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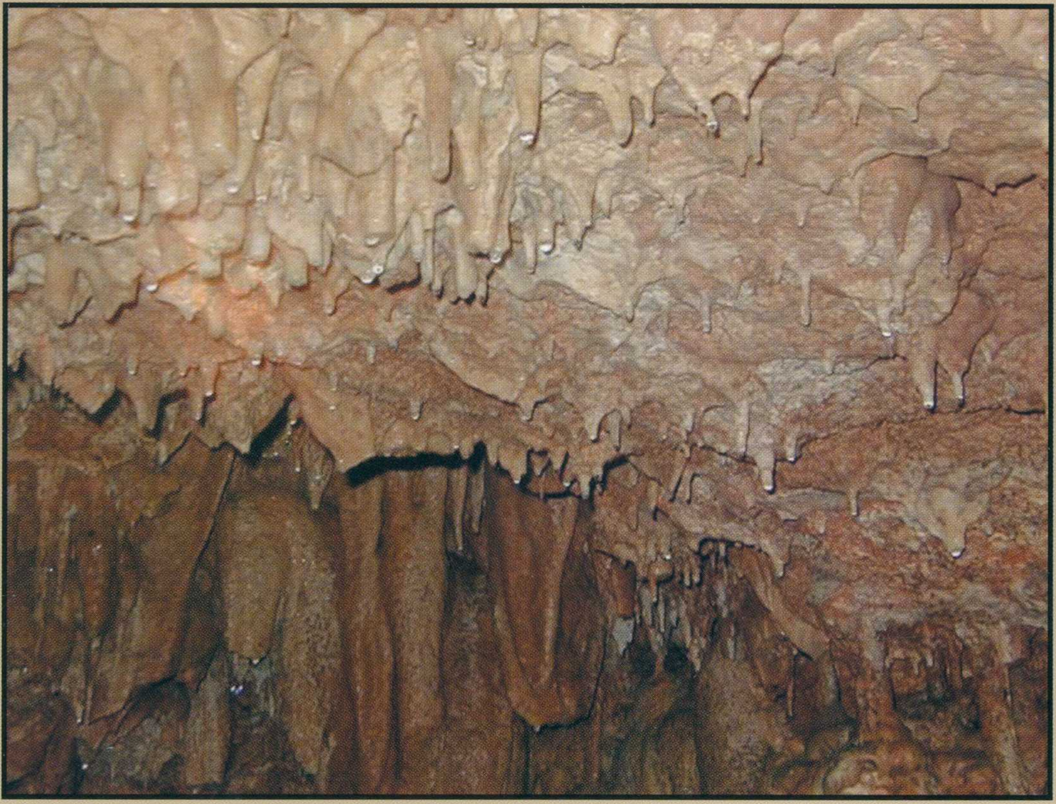
# USE OF GROUND-WATER TRACERS TO EVALUATE THE HYDRAULIC CONNECTION BETWEEN KEY CAVE AND THE PROPOSED INDUSTRIAL SITE NEAR FLORENCE, ALABAMA, 2000 AND 2001

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 01-4228



Prepared in cooperation with the

CITY OF FLORENCE

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Montgomery, Alabama
2001

U.S. DEPARTMENT OF THE INTERIOR
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U.S. GEOLOGICAL SURVEY
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Photograph on cover was made inside Key Cave.

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## CONVERSION FACTORS AND VERTICAL DATUM

| Multiply | By | To obtain |
|---|---|---|
| inch (in.) | 25.4 | millimeter |
| foot (ft) | .3048 | meter |
| mile (mi) | 1.609 | kilometer |
| square mile ($mi^2$) | 2.590 | square kilometer |
| gallon (gal) | 3.785 | liter |
| pound (lb) | 4.536 | kilogram |

**Sea level**: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

# USE OF GROUND-WATER TRACERS TO EVALUATE THE HYDRAULIC CONNECTION BETWEEN KEY CAVE AND THE PROPOSED INDUSTRIAL SITE NEAR FLORENCE, ALABAMA, 2000 AND 2001

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## ABSTRACT

In an effort to attract new industries and jobs, the city of Florence, Alabama has proposed development of an industrial park southwest of the city. Carbonate rock underlines the area and sinkholes, springs, caves, and sinking streams are common. Key Cave, located about 5 miles southwest of the proposed park, is the only know habitat for the Alabama Cavefish (*Speoplatyrhinus poulsoni*). The Alabama Cavefish is a Federally designated Endangered Species, and Key Cave has been designated as Critical Habitat. The U.S. Geological Survey was requested by the city of Florence and the U.S. Fish and Wildlife Service to assist in determining if a hydraulic connection exists between the proposed industrial park and Key Cave.

Dye tracing methods were used in the investigation to determine if a hydraulic connection exists. Dye tracing is a technique that involves labeling a discrete quantity of ground water with a fluorescent dye so that its flow in the subsurface can be tracked to a ground-water discharge point. Monitoring for dyes involved the use of passive dye detectors placed in springs, wells, caves and surface streams. During the passage of ground water containing fluorescent dye, the dye is absorbed and concentrated on the detectors. Spectrofluorometric analyses of the detectors determines the presence or absence of dye.

Dye injected in well I-1 on January 10, 2001, was recovered from site 67, Cypress Creek at General John Coffee Highway (State Highway 20) on January 17, 2001. No dye was recovered from site 68, Cypress Creek at Waterloo Road (County Road 14), indicating an east-southeast flow path from well I-1 to Cypress Creek. No positive dye recovery was made from dye injected in well I-2 on January 10, 2001. Water samples collected from the well February 1 and 15, 2001, showed little movement into the ground-water system. Dye injected in well I-3 on January 10, 2001, was recovered at two sites in Key Cave and at other locations. This test indicates a hydraulic connection exists between Key Cave and the proposed industrial site.


## INTRODUCTION

A change in land-use activities is proposed for approximately 300 acres in an area locally known as the "Bend of the River," located southwest of the city of Florence in Lauderdale County, Alabama (fig. 1). Improved watershed characterization and flow-system definition are needed to enhance the management of the aquifers and streams that support the local ecosystem. Lands that have until now been undeveloped or rural in nature may shift to more industrial and commercial uses.

