity in karst environments. Toward this goal, dye tracing was conducted by the U.S. Geological Survey from 2021 to 2024 to better understand the pathways that karst groundwater follows at Oregon Caves National Monument and Preserve and to delineate recharge areas for two caves, Oregon Caves and Cave Next Door. During the project, eight dye injections were conducted, delineating a 0.51-square-mile recharge area for Oregon Caves and a 0.69-square-mile recharge area for Cave Next Door. Additionally, the study helped to identify three resurgences associated with Oregon Caves that were previously unknown and showed that the recharge areas for the two caves were distinct from one another. The dye traces also illuminated some unique recharge characteristics of the karst at Oregon Caves, including a high variance in karst groundwater velocities, retention within the karst aquifers, and a significant diffuse-flow component.

Introduction

Oregon Caves National Monument and Preserve (ORCA) is located in southwest Oregon in Josephine County, approximately 11 miles (mi) east of Cave Junction ([fig. 1A, B](#)). Several streams in ORCA drain the western slope of the Inland Siskiyou Mountain ecoregion (U.S. Environmental Protection Agency, 2003), forming the headwaters of Cave Creek, a tributary to Sucker Creek. The geology of the area is complex and varied, and portions of ORCA are underlain by bodies of marble that are subject to dissolution. This

dissolution initiates karst processes, and in turn, connectivity develops between surface streams and karst groundwater systems. This karstification can lead to the formation of solutional caves such as Oregon Caves, a 3.03-mi-long cave (Oregon's longest) with an active stream (River Styx). Additionally, because of this karstification, activities that occur on the surface can have a direct impact on groundwater quality and quantity (Leibundgut, 1998; Urich, 2002). In karst environments, groundwater flow can be complex and unpredictable, so techniques such as dye tracing are used to map karst groundwater pathways and delineate recharge areas for caves and springs.

In 2017, the extent of ORCA increased from 484 to 4,554 acres through a land transfer from Rogue River-Siskiyou National Forest, as described in the Oregon Caves National Monument Boundary Adjustment Act of 2010 (U.S. Senate, 2010). This newly acquired land included several bodies of marble that are karstified and contain springs, caves, sinkholes, and sinking/losing streams. A spring within this newly acquired area specifically warranted new study. The spring along Lake Creek was known to drain a cave system (Cave Next Door) that had been dug into during the late 1990s, but the entrance collapsed soon thereafter (Knutson, 2021). This spring had previously had a positive dye trace from a sinkpoint located 0.5 mi to the southwest, in an unnamed tributary to Panther Creek known locally, and referred to herein, as “south fork Panther creek,” (Barnes, 1999; Knutson, 2021). Any other recharge contributions to the spring were unknown.

From 2021 to 2024, the U.S. Geological Survey (USGS), in cooperation with the National Park Service (NPS), conducted dye tracing at ORCA in an effort to delineate recharge areas for both Oregon Caves and the spring for Cave Next Door (known locally and referred to herein as “Cave Next Door spring”) and to determine if any hydrologic connection existed between the two karst systems. The goal of the traces was to aid NPS personnel in the management of both karst systems and contribute information for a Wild and Scenic River Management Plan for Cave Creek and River Styx, which were established as a Wild and Scenic River in 2014 (NPS, 2018). The purpose of this report is to

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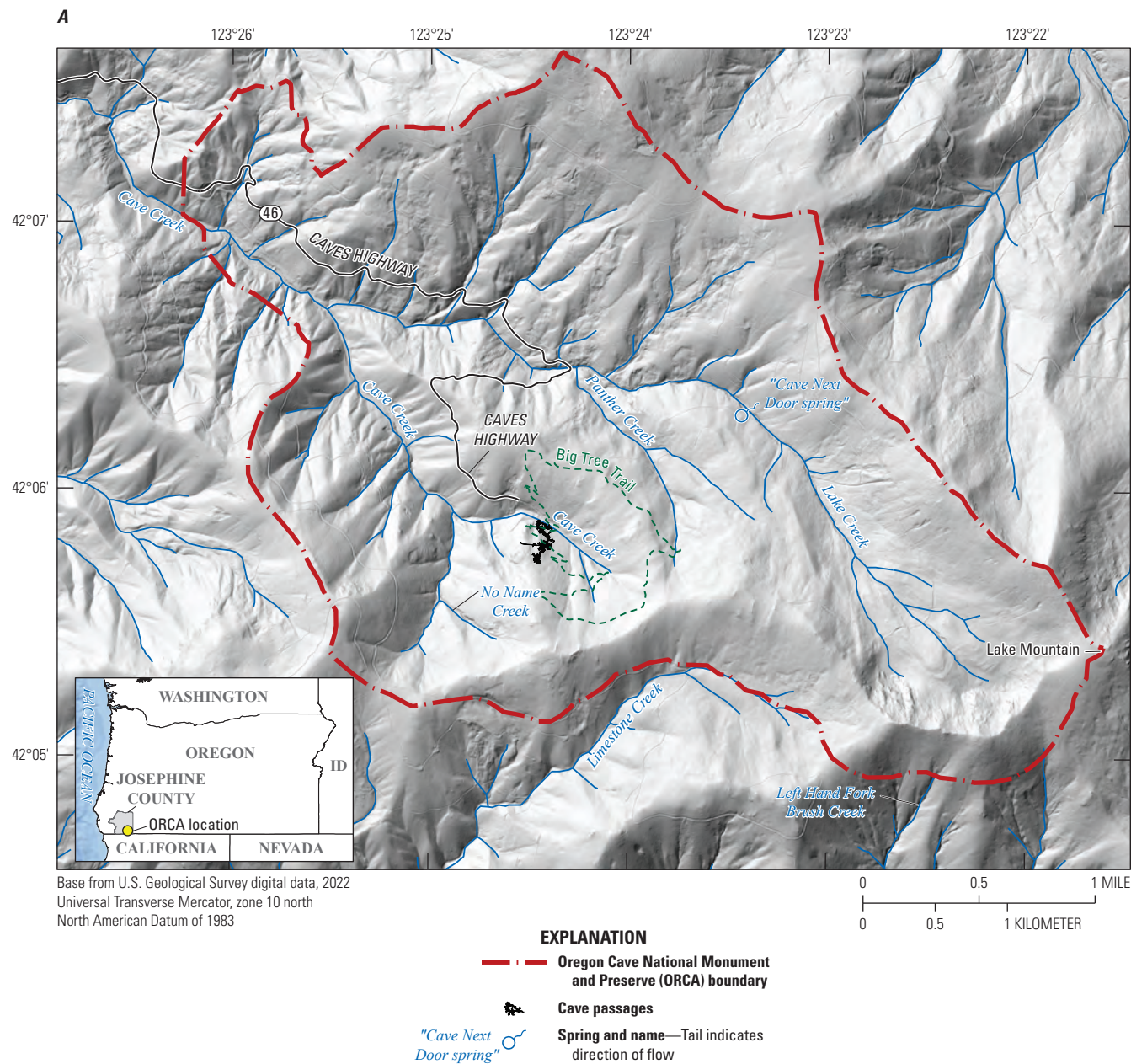


Figure 1. Geographic and administrative features mentioned in the report, including A, Oregon Caves National Monument and Preserve; B, Siskiyou Mountains; and C, Klamath Mountains.

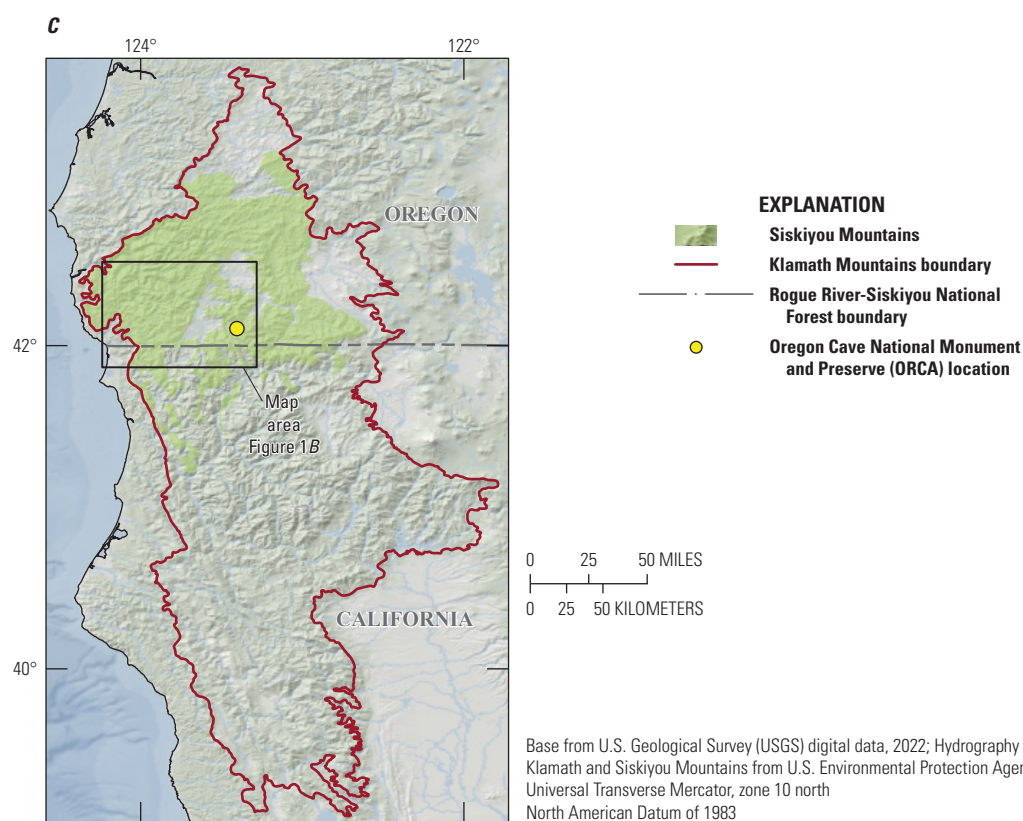
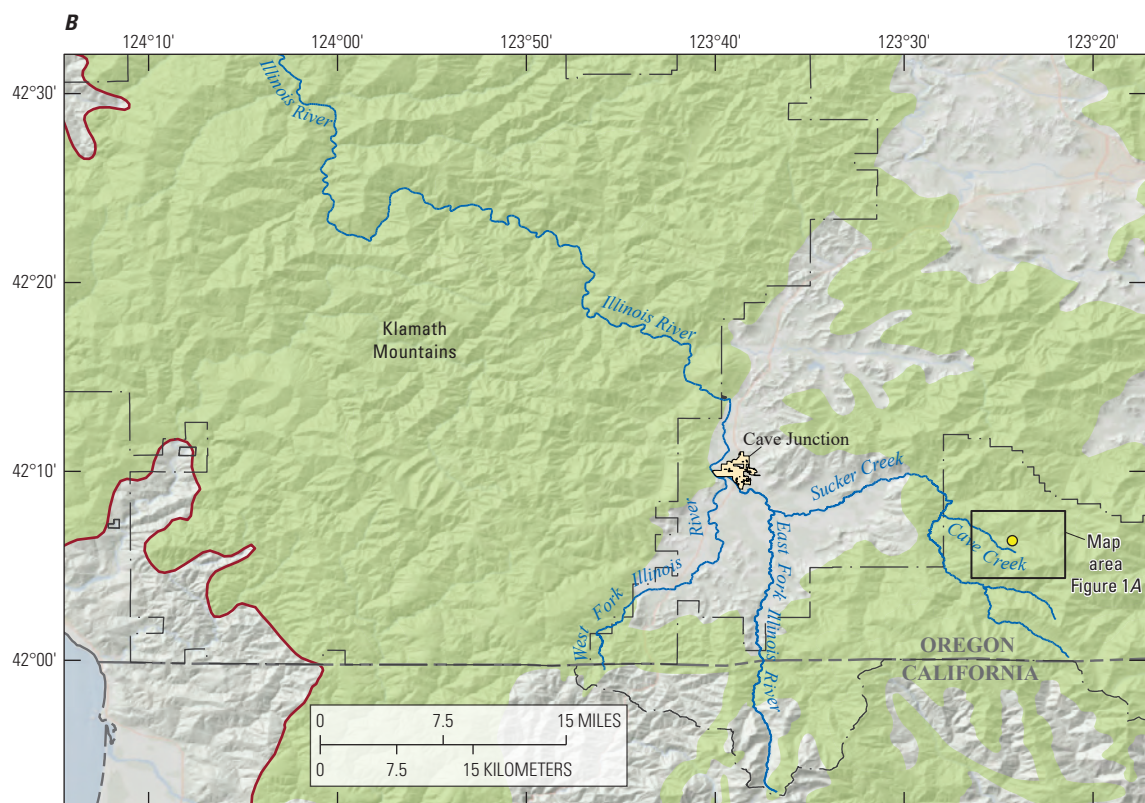