Extensive caves are found in the study area, with most of the known cave passages located in Key Cave or other nearby caves. Key Cave contains 12,381 feet of mapped passages (Aley, 1990). Key Cave is the only known habitat for the Alabama Cavefish (*Speoplatyrhinus poulsoni*), a Federally designated Endangered Species, and Key Cave has been designated as Critical Habitat (Federal Register 53:188 pp. 37968-37970 of September 28, 1988). Key Cave is inaccessible from April through September because of the presence of a maternal colony of the Federally Endangered Gray Bat (*Myotis grisescens*). This valuable ecosystem merits special attention from the U.S. Geological Survey (USGS) because of the importance of the fish and wildlife habitat for which the Department of the Interior has substantial mission responsibility. The USGS was requested by the city of Florence and the U.S. Fish and Wildlife Service to assist in deter-mining if a hydraulic connection exists between the proposed industrial park area and Key Cave.

## Purpose and Scope

The purpose of this report is to describe dye-tracing studies conducted from April 2000 through March 2001 in the study area and present the results. Geologic and hydrologic data compiled as part of previous investigations were used in this investigation. The original scope of work was expanded to include the drilling and construction of two dye-injection wells at the proposed industrial park.

## Location and Extent of the Area

The study area is bounded on the south by the Tennessee River, the east by Cypress Creek, the north by Waterloo Road, and on the west by County Road 15 (fig. 1). The study area encompasses about 25 square miles. Although there is a trend towards industrialization, the area is predominantly an agricultural region.

The proposed industrial park is located in the southeast quarter of Section 8, Township 3 south, Range 11 west and a 660-foot strip of land in the northernmost part of the northeast quarter of Section 17, and extreme northwest quarter of Section 16, Township 3 south, Range 11 west (fig. 2). Key Cave is located in the southwest quarter of Section 35, Township 3 south, Range 11 west, about 5 miles southwest of the proposed industrial park (fig. 1).

## Physical Features

The study area is in the Highland Rim section of the Interior Low Plateau physiographic province. The section is typically an area of low relief and flat to rolling topography. The altitude of the land surface generally ranges from about 500 to 580 feet. A bluff about 100 feet high extends along the Tennessee River at the southern boundary of the study area.

Depth to bedrock in the study area ranges from about 25 feet near the Tennessee River to over 75 feet at higher elevations (Moser and Hyde, 1974). In two test wells drilled at the proposed industrial park, bedrock was found at 42 feet below land surface in the northwest corner of the property and at 53 feet below land surface in the central part of the property. The weathered, unconsolidated material overlying the bedrock commonly consists of an upper, loose, soil zone containing organic material; a middle zone of clay with some chert fragments; and a lower zone of chert rubble known as the epikarst zone. The southeastern part of the proposed park drains southeastward to Cypress Creek (fig. 2).

Carbonate rock of the Tuscumbia Limestone of the Mississippian System underlies the area. Sinkholes are the most common solutional feature; springs, caves, and other karst features also are present. Surface drainage is poorly developed and subsurface drainage predominates. Four large springs or spring complexes are present within the boundaries of the study area. These are O'Neal Spring, Cypress Knee Spring complex, Key Spring, and Fish Camp Spring. Other springs that flow during the wetter months are also found in the study area. There is extensive cave development along the southern boundary of the study area. Some of the named caves near the Tennessee River bluff are Dust Cave, Collier Cave, and Key Cave. Published data show that the caves are joint controlled and passages are preferentially developed

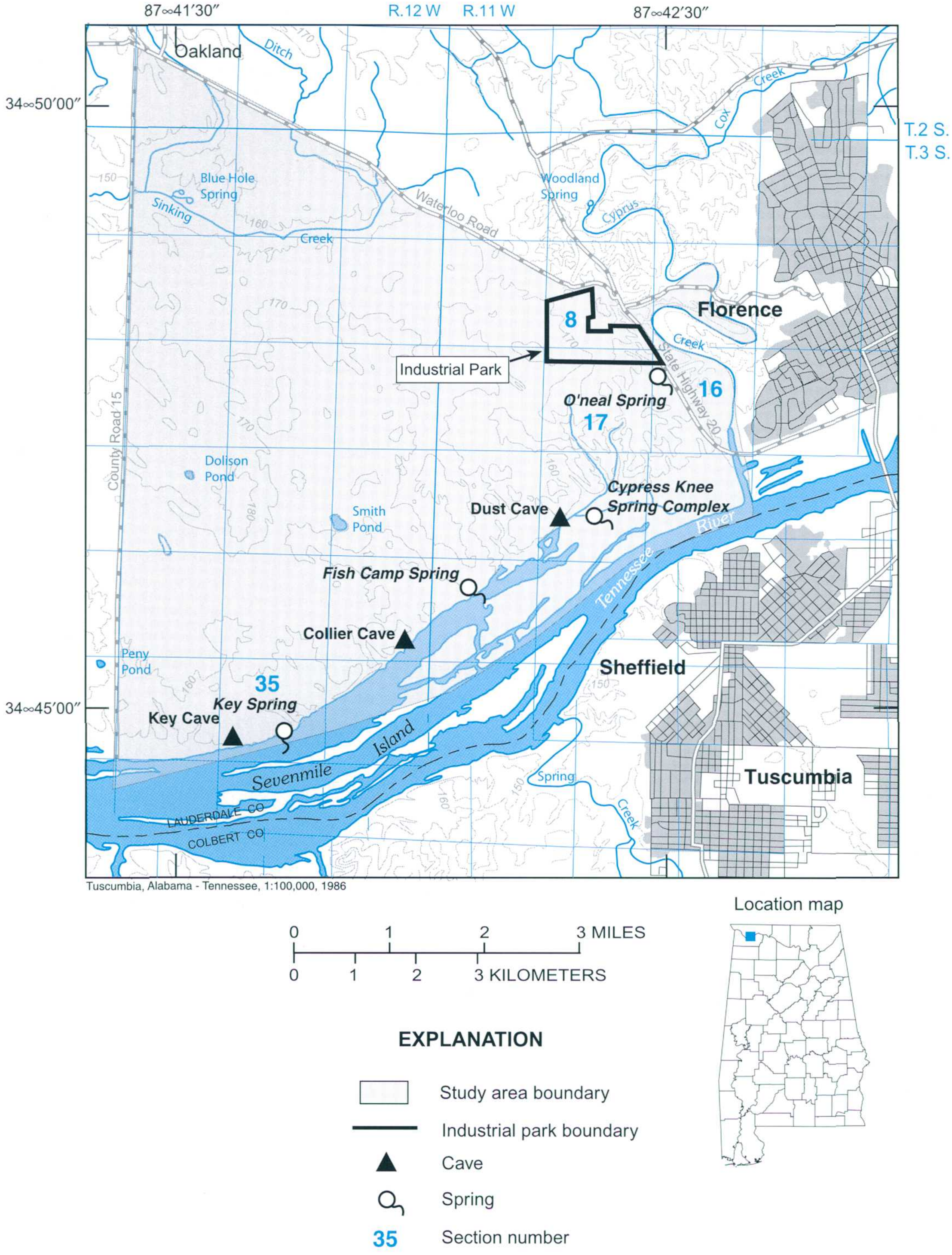



**Figure 1**. Location of the study area, proposed industrial park, and Key Cave.

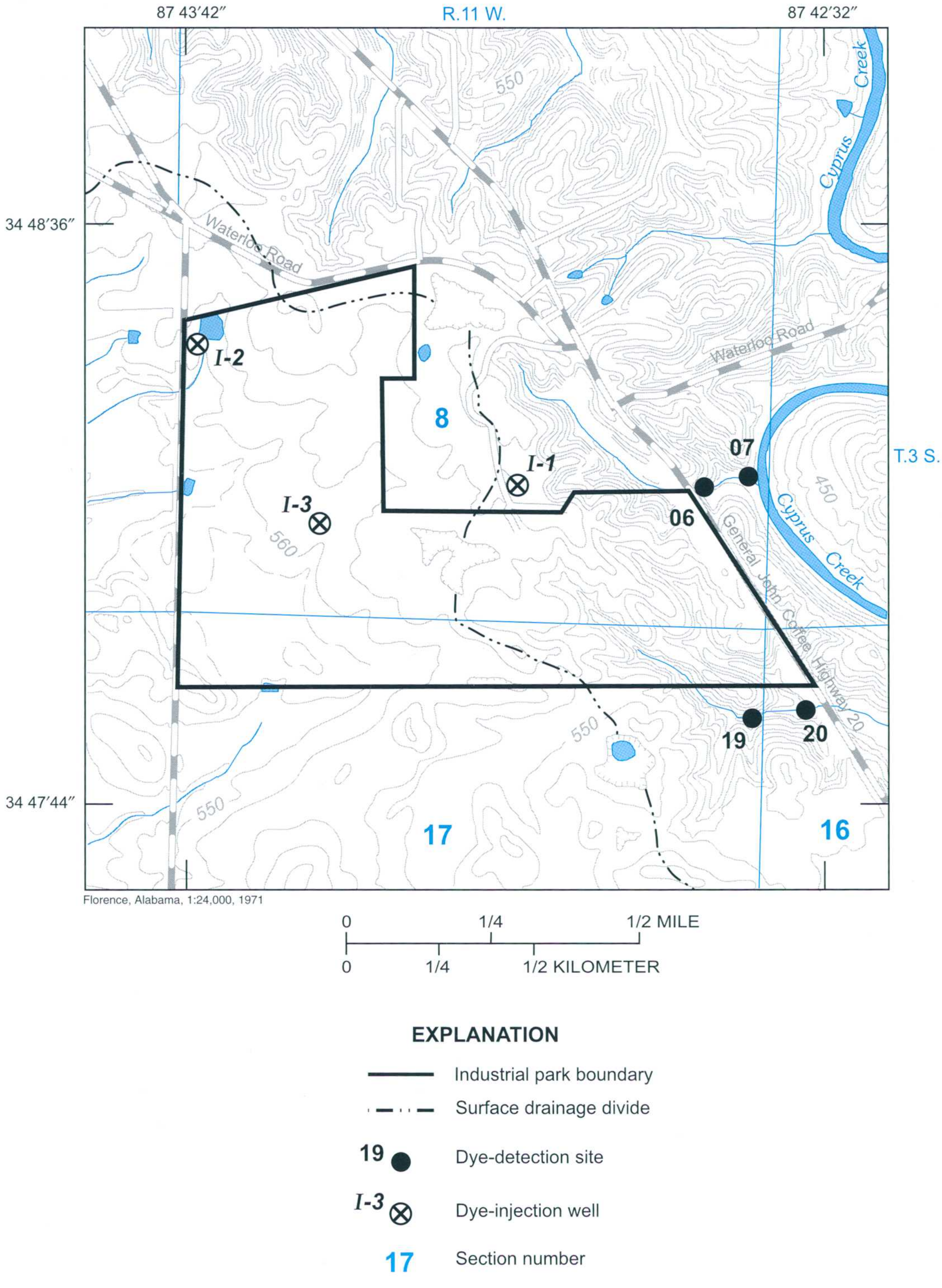



**Figure 2**. Location of the proposed industrial park, dye-injection wells, and surface drainage divide based on a 10-foot contour interval.

along certain orientations (Aley, 1986). The primary orientation of linear solution passages is between 21 and 50 degrees with a secondary orientation between 291 and 320 degrees (fig. 3).

The study area has a mild, humid climate. The average annual precipitation is 53.85 inches (U.S. Department of Commerce, 2001). Most of the precipitation is rain, but occasionally there is snow that remains on the ground a relatively short time. The monthly normal total rainfall for January is 4.48 inches; January 2001 monthly total was 5.31 inches. February monthly normal total is 4.45 inches; February 2001 total was 6.52 inches. March monthly normal total is 5.90 inches; March 2001 total was 4.25 inches. The normal total rainfall for the period January through March is 14.83 inches (fig. 4). The total rainfall for the period January through March 2001 was 16.08 inches.

### Previous Investigations

Several reports discuss the geology and ground-water resources of northwest Alabama, including Lauderdale County and the study area. Harris and others (1963) provided an inventory of wells and springs in Lauderdale County. Moser and Hyde (1974) presented a potentiometric map and showed the direction of ground-water movement in the study area. Bossong and Harris (1987) delineated major aquifers and described aquifer susceptibility to contamination for counties in northwest Alabama. Aley (1990) prepared a report for the U.S. Fish and Wildlife Service that described the recharge area for Key Cave based on results of 10 ground-water tracer studies.