Figure 1.—Continued

document the groundwater tracing used to delineate recharge areas and map karst groundwater pathways for subterranean streams at ORCA.

Setting

Geographic and Geologic

ORCA is located in southwest Oregon in the Siskiyou Mountains, a coastal subrange of the Klamath Mountains (fig. 1B, C; Garwood and Kauffmann, 2022). ORCA consists of 4,554 acres, primarily covered in old-growth and second-growth *Pseudotsuga menziesii* (Douglas-fir) forests. According to 2019 land use-land cover data, approximately 88 percent of ORCA is evergreen forest (Dewitz and USGS, 2021). Vertical relief within the study area is 4,037 feet (ft), ranging from 2,650 to 6,687 ft above the National Geodetic Vertical Datum of 1929 (USGS, 1996a, b), with the lowest and highest points in elevation being the streambed of lower Cave Creek and the summit of Lake Mountain, respectively (fig. 1). The climate is classified as Csb, warm-summer Mediterranean, by the Köppen Classification System (Peel and others, 2007). The area receives approximately 60 inches of precipitation annually, although most of the precipitation falls as snow, which can exceed 155 inches each winter (U.S. Department of Agriculture Natural Resources Conservation Service, 2025). The NPS boundaries include the topographic drainage boundaries for Lake Creek, Cave Creek, and No Name Creek, although a small portion of Limestone Creek and Left Hand Fork Brush Creek to the south is included near the divide with No Name Creek. Cave Creek flows into Sucker Creek, which in turn, is a tributary to the East Fork Illinois River, joining the main Illinois River in Cave Junction (fig. 1B).

ORCA is underlain by a complex mélange of accreted terranes with plutonic intrusions of diorite (fig. 2). The underlying bedrock is late Triassic and Jurassic and includes the Grayback pluton (diorite) and the Applegate Group, a highly varied and complex group of metavolcanic and metasedimentary strata (Mack, 1982; Donato and others, 1996). Although not an officially designated formation, the underlying strata is referred to as the “Rattlesnake Creek terrane” in much of the geologic literature related to ORCA, as well as the surrounding vicinity (Irwin and Blome, 2004; Barnard, 2007; KellerLynn, 2011; NPS, 2012), which has been correlated with strata from the Applegate Group on the basis of lithologic similarities, geochemistry, and isotopic dating (Donato and others, 1996). Rattlesnake Creek terrane is, by definition, varied in age, composition, and origin (KellerLynn, 2011; NPS, 2012). The terrane contains a wide diversity of metamorphic strata, including metaigneous and metasedimentary rocks, largely consisting of ophiolite that has been heavily fragmented and then accreted. In several cases, the original strata of the Rattlesnake Creek terrane was

metamorphosed during the intrusion of the Grayback pluton in the Jurassic Period. The marble present at ORCA, where karst development occurs, would have initially formed as a marine limestone that was later metamorphosed into marble during contact with the adjacent Western Hayfork terrane and during the plutonic intrusion (Medaris and others, 2009; KellerLynn, 2011).

The study focused primarily on the marble bodies of the Rattlesnake Creek terrane and strata directly adjacent to the marble (quartzite, meta-basalt, skarn, serpentinite, and diorite), because these are the areas that create allogenic recharge to the karst systems present in the marble (fig. 2). As such, in the “Results” and “Discussion” sections, the adjacent nonmarble units may be referred to as “noncarbonate” or “insoluble” strata and the marble units may be referred to as “carbonate” or “soluble” strata if not directly identified.

Caves and Karst

Cave and karst areas at ORCA are focused around areas underlain by marble (Brooks, 1989; KellerLynn, 2011; NPS, 2012). These areas exist within the Lake Creek, Panther Creek, No Name Creek, and Cave Creek watersheds; however, the karst in the Cave Creek drainage is primarily located high in the watershed. Karst features within these areas include springs, sinkholes, sinking streams, caves, and exposed epikarst/“marble pavement.” Many of the karst areas are recharged by allogenic recharge from the noncarbonate strata located upslope from the marble areas (Meiman, 1996). Some areas have more pronounced karst development than others; in particular, the expanse of marble between Cave Creek and “south fork Panther creek” has extensive karst development, complete with well-developed epikarst, numerous sinkholes, and a total lack of surface water.

Although ORCA contains nine caves, many of these are short and relatively limited in extent. The longest and largest cave in ORCA is Oregon Caves, with 3.03 mi of mapped passages (fig. 3). Oregon Caves is a maze cave with horizontal and vertical complexity. The main stream in the cave is River Styx, which is present throughout the northern portion of the cave system and is designated by the NPS as a Wild and Scenic River (NPS, 2018). Other, minor streams exist in the cave system, some of which originate as falling water from domes and speleothem seepage. Streamflow in the cave is generally from the south to the north, where the stream discharges from the cave entrance and several satellite springs. The second longest cave is Cave Next Door, which is an 837-ft-long stream cave located on the 2017 expanded preserve. The cave was discovered in 1999 and was accessed via a manmade dig from the spring that issues into Lake Creek (fig. 4). Less than 1 year after the initial discovery, the entrance collapsed and the cave has not been enterable since that time; however, the cave stream resurgence (“Cave Next Door spring”) remains as a spring (Knutson, 2021).

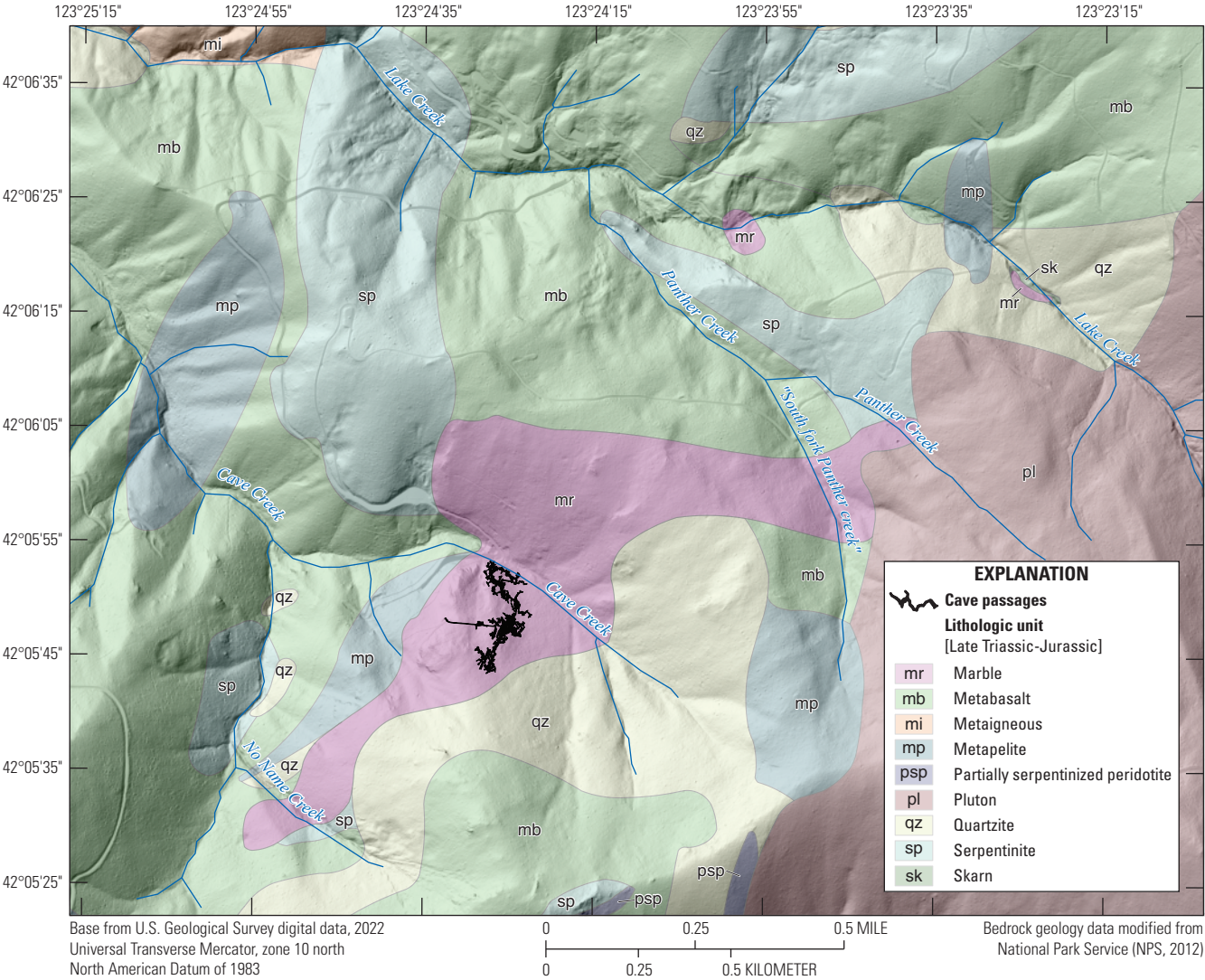


Figure 2. Geology of the main study area.