Useful information was obtained from reports on dye-tracing methods. Quinlan (1986) presented general guidelines for dye dosage. The guidelines take into account the straight-line distance to the furthest anticipated resurgence point and the flow conditions at the time the dye is injected. Smart and Laidlaw (1977) evaluated fluorescent dyes for water tracing.

### Acknowledgments

Acknowledgment is made to the residents and land owners of the study area who graciously allowed access to their property and furnished information on wells and springs and other significant data. James Stevenson of the Industrial Expansion Board and Steve Seibert of the U.S. Fish and Wildlife Service also provided valuable assistance to the study.

## DYE-TRACING TEST METHODS

Dye-tracing is a hydrogeologic investigative technique that involves labeling a discrete quantity of ground water with a fluorescent dye (dye tracer) so that its flow in the subsurface can be tracked to a ground-water discharge point. Dye-tracing tests can be broadly classified as either qualitative or quantitative tests, depending on the purpose of the test and the level of data collection required. Qualitative dye-tracing tests, as used in this study, are usually intended to (1) establish point-to-point hydraulic connections between the dye-injection and dye-recovery site(s), (2) identify the general direction of ground-water flow, and (3) identify or confirm the presence of ground-water divides that act as subsurface basin boundaries.

### Design of Dye-Tracing Tests

Dye-tracing tests require proper planning and test design. Dye injections should not be done without first attempting to identify ground-water flow directions and potential dye-resurgence points. Field reconnaissance of all springs, streams, and sinkholes in the study area is needed to identify potential dye-monitoring sites. Dye-monitoring sites should be carefully selected so that every attempted tracer test results in one or more positive recoveries of dye. Failure to achieve a positive