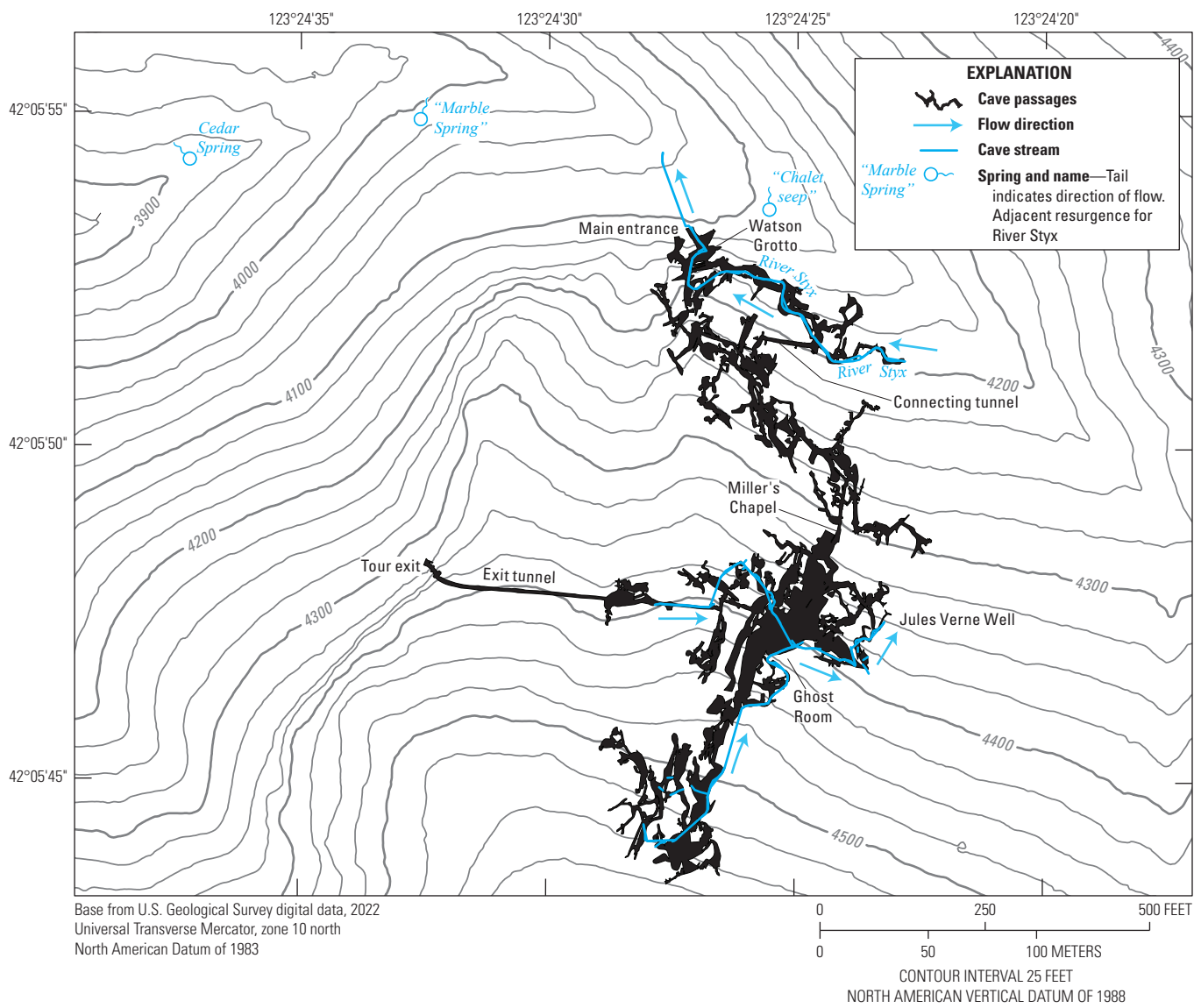


Figure 3. Topographic overlay of Oregon Caves mapped passages with major place names, spring resurgences, and showing the path of the River Styx.



Figure 4. National Park Service employees stand above the spring outlet for “Cave Next Door spring” along Lake Creek. Photograph by Benjamin V. Miller, U.S. Geological Survey.

Methods

Dye Tracing

Dye tracing methodology follows standard methods for groundwater tracing by using fluorescent dyes to map karst groundwater pathways and delineate recharge features. Methods utilized in this study are outlined below and generally follow procedures similar to those outlined in Miller and Tobin (2023), Crawford Hydrology Laboratory (2023), and Miller (2024).

A detailed hydrologic inventory was conducted from April 24–26, 2021, at the beginning of the study to identify possible monitoring sites such as springs, seeps, cave streams, and surface streams (fig. 5, table 1). Although the majority of monitoring sites were identified at the start of the study, some additional monitoring sites were added throughout the project if new features were discovered. Features were monitored (figs. 5 and 6, table 1) using receptors containing activated coconut charcoal tied to a wire and placed directly in the streamflow. Receptors were then changed at timed intervals postinjection to determine approximate travel times from injection location to monitoring site. Changeout intervals for charcoal packets ranged from once every 12 hours for the high-resolution sampling in the third round of dye injections, to daily or weekly during the first 8 weeks and monthly thereafter for several months following the dye injections. In addition to monitoring using charcoal packets, the third round of dye injections utilized grab samples of water collected at the time of packet retrieval for specific high-resolution monitoring. These samples were collected in a glass vial, the cap was secured with Parafilm, and the vial was placed in the sample bag with the charcoal packets. Following sample collection, all packets and grab samples were kept in a dark location until receipt at the laboratory.

While identifying monitoring sites, recharge features and possible dye injection locations, such as stream sinks, were also identified and examined. The initial dye injection locations for the study were chosen with the goal of identifying flow paths that may flow to either the Oregon Caves or Cave Next Door hydrologic systems. For this study, a total of three rounds of dye injections were conducted, with each round consisting of 1–4 dye injections at different locations. The first and third rounds of injections took place during higher-flow conditions in spring, following snowmelt, whereas the second took place during low-flow conditions in late summer-early fall 2021. Dye injection locations were selected on the basis of their proximity to the two cave systems and identified marble bodies, the hydrologic conditions present at each site, and the presence of flowing water sinking (in whole or in part) into the subsurface. Locations for the second round were selected by using the results from the previous dye injection round as well as the selection criteria just mentioned to plan the low-flow traces. The dye injections utilized four nontoxic fluorescent dyes

(fluorescein, eosine oj, rhodamine wt, and sulphorhodamine b) that were injected into losing streams, swallets, or cave streams. In several cases, during the injection of dyes, Tyvek suits were worn in an effort to prevent cross-contamination among injection sites and between monitoring sites. The dyes used in this study are frequently utilized in karst groundwater studies because of unique emission wavelengths for each dye that can be identified through laboratory analysis.

Following retrieval of the receptors, processing and analysis were conducted by the Crawford Hydrology Laboratory at Western Kentucky University on a Shimadzu Rf-5301PC or Shimadzu RF 6000 scanning spectrofluorophotometer using established protocols (Crawford Hydrology Laboratory, 2023). Once positive traces were confirmed, results were then plotted in a geographic information system (GIS) framework to begin delineating the recharge area of the cave. Additional information, related to methods, is included as part of the metadata within the data release of the dye tracing data for this study (Miller and others, 2025).

From these dye injections, karst recharge areas for Oregon Caves and Cave Next Door were delineated by following topographic divides upstream from injection points with considerations of the underlying geology and groundwater flow paths. This method of delineation is limited by the hydrologic conditions during the injections. Because of precipitation heterogeneity and changes in groundwater and stream levels, karst groundwater basin divides may shift slightly based upon hydrologic conditions.

Discharge Measurement Methods and Determination of Losing and Gaining Reaches of Streams

Because of the hydrologic conditions present during the second round of dye injections, many of the streams targeted for these dye injections had overland flow where the stream was not sinking entirely into the subsurface. Because of this characteristic, several streams required small seepage investigations to determine whether the stream was only gaining or whether a substantial percentage of flow was lost, warranting a dye injection. Discharge measurements along streams utilized two methods for measuring streamflow: current-meter midsection measurements using acoustic Doppler velocimeters (ADV) on wading rods and volumetric methods using a graduated bucket and stopwatch. In all cases, discharge measurements were made along the stream within a short period and the measurements distributed above, within, and below marble outcrops to determine any loss of streamflow into the karstic geologic units.

At measurement sites where the channel was deep and wide enough, ADVs were used to measure discharge while wading. Overall, the discharge methods followed those outlined in Turnipseed and Sauer (2010). In especially narrow sites on smaller streams, however, conditions were suboptimal

and channel width may have limited the total number of measurement sections or shallow conditions may have caused ADV measurement quality issues. In these instances, the measurement quality rating was downgraded, and the conditions were considered when determining whether stream reaches were gaining or losing.

Smaller streams with pour over ledges permitted the use of graduated buckets and stopwatches for making volumetric measurements of streamflow. If 100 percent of the streamflow could be captured, then a hydrographer would use a graduated bucket and stopwatch to make repeat measurements of discharge, typically collecting six to seven repeat measurements. This method is also outlined in Turnipseed and Sauer (2010).

In general, decreases in discharge in the downstream direction indicate a loss in streamflow to the subsurface (not accounting for evaporation), and increases in discharge in a downstream direction indicate a gain in streamflow. Discharge measurements along streams were plotted using the Global

Positioning System and GIS. If the measurements were within the measurement error for the larger of the two discharge measurements, either in the upstream or downstream direction, then the intervening reach would be designated as neutral. If the measurement error was less than the difference between the two measurements and discharge increased in the downstream direction, then the reach was designated as gaining. If the measurement error was less than the difference between the two measurements and discharge decreased in the downstream direction, then the reach was designated as losing, indicating a loss to the subsurface. Measurement error was determined by a combination of measurement methodology and uncertainties attributed to channel conditions and velocity profiles, and generally followed guidelines outlined in Turnipseed and Sauer (2010). Seepage investigations and stream reach determinations followed the methodology used by Knierim and others (2015) and Miller and others (2022).