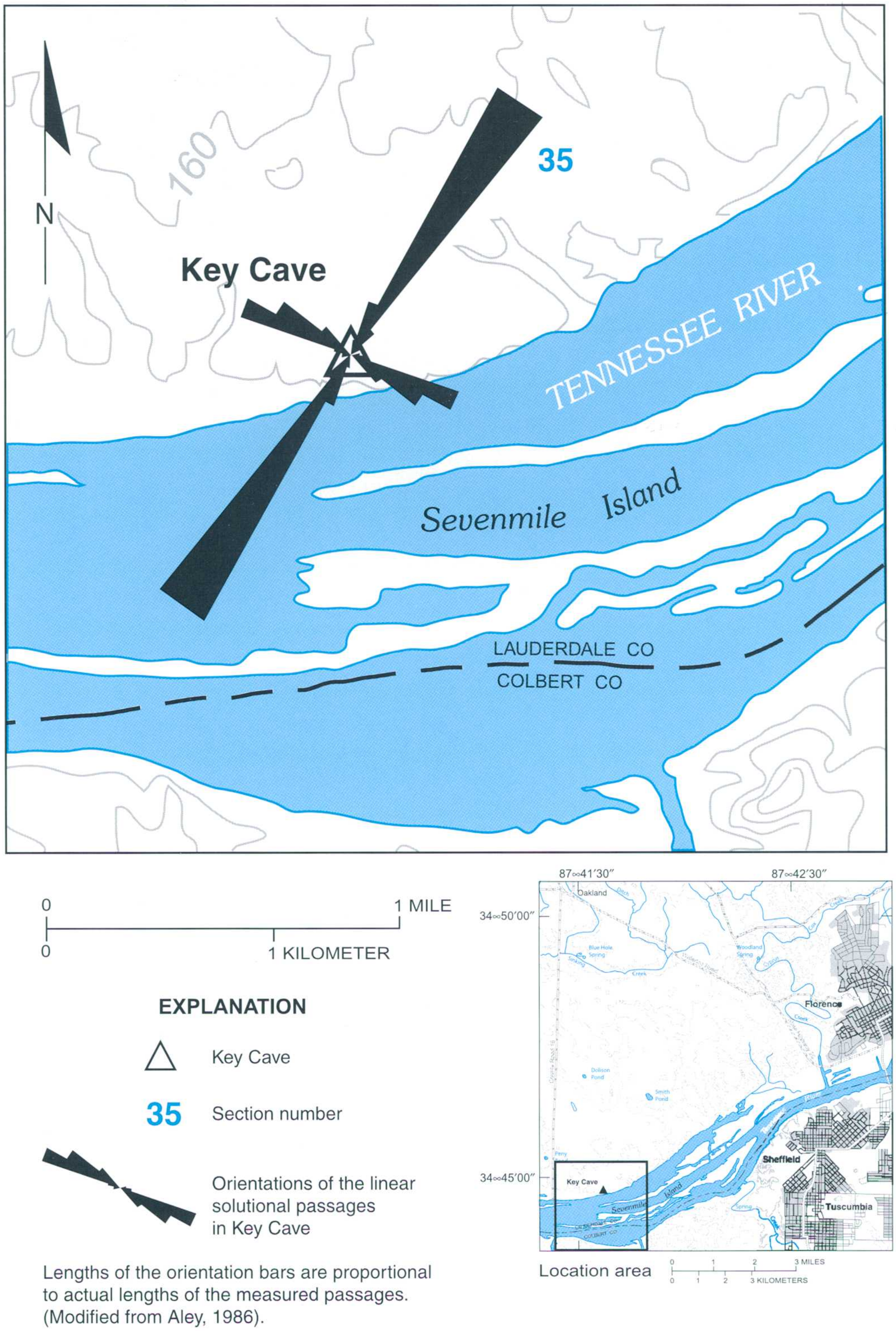



**Figure 3**. Orientation of linear solution passages in Key Cave.

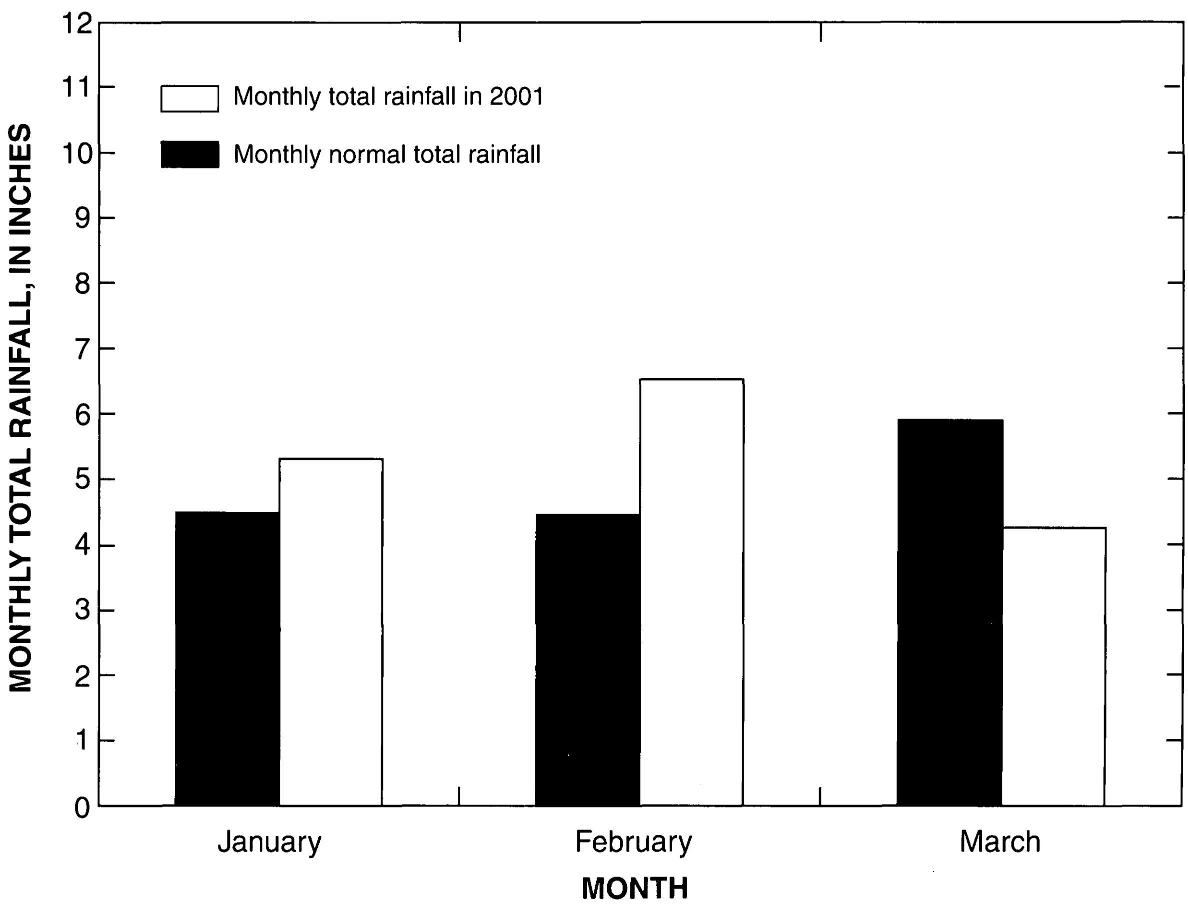



**Figure 4**. Monthly normal total rainfall amounts at Florence, Alabama, compared to monthly totals of January, February, and March 2001.

recovery of dye (a negative test result) does not necessarily indicate the lack of a point-to-point hydraulic connection between a dye-injection site and the dye-monitoring site(s). Rather, a positive dye recovery (a positive test result) conclusively demonstrates the existence of such a connection.

Negative or inconclusive tracing test results are usually from (1) an insufficient amount of time allowed to monitor for dye resurgence, (2) the injection of an insufficient quantity of dye to achieve the trace, or (3) a lack of monitoring at actual dye-resurgence points during the test. In such cases, careful reassessment of the tracing test design and a repeat of the test usually results in a successful test conclusion.

### Quality-Assurance and Quality Control Objectives

Most of the quality-assurance and quality control (QA/QC) measures applied in dye-tracing tests are designed to prevent inadvertent contamination of dye detectors or water samples and to minimize the chances for misinterpretation of test results. Specific field and laboratory procedures are also designed to address problems related to the presence of ambient (background) fluorescence caused by (1) naturally occurring fluorescent compounds (usually humic or fulvic acids and some petroleum hydrocarbons), (2) fluorescent solutes present as ground-water contaminants (septic water, leachate, petroleum hydrocarbons), or (3) residual tracer—dye injected during a previous tracing test that has not been flushed from the ground-water flow system or diluted below detection limits.

### Types of Fluorescent Dyes Used

A thorough description of the physical and chemical properties of commonly used fluorescent dyes is provided by Smart and Laidlaw (1977). A recent discussion of dye toxicity and use is contained in the paper by Field and others (1995). Dyes sold by different manufacturers and chemical warehouses commonly have similar names or trade names. Therefore, to avoid confusion, all dyes marketed in the U.S. are assigned a color index (C.I.) code by the American Society of Dyes and Colorists. Reference should be made to the C.I. code when identifying a dye used for tracing tests.

The dyes used in this investigation included Rhodamine WT (C.I. Acid Red 388); Uranine (sodium fluorescein) (C.I. Acid Yellow 73); and eosine (C.I. Acid Red 87). These dyes are non-toxic to humans and have low toxicity and low mutagenicity characteristics for aquatic life (Smart and Laidlaw, 1977).

### Laboratory Analyses and Spectrofluorometric Methods

Dye detectors collected from the field were shipped within 24 hours to the USGS laboratory in Louisville, Kentucky. Elutant obtained from the charcoal detectors was examined using a spectrofluorophotometer. An explanation of laboratory analyses and spectrofluorometric methods is beyond the scope of this report. The reader is referred Duley (1986) and Wilson and others (1986) for detailed presentations of these subjects.

## DYE INJECTION

Three dye-tracing tests were made during the investigation. The number of tests was limited for two reasons. The first reason was the time needed to monitor and recover an injected dye and to ensure that the dye had been completely flushed from the aquifer or had been diluted below detection lines. The second reason was access to Key Cave was needed to determine if the injected dye was detected in the cave, and Key Cave is inaccessible from April through September.

As a result, the three tests were conducted simultaneously from January through March 2001.

Plans were made to conduct dye-tracing tests in sinkholes or swallow holes in surface drainages at locations on the proposed industrial park site. Because the site lacked open sinkholes (or swallets) suitable for dye injection, an existing well and two wells constructed at the site were used for injection points for three tests. A tanker truck was used to haul potable water to the well injection sites to flush the dye solution out of the borehole interval.