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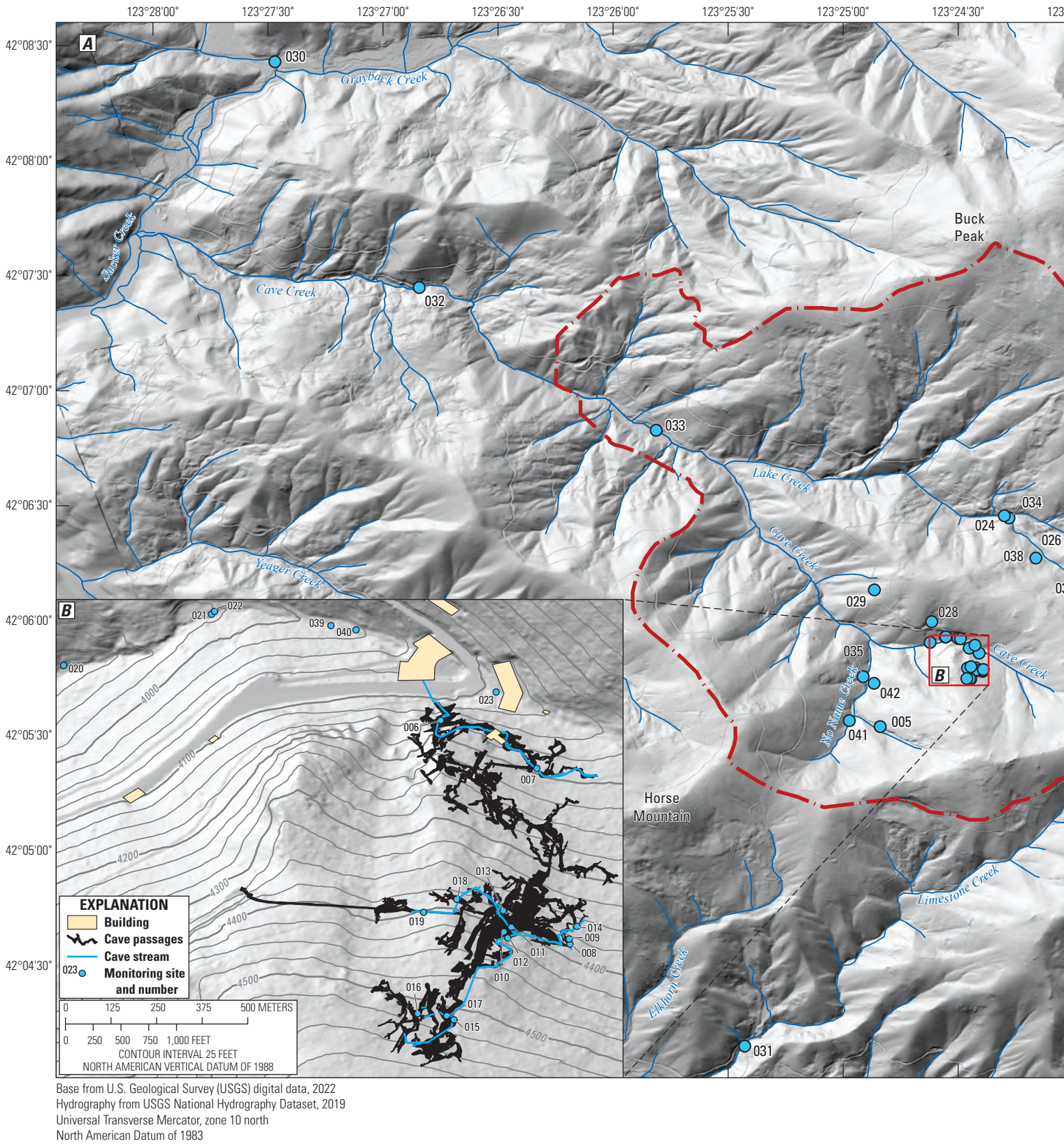


Figure 5. A, Locations of all features monitored for the dye tracing study, and B, features monitored in and near Oregon Caves.

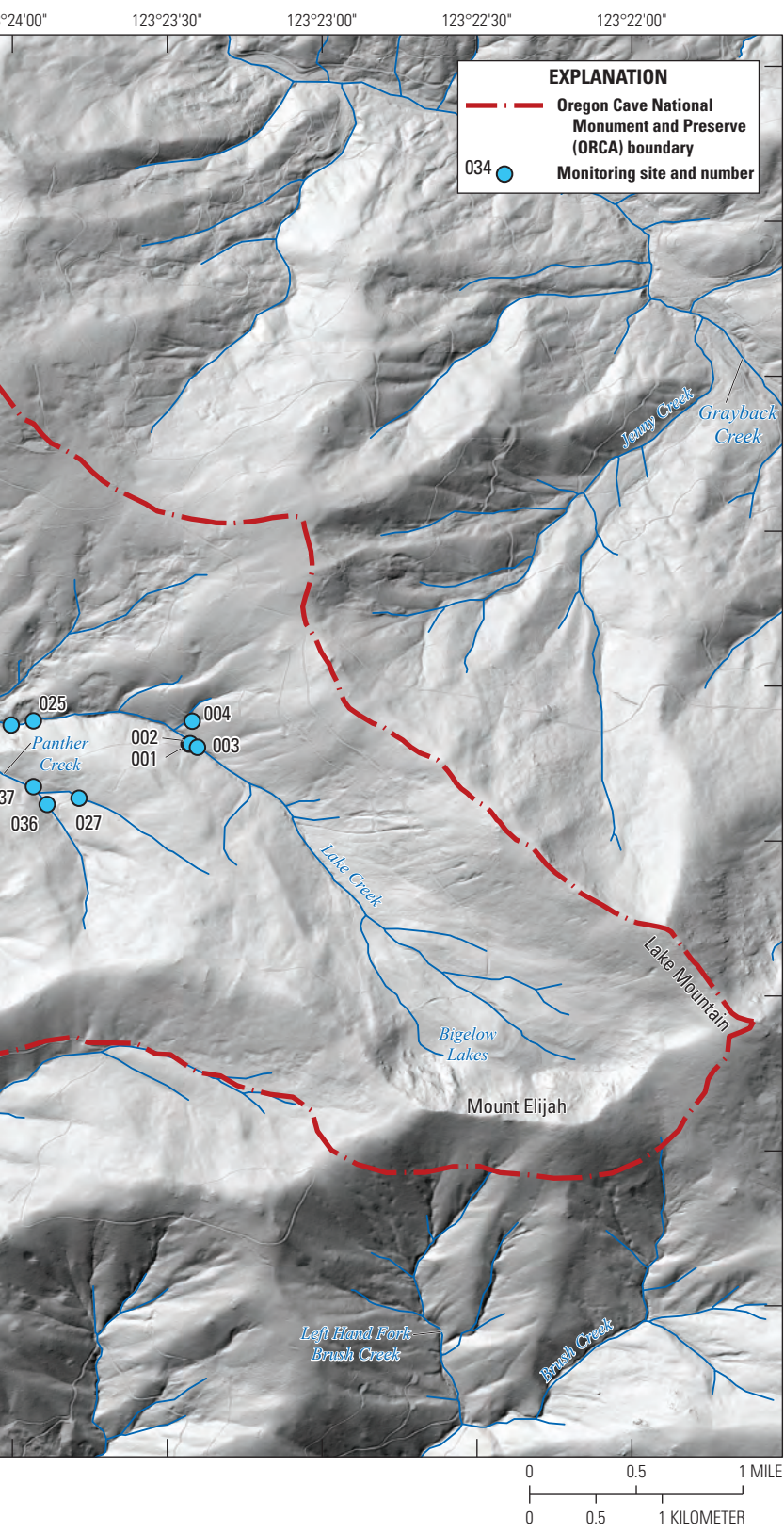


Table 1. Monitoring sites used in this study.

[Elevation data from the 3DEP lidar explorer (U.S. Geological Survey, 2024). Elevation data referenced to the North American Vertical Datum of 1988 (NAVD 88). Site type: SP, spring; ST, surface stream; CV, cave stream. CND, Cave Next Door; ORCA, Oregon Caves National Monument and Preserve; FS, Forest Service; NPS, National Park Service]

Site no.	Site name	Site type	Elevation (feet above NAVD 88)
001	Cave Next Door spring resurgence	SP	4,233
002	Cave Next Door spring resurgence backup site	SP	4,226
003	Lake Creek upstream from CND spring	ST	4,260
004	Small seep along road near Lake Creek	SP	4,302
005	No Name Creek spring	SP	4,193
006	Oregon Caves-River Styx at Watson Grotto	CV	4,016
007	Oregon Caves-River Styx below Connecting Tunnel	CV	4,026
008	Oregon Caves-Rain Room, bucket A, south end of dome	CV	4,117
009	Oregon Caves-Rain Room, bucket B, north end of dome	CV	4,117
010	Oregon Caves-Paradise Lost	CV	4,160
011	Oregon Caves-Ghost Room - small stream A closer to trail	CV	4,103
012	Oregon Caves-Ghost Room - small stream B	CV	4,097
013	Oregon Caves-Waterfall Passage stream	CV	4,118
014	Oregon Caves-Jules Verne Well	CV	4,054
015	Oregon Caves-Whitfield Dome Stream in Snake Room	CV	4,146
016	Oregon Caves-Base of climb leading up to Bone Dome near Bear Scratches	CV	4,202
017	Oregon Caves-Snake Room, stream from Bone Dome	CV	4,145
018	Oregon Caves-North Canyon Passage Dome above Bear Bones	CV	4,158
019	Oregon Caves-Exit tunnel stream near Clay Pocket	CV	4,174
020	Cedar Spring	SP	3,810
021	Marble spring A-downstream	SP	3,872
022	Marble spring B-upstream	SP	3,874
023	Chalet seep spring	SP	4,008
024	Lake Creek at highway crossing below Panther Creek	ST	3,541
025	Lake Creek above marble outcrop near quarry	ST	3,849
026	Lake Creek below marble outcrop near quarry	ST	3,788
027	Main stem of Panther Creek above road	ST	4,311
028	Parking lot seep near ORCA main lot	SP	3,984
029	Willow Spring near highway	SP	3,869
030	Sucker Creek below Greyback	ST	1,830
031	Limestone Creek at FS Road 80	ST	2,963
032	Cave Creek at FS Road 4612 bridge	ST	2,354
033	Cave Creek at NPS campground	ST	2,730
034	Panther Creek at Lake Creek	ST	3,588
035	No Name Creek at trail dead end	ST	3,793
036	South fork Panther resurgence	SP	4,232
037	North fork Panther Seep	SP	4,161
038	Panther Creek spring	SP	3,977
039	Culvert below Chateau	SP	3,909
040	Seep below Chateau	SP	3,920
041	West Fork No Name Creek spring	SP	4,061
042	Ivan spring	SP	3,900

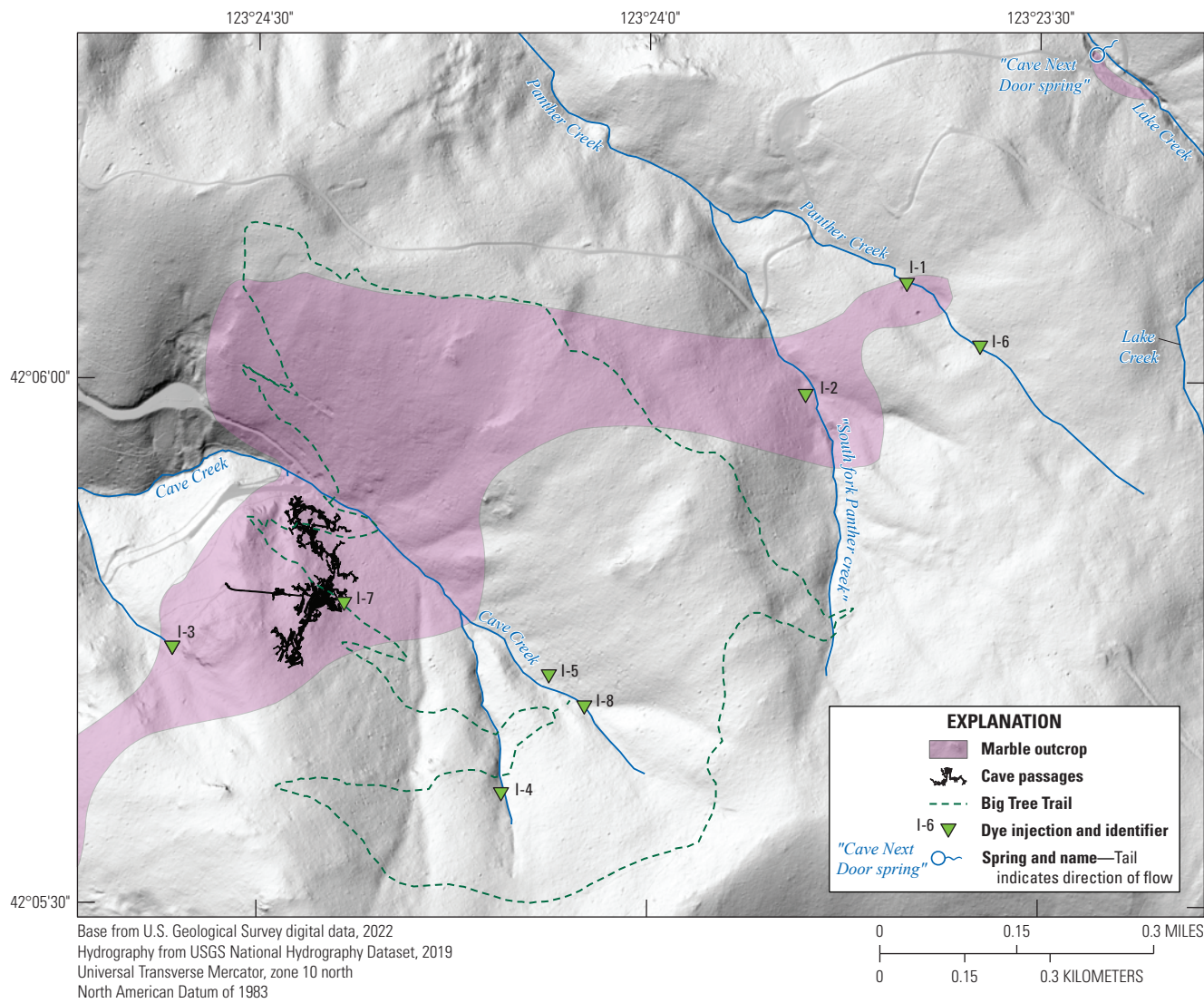


Figure 6. Locations of dye injections conducted during this study.

Results

Round 1 Injections, April 2021

The first round of dye injections took place during snowmelt in April 2021. Four injections, I-1 to I-4, were conducted and included four total sites, with two sites located closer to Oregon Caves and two sites located closer to Cave Next Door ([table 2](#), [fig. 6](#)).

Dye Injections for Round 1

Injections took place April 27–28, 2021, during the spring thaw. The first dye injection was conducted in a modified sinkhole located just south of the main stem of Panther Creek (injection I-1). The sinkhole has been subject to substantial human modification, and the dig was initiated in the early 2000s in an attempt to access the passages in Cave Next Door following the collapse of the cave's entrances (Knutson, 2021). Although much of the 90-ft-deep dig was through noncarbonate strata, including serpentine, the dig had encountered marble in the bottom 15–20 ft. Dripping and seeping water at the base of the sinkhole was creating a small temporary stream. A total of 2 pounds (lb) of rhodamine wt was injected into this stream, which then flowed into a small solutional opening following injection. The second injection site was in the “south fork Panther creek,” upstream from a sinkpoint where 100 percent of the streamflow sank into the subsurface (injection I-2). At this location, 1 lb of powdered fluorescein was injected into flowing water ([fig. 7](#)). Dyes from injections I-1 and I-2 were positively traced to “Cave Next Door spring,” located 2,300 and 3,500 ft to the north of the injection sites, respectively ([fig. 5](#), [table 3](#)). The fluorescein from injection I-2 was detected at “Cave Next Door spring” between 2 and 3 days postinjection, whereas the rhodamine wt was detected on packets changed after 22 days.

On April 28, two dye injections were performed in the Cave Creek drainage basin in the vicinity of Oregon Caves ([table 2](#)). Injection I-3 was located along a short reach of flowing stream in a ravine southwest of the exit tunnel for Oregon Caves ([fig. 6](#)). The seeping water was visible for a length of approximately 200 ft and was the result of snowmelt from snowbanks further up the ravine. Two lb of sulphorhodamine b was injected into the seeping water and was observed sinking into the subsurface approximately 40 ft downstream from the injection site. Dye from injection I-3 was not detected at any of the monitoring sites in or around

Oregon Caves ([table 3](#)). Injection I-4 was located along a short reach of flowing stream high in a ravine along the Big Tree Trail. Two lb of eosine oj was injected into the small flowing stream ([fig. 8](#)), which was draining a melting snowfield, and sank entirely into the subsurface 100 ft downstream from the injection site. Eosine oj was detected in River Styx 20 days postinjection, appearing at the recovery site between May 4 and May 18.

Round 2 Injections, August 2021

The second round of dye injections for the project focused on trying to define the broader recharge areas for both cave systems and confirm whether the cave stream network in the southern portion of Oregon Caves is connected to River Styx in the northern portion of the cave. Three injections, I-5 to I-7, were conducted for the second round ([table 2](#), [fig. 6](#)), during August 26–30, 2021, when hydrologic conditions at ORCA were much drier than during round 1.

Seepage Investigations

Seepage investigations were conducted along Lake Creek, the main stem of Panther Creek, and portions of No Name Creek ([fig. 9](#), [table 4](#)) to determine whether a substantial percentage of streamflow was being lost to the groundwater system because of karst processes (Miller, 2025). Multiple measurements were made along the selected streams within a single day, with unchanging hydrologic conditions, at locations in and adjacent to marble outcrops.

Flow was measured at four locations along Lake Creek on August 24, 2021, starting 1,620 ft above the upstream marble outcrop and ending downstream at the center of the outcrop near “Cave Next Door spring” ([fig. 9](#), [table 4](#)). Measurements started above the intake for the NPS water system, where a total streamflow of 0.415 cubic foot per second (ft³/s) was measured (site LC1). Downstream from the intake, 0.190 ft³/s was measured (site LC2), indicating the water system was utilizing 0.226 ft³/s of the streamflow for drinking-water supplies. Approximately 555 ft further downstream, 0.377 ft³/s was measured (site LC3, [fig. 10](#)), which indicated a 98-percent increase in streamflow. At the downstream end of the seepage investigation on Lake Creek, a total of 0.406 ft³/s was measured at the center of the marble outcrop (site LC4). These measurements indicated that Lake Creek was a gaining stream with no major losing reaches; thus, Lake Creek was not selected for a dye injection.

Table 2. Summary of dye injections performed during this study.

[Dates are in month, day, year format. Elevation data from the 3DEP lidar explorer (U.S. Geological Survey, 2024). Elevation data referenced to the North American Vertical Datum of 1988 (NAVD 88). ID, identifier; ft, foot; lb, pound]

Round no.	Injection ID	Injection setting	Elevation (ft above NAVD 88)	Strata	Injection date	Flowing water present	Dye injected	Amount injected (lb)
1	I-1	At base of 90-ft deep manmade vertical shaft alongside main stem of Panther Creek	4,370	Marble	4/27/2021	Yes	Rhodamine wt	2
1	I-2	“South fork Panther creek” upstream from sink point	4,429	Marble	4/27/2021	Yes	Fluorescein	2
1	I-3	Short segment of seeping flow in ravine west of exit tunnel for Oregon Caves	4,217	Marble	4/28/2021	Yes	Sulphorhodamine b	2
1	I-4	Short segment of flowing stream in ravine at top of Big Tree Trail	4,692	Quartzite	4/28/2021	Yes	Eosine oj	2
2	I-5	Cave Creek near Big Tree Trail, approximately 150 ft upstream from sinkpoint	4,477	Quartzite	8/26/2021	Yes	Fluorescein	1
2	I-6	Main stem of Panther Creek, upstream from losing reach, downstream from intake structure	4,630	Diorite	8/26/2021	Yes	Eosine oj	2
2	I-7	Flowing cave stream at Jules Verne Well in Oregon Caves	4,054	Marble	8/30/2021	Yes	Rhodamine wt	0.5
3	I-8	Cave Creek at Big Tree Trail, sinks 855 ft downstream	4,477	Quartzite	8/26/2024	Yes	Sulphorhodamine b	2

Table 3. Summary of dye traces used in this study.

[Dates are in month, day, year format. Elevation data from the 3DEP lidar explorer (U.S. Geological Survey, 2024). Elevation data referenced to the North American Vertical Datum of 1988 (NAVD 88). ID, identifier; ft, foot; lb, pound; h, hour; ORCA, Oregon Caves National Monument and Preserve; na, not applicable]

Round no.	Injection ID	Recovery site names (site nos.)	Elevation (ft above NAVD 1988)	Strata	Date recovered
1	I-1	Cave Next Door spring resurgence (001, 002), south fork Panther resurgence (036), Panther Creek at Lake Creek (034), and subsequent packets downstream from 001 (024, 025, 026, 033)	4,233–3,587	Marble at resurgences	5/18/2021
1	I-2	Cave Next Door spring resurgence (001, 002), south fork Panther resurgence (036), Panther Creek at Lake Creek (034), and subsequent packets downstream from 001 (024, 025, 026, 033)	4,233–3,587	Marble at resurgences	4/29/2021
1	I-3	Dye not detected at any monitoring sites.	na	na	na
1	I-4	ORCA-River Styx below connecting tunnel (007), ORCA-River Styx at Watson Grotto (006), Cedar Spring (020), Marble spring A-downstream (021), and Chalet seep spring (023)	4,026–3,810	Marble	5/18/2021
2	I-5	Dye not detected at any monitoring sites.	na	na	na
2	I-6	Cave Next Door spring resurgence (001), main stem of Panther Creek above road (027), south fork Panther resurgence (036), Panther Creek at Lake Creek (034) and subsequent packets downstream from 001 (024, 025, 026, 032, 033)	4,233–3,587	Marble at resurgences	9/2/2021
2	I-7	ORCA-River Styx below connecting tunnel (007), ORCA-River Styx at Watson Grotto (006), Cedar Spring (020), Marble spring (021), Chalet seep spring (023), and subsequent packet downstream from 020 (033)	4,026–3,810	Marble at resurgences	8/30/2021
3	I-8	ORCA-River Styx below connecting tunnel (007), ORCA-River Styx at Watson Grotto (006), Marble spring (021), and Chalet seep spring (023)	4,026–3,810	Marble	5/8/2024 0900, ~48 h



Figure 7. National Park Service employees next to a dye injection of fluorescein into “south fork Panther creek,” April 27, 2021. Photograph by Benjamin V. Miller, U.S. Geological Survey.



Figure 8. National Park Service employee conducting dye injection of eosine oj into a ravine in the upper Cave Creek watershed (injection I-4), April 28, 2021. The person injecting the dye is wearing gloves and a Tyvek suit to prevent cross-contamination of dye to monitoring sites or other dye injection locations. Photograph by Benjamin V. Miller, U.S. Geological Survey.