Nomographs or equations for dye dosage have been developed for some water-tracing applications (Aley and Fletcher, 1976), but they are difficult to apply to many ground-water tracing tests. General guidelines for dye dosage suggested by Quinlan (1986) were followed during this investigation. The guidelines take into account the straight-line distance to the furthest anticipated resurgence point and the flow conditions at the time the dye is injected. Dye-dilution factors are highly dependent on flow conditions that cannot be assessed easily.

### Construction and Use of Passive Dye Detectors

Detection of dyes involved the use of passive dye detectors (informally called "bugs") placed in springs, wells, and surface streams selected as monitoring sites for each test conducted during the investigation. The dye detectors were made of fiberglass-mesh-screen packets containing laboratory grade activated coconut charcoal. During the passage of fluorescent dye from a ground-water resurgence, the dye is absorbed and concentrated on the detectors.

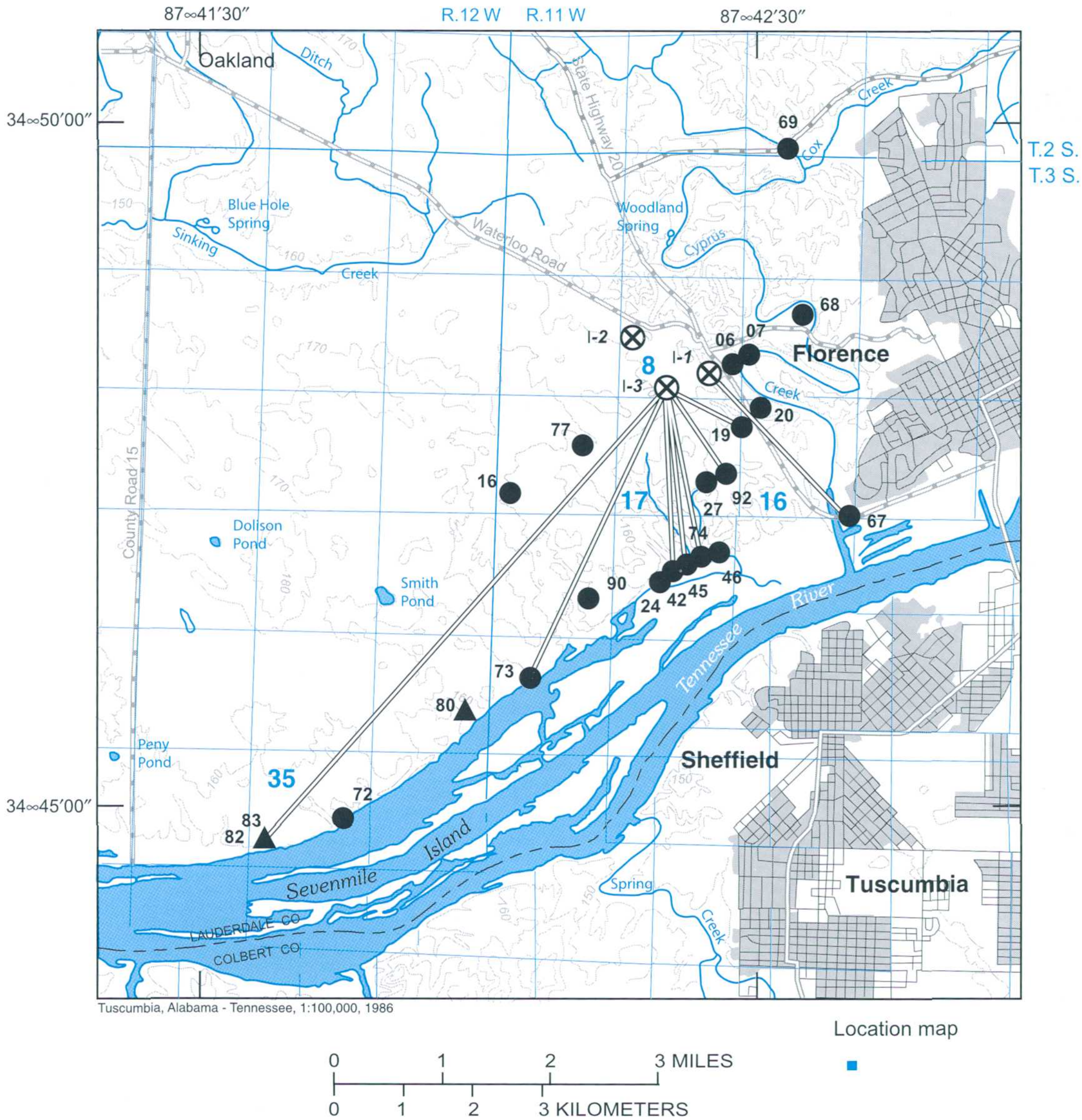
The dye detectors were immersed in the main part of the flow from a spring or in a stream using specially constructed concrete anchors, which enabled the detectors to be suspended by wire above the bottom sediment. All anchors were securely tied off to a nearby tree or stake using nylon cord.

### Field Collection of Dye Detectors

To eliminate possible accidental contamination, dye detectors were constructed prior to handling any dye, and in an area separate from where dyes were mixed. Individual sealable plastic bags were used to transport the detectors to the field. A metal tag imprinted with site identification number was attached to each detector before installation. Dye detectors recovered from field monitoring sites were placed in individual sealable plastic bags and labeled with the site name, identification number, the date the detectors were installed, and the date the detectors were removed.

Prior to dye injection, background detectors were placed at selected monitoring sites from November 10, 2000, to January 3, 2001. The background detectors were collected and replaced every 3 to 7 days. The background detectors were analyzed to determine if ambient conditions would interfere with the use of selected dyes. No background detector tested positive for fluorescent compounds that would interfere with the dye tests prior to dye injection.

A total of 21 detection sites were monitored during the three dye-tracer tests. The use of a different fluorescent dye in each test allowed the use of the same detection sites for all tests. Dye detectors were placed in five wells, nine springs, four surface-water sites, and three cave sites. Tables 1-3 list the dates when detectors were installed and removed. The frequency of detector exchange decreased over the period of the test. After dyes were injected on January 10, exchange frequency was 4 to 6 days until February 6. Thereafter, the exchange frequency was 7 to 9 days from February 6 to March 2 and 13 days from March 2 to March 28.