Table 4. Discharge measurements made during the dye tracing investigation.

[Data from Miller (2025). Dates are in month, day, year format. Q, discharge; ft³/s, cubic foot per second]

Measurement site identifier	Q (ft ³ /s)	Date
Lake Creek watershed		
LC1	0.415	8/24/2021
LC2	0.190	8/24/2021
LC3	0.377	8/24/2021
LC4	0.406	8/24/2021
CND	0.318	4/30/2021
Main stem Panther Creek watershed		
NP1	0.038	8/24/2021
NP2	0.036	8/24/2021
NP3	0.032	8/24/2021
NP4	0.017	8/24/2021
NP5	0.014	8/24/2021
Cave Creek watershed		
UCC1	0.017	8/26/2021
UCC1	0.505	5/6/2024
UCC2	0	8/26/2021
OC	0.467	4/30/2021
OC	0.128	9/2/2021
OC	1.65	5/2/2024
OC	1.69	5/6/2024
CC	0.265	8/27/2021
No Name Creek watershed		
NN1	0	8/25/2021
NN2	0.019	8/25/2021
NN3	0.023	8/25/2021
NN4	0.022	8/25/2021

Flow was measured at five locations along the main stem of Panther Creek on August 24, 2021 (fig. 9, table 4). The upstream measurements were made 650 ft upstream from the mapped marble outcrop, and a total of 0.038 ft³/s was measured using volumetric methods (site NP1). Flow was nearly constant, with 0.036 ft³/s measured 500 ft downstream from the first site (site NP2) and 0.032 ft³/s measured 400 ft further downstream from the second site (site NP3). The next discharge measurement, made where the stream flowed over marble, was only 0.017 ft³/s, a 47-percent loss in streamflow (site NP4) compared to the upstream site. This reduction in streamflow continued to the furthest downstream site (site NP5) located below the marble outcrop, where 0.014 ft³/s was measured, indicating a further 17-percent loss in streamflow.

On the basis of these measurements, the main stem of Panther Creek was determined to be a losing stream, and a dye injection was planned for round 2.

Four sites along the eastern branch of No Name Creek were visited on August 25, 2021, for discharge measurements or zero flow observations (fig. 9, table 4). The upper portions of No Name Creek above the marble outcrop were found to be completely dry (site NN1). At the upstream end of the marble exposure, a spring discharges and creates perennial flow along this portion of No Name Creek. At the spring, a total of 0.019 ft³/s was measured using volumetric methods (site NN2). Approximately 250 ft further downstream, 0.023 ft³/s was measured at the lower end of the marble outcrop, indicating an overall gain in flow (site NN3). Approximately 450 ft further downstream, a total of 0.022 ft³/s was measured,

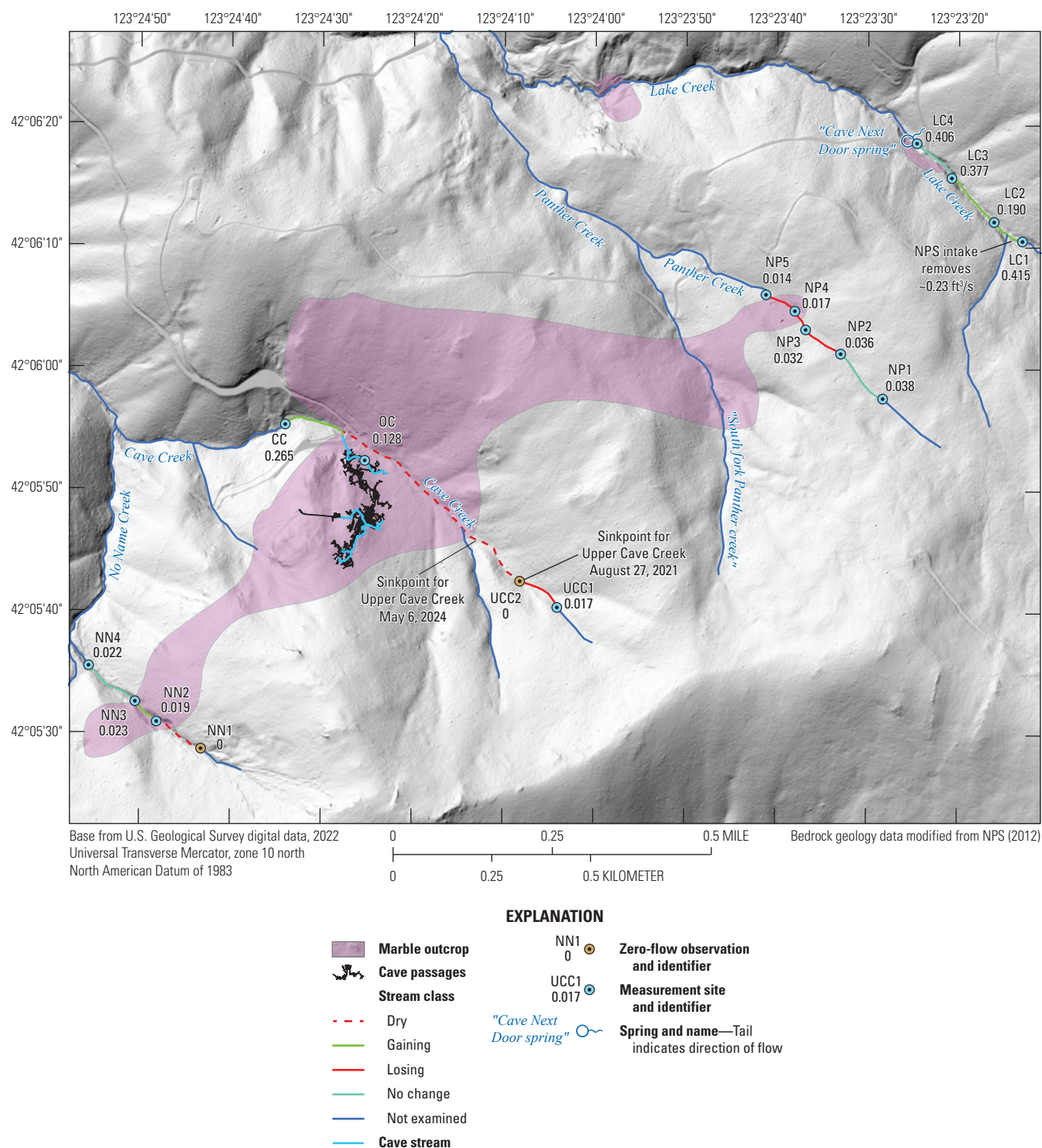


Figure 9. Location of measurement sites for seepage investigation and resulting classes of streams. Data shown on map from Miller (2025). NPS, National Park Service; ft³/s, cubic foot per second.



Figure 10. Lake Creek near the third discharge measurement site, August 24, 2021. Photograph by Benjamin V. Miller, U.S. Geological Survey.

further indicating no loss of streamflow to the subsurface (site NN4). Given that the stream only increased in flow or remained stable, it was determined that the eastern branch of No Name Creek was gaining and no dye injection was planned for the stream as a result. The western branch of No Name Creek does not flow across any exposures of marble and thus was not examined for streamflow or as a possible injection site.

Dye Injections for Round 2

Injection I-5 in upper Cave Creek and injection I-6 in the main stem of Panther Creek were both conducted on August 26, 2021 (table 2, fig. 6). Upper Cave Creek at injection I-5 had a measured streamflow of 0.017 ft³/s that completely sank into the streambed within 200 ft of the injection site (table 4, site UCC1). A total of 1 lb of fluorescein was injected into upper Cave Creek, identified as the stream reach upslope from Oregon Caves. This stream reach had previously been traced to River Styx in Oregon Caves (NPS, 1999; Roth, 2005); however, dye from injection I-5 was not detected at any of the established monitoring sites. Injection I-6 was in the main stem of Panther Creek upstream from the contact between the Grayback pluton and marble (figs. 2 and 6). The stream had a measured flow of 0.032 ft³/s (site NP3, fig. 9) at the injection site where 2 lb of eosine oj was injected into the flowing water (figs. 6 and 11). Dye from this injection sank, in part, into the subsurface and was later detected at “Cave Next Door spring” 28 days postinjection as well as downstream on the main stem of Panther Creek at site 027 (table 3). It is believed that dye injected into the main stem of Panther Creek both sank and flowed to Cave Next Door, although a portion of the dye remained in the surface stream channel and was detected downstream at monitoring site 027.

The cave streams in the southern portion of the Oregon Caves system were not known to be a part of the River Styx system because of the lack of a humanly passable connection or a formal dye trace between the two portions of the cave. On August 30, 2021, at 1145, approximately 0.5 lb of rhodamine wt was injected into the cave stream at Jules Verne Well (fig. 3), injection site I-7. This cave stream is located below and east of the Ghost Room and receives flow from several smaller streams in the southern portion of Oregon Caves. Following the injection, dye was visually confirmed to be exiting the entrance to Oregon Caves at 1730 on August 30, 5.75 hours postinjection (fig. 12). A quick trip into the cave revealed dye in River Styx from the entrance continuously upstream to the connecting tunnel (fig. 13). Additionally, a visit to several features in the proximity of the Oregon Caves entrance revealed several resurgences issuing dye-colored water, including a seep below the historical structure known as “The Chalet” (site 023), and two springs known locally and referred to herein as “Cedar spring” (site 020), and “Marble spring” (sites 021, 022) (fig. 14). These features were not previously known to be resurgences for Oregon Caves, and

these connections were further confirmed later by charcoal packet analysis (table 3). The exact location where this flow departs Oregon Caves is not precisely known, and as such, dye flow paths are drawn from site I-7 at Jules Verne Well (fig. 3) to the resurgences as well as to sites along River Styx (fig. 15).

Round 3 Injections, May 2024

In May 2024, a third round of dye injections was conducted and consisted of a single dye injection, I-8, in upper Cave Creek in an attempt to find a hydrologic connection with River Styx in Oregon Caves. This trace repeated an attempted trace during low-flow conditions in August 2021 (I-5); however, dye from that injection had not been detected at any of the monitoring sites. This outcome may have been



Figure 11. U.S. Geological Survey (USGS) scientist conducting dye injection of eosine oj into Panther Creek, April 26, 2021. The person injecting the dye is wearing gloves and a Tyvek suit to prevent cross-contamination of dye to monitoring sites or other dye injection locations. Employee was wearing a mask to comply with COVID-19 travel guidelines. Photograph by Benjamin V. Miller, USGS. USGS scientists followed all appropriate safety protocols and requirements for working near, on, in, or over water consistent with approved USGS Job Hazard Analysis.



Figure 12. Visual confirmation of rhodamine wt at the entrance to Oregon Caves on August 30, 2021, at 1811. Photograph by Benjamin V. Miller, U.S. Geological Survey.

due to hydrologic conditions or to high dye concentrations from the in-cave trace (I-7) that may have obscured lower levels of fluorescein from the upper Cave Creek injection (I-5). Hydrologic conditions were much wetter for the May 2024 injection, as the injection was planned for peak snowmelt season.