**EXPLANATION**

| | |
|---|---|
| ══════ | Dye-flow path lines represent hydraulic connections between points of injection and points of detection |
| 83 ▲ | Dye-detection site in caves |
| 72 ● | Dye-detection site |
| *1-3* ⊗ | Dye-injection well |
| 35 | Section number |

**Figure 5**. Dye flow paths from the injection wells to the detection sites.

## RESULTS OF THE DYE-TRACING TESTS

The results of dye-tracing tests conducted during the investigation are summarized in tables 1-3. Successfully completed dye-tracing tests are graphically illustrated as straight-line traces on the map in figure 5. No dye was recovered from injection well I-2; therefore, no straight-line trace is plotted.

The straight-line traces, called "dye flow paths" in this report, represent hydraulic connections between dye-injection and dye-detection sites from which the general direction of ground-water flow can be inferred. The dye flow paths do not represent true flow lines in the karst aquifer system nor do they delineate the trends of actual solutional conduits in the subsurface. Details of each dye-tracing test listed in tables 1-3 are discussed in the following paragraphs.

### Test 1

Well I-1 is 139 feet deep and is completed in bedrock with an unknown amount of 6-inch-diameter surface casing. The well is located on the Abramson property about 150 feet north of the proposed industrial park in the southeast quarter of Section 8, Township 3 South, Range 11 West (fig. 2). Test 1 began on January 10, 2001, with the injection of 7.5 pounds (3 liters) of Rhodamine WT dye. The color index for this dye is Acid Red 388. After dye injection, the well was injected with about 1,250 gallons of potable water to flush the dye into the ground-water system. Injected dye was detected at site 67, Cypress Creek at State Highway 20 on January 17, 2001. No dye was detected at site 68, Cypress Creek at County Road 14, indicating an east-southeast flow path from well I-1 to Cypress Creek (table 1; fig. 5).

### Test 2

Well I-2 was drilled in the northwest corner of the proposed industrial park property (fig. 2). Well I-2 is 43 feet deep and has 33 feet of 3-inch-diameter casing and 10 feet of slotted screen. Bedrock was found at 42 feet and drilling continued 1 foot into bedrock. Test 2 began on January 10, 2001, with the injection of 100 gallons of potable water, followed by the injection of 9 pounds of eosine dye. Potable water was injected prior to the dye to wet the well screen and surrounding material so that dye would move readily into the ground-water system. The color index for this dye is Acid Red 87. After dye injection, the well was flushed with about 325 gallons of potable water. Water samples collected from the well on February 1 and 15 showed visible dye in both samples, indicating little movement of the dye into the ground-water system. No dye was detected at any monitoring site from the injection date to March 28, 2001 (table 2).

### Test 3

Well I-3 was drilled in the central part of the proposed industrial park (fig. 2). Well I-3 is 54 feet deep and has 44 feet of 2-inch-diameter casing and 10 feet of slotted screen. Bedrock was found at 53 feet and drilling continued 1 foot into bedrock. Test 3 began on January 10, 2001, with the injection of 150 gallons of potable water followed by the injection of 10.5 pounds of Uranine dye. The color index for this dye is Acid Yellow 73. After dye injection, the well was flushed with 275 gallons of potable water. Dye was detected at two sites in Key Cave and at other locations as indicated on table 3 and shown on figure 5. This test result indicates a hydraulic connection between Key Cave and well I-3.

## SUMMARY

In an effort to attract new industries and jobs, the city of Florence, Alabama, has proposed development of an industrial park southwest of the city. Carbonate rock underlies the area and sinkholes, springs, caves, and

sinking streams are common. Key Cave, located about 5 miles southwest of the proposed park, is the only known habitat for the Alabama Cavefish (*Speoplatyrhinus poulsoni*). The Alabama Cavefish is a Federally designated Endangered Species, and Key Cave has been designated as Critical Habitat. The U.S. Geological Survey was requested by the city of Florence and the U.S. Fish and Wildlife Service to assist in determining if a hydraulic connection exists between the proposed industrial park and Key Cave.

Dye-tracing methods were used in the investigation to determine if a hydraulic connection exists. Dye tracing is a technique that involves labeling a discrete quantity of ground water with a fluorescent dye (dye tracer) so that the dye flow in the subsurface can be tracked to a ground-water discharge point. Dye-tracing tests can be broadly classified as either qualitative or quantitative tests, depending on the purpose of the test and the level of data collection required. Qualitative dye-tracing tests, such as those used in this study, are intended to (1) establish point-to-point hydraulic connections between the dye-injection and dye-recovery site(s), (2) identify the general direction of ground-water flow, and (3) identify or confirm the presence of ground-water divides that may act as subsurface basin boundaries.

Three dye-tracing tests were made during the investigation. The number of tests was limited by two reasons. The first reason was the time needed to monitor and recover an injected dye and to ensure that the dye had been completely flushed from the aquifer or had been diluted below detection limits. The second reason was access to Key Cave was needed to determine if the injected dye was detected in the cave, and Key Cave is inaccessible from April through September. As a result, the three tests were conducted simultaneously from January through March 2001.

Plans were made to conduct dye tracing tests in sinkholes or swallow holes in surface drainages at locations on the proposed industrial park site. Because the site lacked open sinkholes (or swallets) suitable for dye injection, an existing well and two wells constructed at the site were used for injection points for three tests. A tanker truck was used to haul potable water to the well injection sites to flush the dye solution out of the borehold interval.

Detection of dyes involved using passive dye detectors placed in carefully selected springs, wells, and surface streams. The dye detectors were made of fiberglass-mesh-screen packets containing activated coconut charcoal. During the passage of a cloud of fluorescent dye from a ground-water resurgence, the dye is absorbed and concentrated on the detectors.

The dye detectors were immersed in the main part of the flow from the spring or in a stream using specially constructed concrete anchors that enable the detectors to be suspended by wire above the bottom sediment. All anchors were securely tied off to a nearby tree or stake using nylon cord.

Prior to dye injection, background detectors were placed at selected monitoring sites from November 10, 2000, to January 3, 2001. The background detectors were collected and replaced every 3 to 7 days. The background detectors showed no fluorescent compounds were present that would interfere with the dye tests.