Dye Injection for Round 3

Injection I-8 was conducted on May 6, 2024, in upper Cave Creek near the closest point along the Big Tree Trail to the stream (fig. 6). At this location, 2 lb of sulphorhodamine b was injected into upper Cave Creek (fig. 16, table 2), which had a measured flow of 0.505 ft³/s at the time of injection (site UCC1, table 4). The injection was performed approximately 500 ft upstream from the sinkpoint where the entirety of the stream sank into the subsurface at the time of the injection and 250 ft upstream from where injection I-5 had been performed. The injection was performed upslope from the sinkpoint in case the stream reach was a losing reach as opposed to just a discrete sink.

Following the dye injection, packets were changed every 12 hours at both River Styx in Watson Grotto within Oregon Caves (site 006) and at “Marble spring” (site 021) for the first 5 days to help bracket any arrival of the dye as much as possible. Dye was detected by means of charcoal packets and water samples on May 8, 2024, at 0900 at River Styx in Watson Grotto in Oregon Caves (site 006) and at “Marble spring” (site 021) (table 3). Dye concentrations continued to increase at both sites over the next several days, as indicated on both packets and in raw water. Additional packets, exchanged 1 week postinjection, confirmed a positive detection of sulphorhodamine b at River Styx near the connecting tunnel in Oregon Caves (site 007) and at the “Chalet seep” (site 023). Dye is assumed to have arrived at these sites at the same time as the sites changed earlier with higher resolution, because site 007 is upstream from site 006 and site 023 was previously established as a resurgence for the cave stream. This trace confirmed a hydrologic connection between upper Cave Creek and River Styx in Oregon Caves and established the eastern portion of the recharge area for Oregon Caves.



Figure 13. National Park Service volunteer next to visual confirmation of rhodamine wt in the River Styx at Watson Grotto within Oregon Caves on August 30, 2021, at 1810. Photograph by Benjamin V. Miller, U.S. Geological Survey.



Figure 14. “Marble spring,” a previously unidentified spring resurgence for streamflow from Oregon Caves. Photograph by Benjamin V. Miller, U.S. Geological Survey.

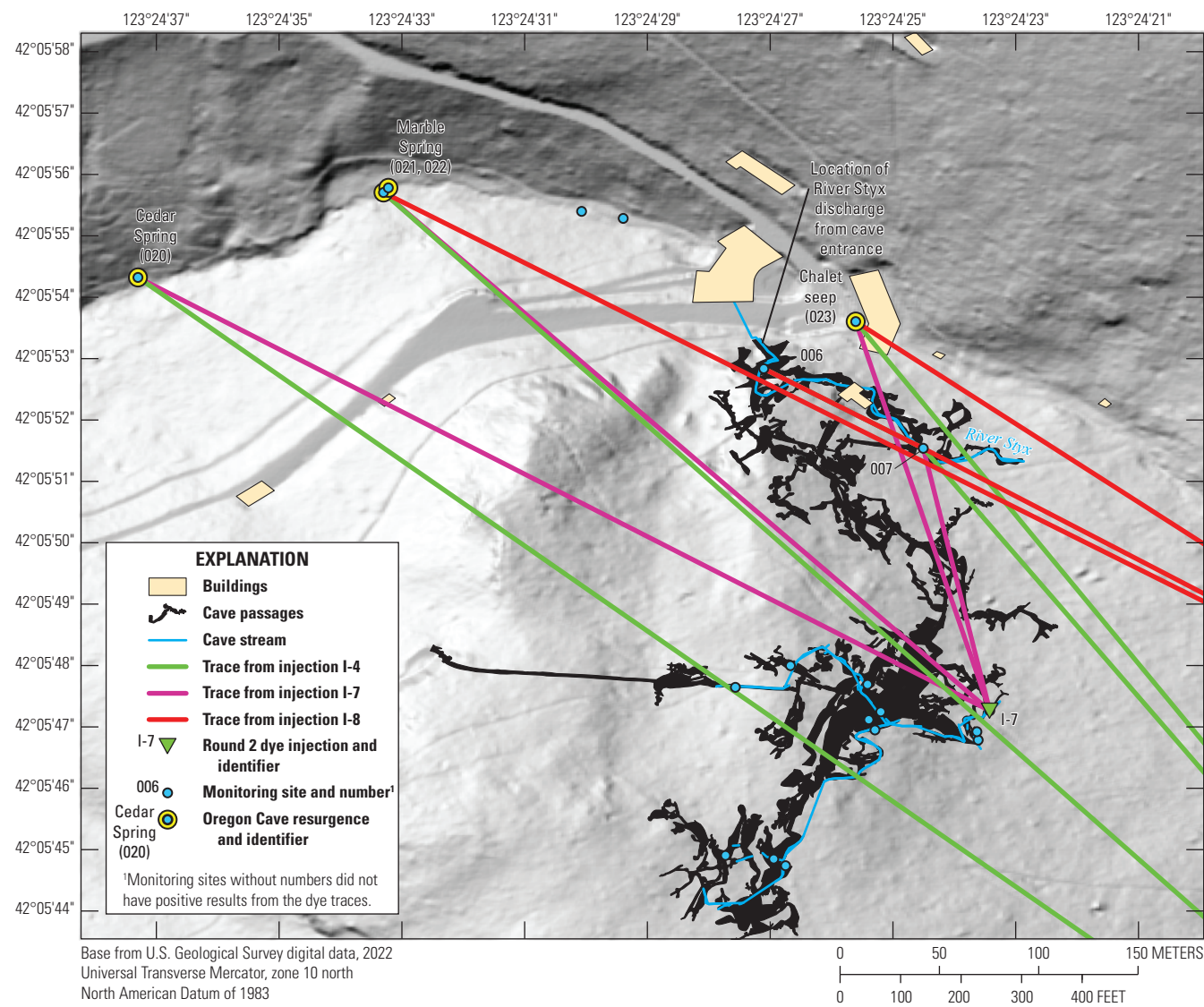


Figure 15. Detail of dye traces near and within Oregon Caves.



Figure 16. National Park Service employees standing next to the dye injection of sulphorhodamine b into the upper Cave Creek near the Big Tree Trail on May 6, 2024, at 0929. Photograph by Benjamin V. Miller, U.S. Geological Survey.

Discussion

Groundwater Basins

The recharge areas for Oregon Caves and Cave Next Door appear to be largely independent of each other, having no overlap (fig. 17). Streams in both systems receive significant amounts of allogenic recharge from nonkarstic strata, because the relatively limited exposure of marble is located downslope from basins underlain by relatively insoluble strata. The recharge area for Oregon Caves largely appears to be located

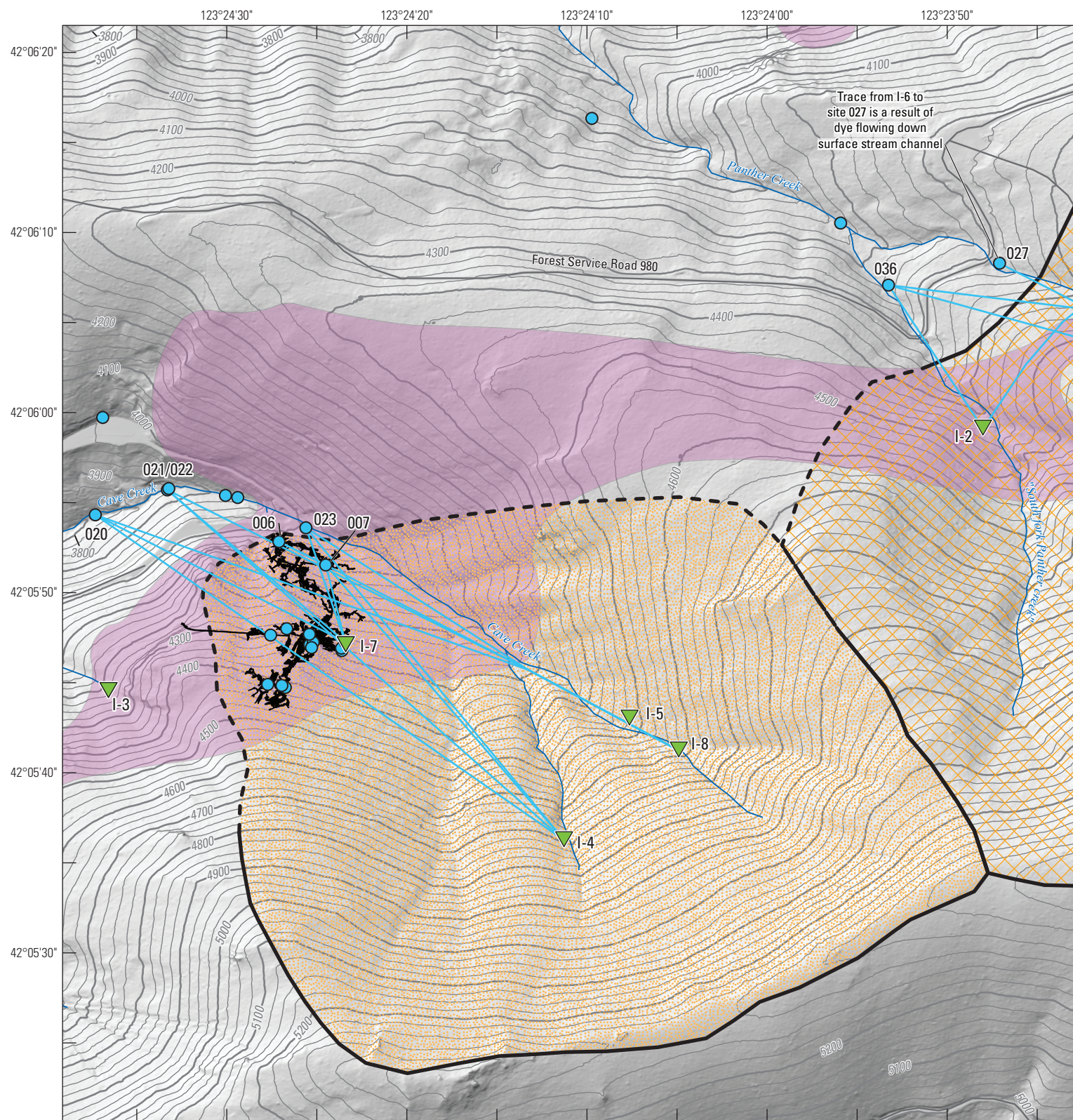
within the Cave Creek watershed and is constrained generally by topography, particularly in areas underlain by noncarbonate strata where karstification is not present. Most of the recharge area for Oregon Caves lies upslope from the natural entrance to the cave. The eastern boundary of the Oregon Caves recharge area coincides with the western boundary of the Cave Next Door recharge area. The Cave Next Door recharge area encompasses Panther Creek and “south fork Panther creek” primarily upslope of Forest Service Road 980. The Cave Next Door recharge area also extends to the upper part of the topographic drainage divide for Panther Creek, as this area, underlain by noncarbonate strata, is part of the contributing area that provides allogenic recharge to the marble units. The two recharge areas do not overlap but do share portions of the largest marble outcrop in the study area, which indicates that a groundwater divide exists within this block of marble. However, although this divide exists, no recharge features with streamflow could be found on this marble outcrop along the boundary between the two recharge areas despite extensive reconnaissance.

The recharge area for Oregon Caves is 0.51 square mile, and land use within the recharge area is classified as 100 percent evergreen forest (Homer and others, 2020, Dewitz and USGS, 2021). The recharge area for Cave Next Door is slightly larger, 0.69 square mile, and has more varied land use/land cover than that of Oregon Caves, with 73 percent evergreen forest, 24 percent shrub/scrub, and 2 percent woody wetland (Dewitz and USGS, 2021). This higher variance may be due to the higher elevations within the Cave Next Door recharge area relative to the Oregon Caves recharge area and is likely influenced by factors such as slope, aspect, and underlying soils.

Within karst areas, the boundaries for recharge areas are subject to changes dependent on ambient hydrologic conditions in the area. During high-flow periods, some flow paths higher in the system may become activated, allowing portions of one recharge area to hydrologically connect to an adjacent, otherwise separate, recharge area. As such, the recharge area boundaries should be considered approximations that are subject to change, particularly in areas underlain by marble.

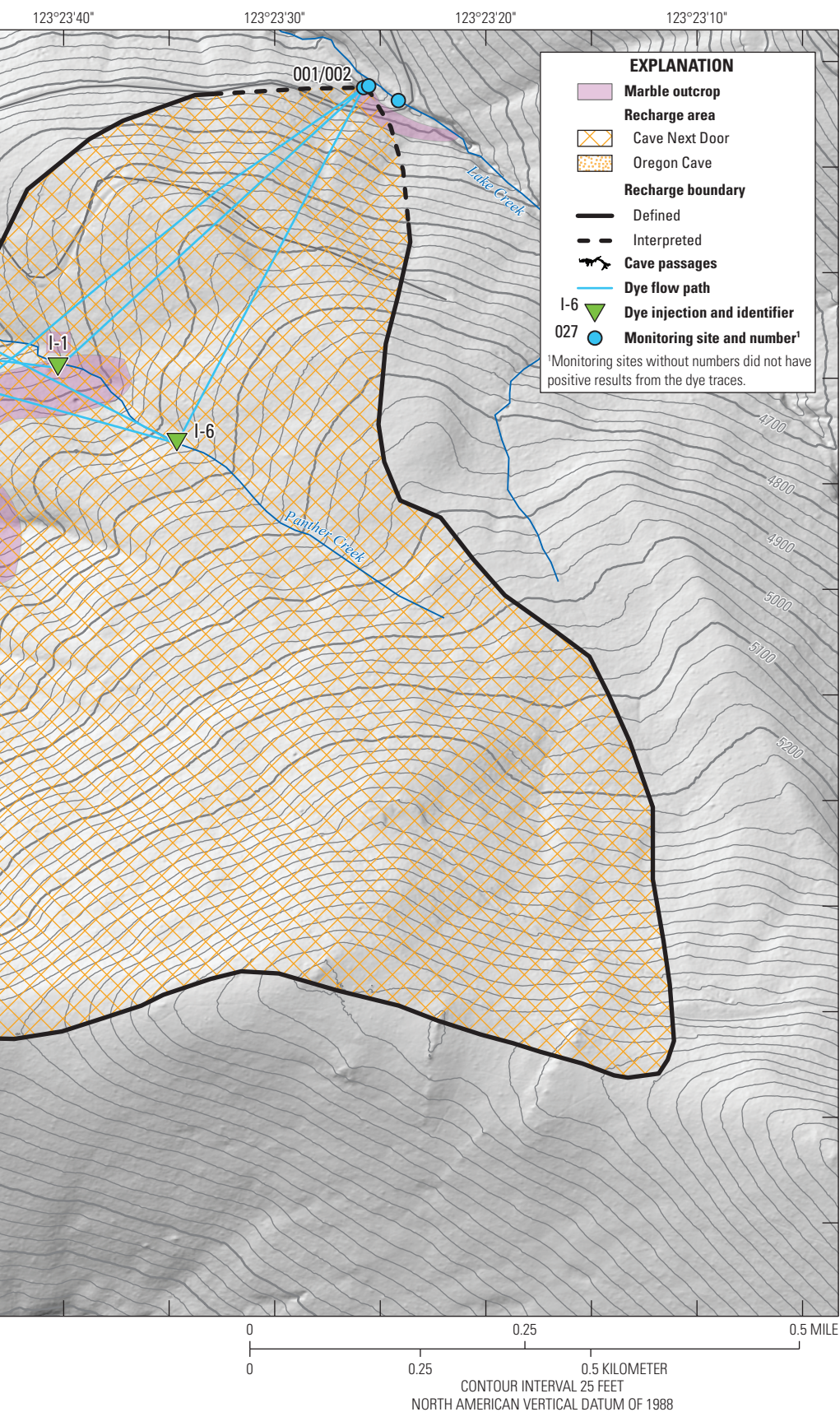
Groundwater Velocities From Traces

Many of the traces conducted as part of this study took significantly longer than anticipated given the often-rapid travel times observed in karst systems, the high relief of the study area, the distance between injections and recovery sites, and the volume of water both sinking into and discharging from the systems. In karst systems, traces often may only require hours to days to travel from dye injection sites to the recovery locations, depending on a number of factors (underlying geology, trace length, and so forth). Several of the traces conducted as part of the Oregon Caves study required weeks to travel to recovery sites, and many of these dyes were



Base from U.S. Geological Survey (USGS) digital data, 2022
 Hydrography from USGS National Hydrography Dataset, 2019
 Universal Transverse Mercator, zone 10 north
 North American Datum of 1983

Figure 17. All dye traces conducted at Oregon Caves and delineated recharge areas for Oregon Caves and “Cave Next Door spring.”



still apparent at monitoring locations months postinjection. Packets retrieved from several of these traces continued to increase in concentration months postinjection. This behavior is indicative of retention within the system that is slowing down or inhibiting flow through the system. The retention may be caused by the mixed geology creating discontinuous flow paths, by fracture flow within the groundwater systems downstream from the injection sites, by dikes in the marble causing pooling of groundwater on the upstream/upgradient sides of the dikes, or by significant storage within the epikarstic aquifer (discussed in the “Diffuse Versus Discrete Recharge” section, next). The exact cause of this retention is unclear at this time, and additional research could help to identify the source of the retention along the flow paths from the injection site to recovery location.

Exceptions to the slow travel times were documented for injections I-2 (“south fork Panther Creek”) and I-7 (Jules Verne Well cave stream in Oregon Caves). Dye from injection I-2 traveled from “south fork Panther creek” to the resurgence at “Cave Next Door spring” within 48 hours, several days faster than the trace performed in 1999 when the dye took 1 week to arrive at the resurgence (Barnes, 1999). The in-cave trace from injection I-7 (Jules Verne Well) was very rapid, appearing in River Styx 5.75 hours postinjection. Considered together, the traces for injections I-7 and I-4 highlight the variations in travel time that can occur within the same system. A trace from a surface source (such as injection I-4) may require many days or weeks to arrive at the cave stream. However, once in the conduit flow system (injection I-7), the dye and (or) groundwater can move rapidly through the system.

Diffuse Versus Discrete Recharge

Many of the water sources within Oregon Caves, with the exception of River Styx, appear to come from epikarstic sources via diffuse recharge. Epikarst is the uppermost zone in karst systems, located above the vadose zone, which has air-filled cavities and free-flowing streams, and the phreatic zone, which is water-filled and occurs below the water table (Klimchouk, 2004; Williams, 2008). Within the epikarstic zone is the soil-bedrock interface, where acidic water encountering soluble bedrock has created a weathered zone in which solutionally enlarged fractures narrow with depth. This creates a perched aquifer above the cave system that can contribute flow to features such as dripping domes, speleothems, and smaller cave streams. Many of the water resources found in the southern portion of Oregon Caves, south of Miller’s Chapel, appear to be fed by epikarstic sources because of their size and how the flow enters the cave system. Epikarstic flow is fed primarily by diffuse recharge from areas directly above and upslope of the cave passages, and as such, these types of recharge sources can be difficult to target using normal groundwater tracing techniques. Often

in tracing, epikarstic or diffuse flow traces may require drilling into the soil using augers, and even natural features (for example, sinkholes, pits, and similar features) typically require additional water to be supplied during dye injections (Ham, 2009; Vanderhoff, 2011). Fluorescent dyes can also bind to some soils, making dye recovery more difficult and unpredictable than would otherwise be the case for dye injections into more discrete recharge features (Kasnavia and others, 1999; Aley, 2003).

Discrete recharge sources also play an important role in providing recharge to streams in the caves of ORCA. Several of the dye injections were conducted at sites that could be classified as discrete recharge locations, including all sites used for the first round of injections, I-1, I-2, I-3, and I-4, as well as the site for injection I-5 in the second round and the site for I-8 in the third round. All of these sites had flowing water that entirely sank at discrete locations in or near areas underlain by marble. Some of the traces for these sites traveled rapidly to flowing cave streams and springs, whereas other traces took significantly more time (discussed in the preceding “Groundwater Velocities from Traces” section). There remain some areas that have major features that could be discrete recharge sources, such as sinkholes and caves; however, flowing water could not be found in these areas, and the remote nature of the karst precluded the ability to provide water by artificial means (for example, by tanker truck). One of the largest expanses of karst lying along the boundary between the two recharge areas contained many such features that could be ideal dye injection sites given the right conditions.

Summary

Dye tracing was conducted by the U.S. Geological Survey at Oregon Caves National Monument and Preserve from 2021 to 2024 to delineate recharge areas for Oregon Caves and Cave Next Door. Three rounds of dye injections were conducted, with a total of eight dye injections occurring at seven distinct locations. The injections resulted in the delineation of two recharge areas and showed that the two karst systems are not hydrologically related to one another. The recharge area for Oregon Caves is 0.51 square mile and lies primarily in the upper portions of the Cave Creek watershed. The recharge area for Cave Next Door is slightly larger (0.69 square mile) and is located predominantly in the upper portions of the Panther Creek drainage basin, including Panther Creek and “south fork Panther creek.” Analysis of the land use and land cover for the recharge areas has shown both areas to be dominated by evergreen forest with no measurable human development, as indicated by data from the National Land Cover Database. Although established trails through the recharge areas are known to exist, no significant impact from this use is expected.

In addition to delineation of the recharge areas for the two karst systems, hydrologic connections were confirmed in Oregon Caves connecting streams in the southern portion of the cave system to River Styx in the northern portion. This work also helped to identify three previously unknown resurgences for Oregon Caves, including “Chalet Seep spring,” “Marble spring,” and “Cedar spring.”

Tracing work illuminated unique characteristics to the karst flow systems at Oregon Caves National Monument and Preserve, including highly variable karst groundwater velocities and occasional retention of flow, resulting in extended travel times for dye from the injection site to the recovery points at monitoring sites. Recharge to these karst resources appears to be from a mix of both diffuse and discrete sources, dependent on underlying geology, and the dye traces conducted as part of this study reveal complexities in the subsurface flow paths to cave streams and karst springs within Oregon Caves National Monument and Preserve.

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