Dye injected in well I-1 on January 10, 2001, was detected from site 67, Cypress Creek at State Highway 20 on January 17, 2001; however, no dye was detected from site 68, Cypress Creek at County Road 14, indicating an east-southeast flow path from well I-1 to Cypress Creek. No positive dye detection was made from dye injected in well I-2 on January 10, 2001. Water samples collected from the well February 1 and 15, 2001, showed little movement of the dye into the ground-water system. Dye injected in well I-3 on January 10, 2001, was detected at two sites in Key Cave and at other locations. The results of this test indicates a hydraulic connection between Key Cave and well I-3.

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Table 1.-- Test 1 dye-tracer detection sites and dates of collection of dye injected at I-1 (Abramson well)
[N, no tracer detected; P, positive tracer detection; --, detector not recovered; R, detector lost or not installed; (B) detector for background fluorescense only]

| Detector identification number | Site name | Rhodamine WT (Acid Red 388) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Date of detector installation | | | | | | | | |
| | | 11/10/00 | 12/05/00 | 01/02/01 | 01/02/01 | 01/08/01 | 01/08/01 | 01/12/01 | 01/12/01 | 01/18/01 |
| | | Date of detector collection | | | | | | | | |
| | | 11/17/00 | 12/08/00 | 01/08/01 | 01/09/01 | 01/11/01 | 01/12/01 | 01/17/01 | 01/18/01 | 01/23/01 |
| AL-KEY-06 | Ram Spring | | N(B) | N(B) | -- | N | -- | N | -- | N |
| AL-KEY-16 | Rock Church well | | | N(B) | -- | N | -- | N | -- | N |
| AL-KEY-19 | O'Neal Spring #1 | | N(B) | N(B) | -- | N | -- | N | -- | N |
| AL-KEY-20 | O'Neal Spring #2 | | | N(B) | -- | -- | -- | N | -- | -- |
| AL-KEY-24 | Cypress Knee Spring | | N(B) | N(B) | -- | -- | N | N | -- | N |
| AL-KEY-27 | O'Neal Farm | | | N(B) | R | R | R | R | R | R |
| AL-KEY-42 | spring | | N(B) | N(B) | -- | -- | N | N | -- | N |
| AL-KEY-45 | spring | | | N(B) | -- | -- | N | N | -- | N |
| AL-KEY-46 | spring | | N(B) | N(B) | -- | -- | N | N | -- | -- |
| AL-KEY-67 | Cypress Creek at Highway 20 | N(B) | N(B) | N(B) | -- | N | -- | P | -- | N |
| AL-KEY-68 | Cypress Creek at County Road 14 | N(B) | N(B) | N(B) | -- | N | -- | N | -- | N |
| AL-KEY-69 | Cypress Creek at Highway 33 | N(B) | N(B) | N(B) | -- | N | R | R | R | R |
| AL-KEY-72 | Key Spring | | N(B) | N(B) | -- | -- | N | -- | N | N |
| AL-KEY-73 | Fish Camp Spring | | N(B) | N(B) | -- | -- | N | -- | N | N |
| AL-KEY-74 | spring | | N(B) | N(B) | -- | -- | N | N | -- | N |
| AL-KEY-77 | Walker well | | | | N(B) | -- | N | -- | N | N |
| AL-KEY-80 | Collier Cave north | | | N(B) | -- | -- | N | -- | N | N |
| AL-KEY-82 | Key Cave west | | | N(B) | -- | -- | N | -- | N | N |
| AL-KEY-83 | Key Cave east | | | | -- | -- | N | -- | N | N |
| AL-KEY-90 | O'Neal old house well | | | | -- | N | -- | N | -- | N |
| AL-KEY-92 | O'Neal Office | | | N(B) | -- | -- | -- | -- | N | N |

Table 1.-- Test 1 dye-tracer detection sites and dates of collection of dye injected at I-1 (Abramson well)--Continued
[N, no tracer detected; P, positive tracer detection; --, detector not recovered; R, detector lost or not installed; (B) detector for background fluorescense only]

| Detector identification number | Site name | Rhodamine WT (Acid Red 388) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Date of detector installation | | | | | | | | |
| | | 01/23/01 | 01/29/01 | 02/02/01 | 02/06/01 | 02/13/01 | 02/22/01 | 03/02/01 | 03/02/01 | 03/15/01 |
| | | Date of detector collection | | | | | | | | |
| | | 01/29/01 | 02/02/01 | 02/06/01 | 02/13/01 | 02/22/01 | 03/02/01 | 03/14/01 | 03/15/01 | 03/28/01 |
| AL-KEY-06 | Ram Spring | N | N | N | N | N | N | N | -- | N |
| AL-KEY-16 | Rock Church well | N | N | N | N | N | N | -- | N | N |
| AL-KEY-19 | O'Neal Spring #1 | N | N | N | N | N | N | N | -- | N |
| AL-KEY-20 | O'Neal Spring #2 | -- | N | N | N | N | N | N | -- | N |
| AL-KEY-24 | Cypress Knee Spring | N | N | N | N | N | N | -- | N | N |
| AL-KEY-27 | O'Neal Farm | R | R | R | R | R | R | R | R | R |
| AL-KEY-42 | spring | N | N | N | N | N | N | -- | N | N |
| AL-KEY-45 | spring | N | N | N | N | N | N | -- | N | N |
| AL-KEY-46 | spring | N | N | N | N | N | N | -- | N | N |
| AL-KEY-67 | Cypress Creek at Highway 20 | N | -- | -- | N | -- | N | N | -- | N |
| AL-KEY-68 | Cypress Creek at County Road 14 | N | N | N | N | N | N | N | -- | N |
| AL-KEY-69 | Cypress Creek at Highway 33 | R | R | R | R | R | R | R | R | R |
| AL-KEY-72 | Key Spring | N | N | N | N | N | N | -- | N | N |
| AL-KEY-73 | Fish Camp Spring | N | N | N | N | N | N | -- | -- | N |
| AL-KEY-74 | spring | N | N | N | N | N | N | -- | N | N |
| AL-KEY-77 | Walker well | N | R | R | R | R | R | R | R | R |
| AL-KEY-80 | Collier Cave north | N | N | N | N | N | N | -- | N | N |
| AL-KEY-82 | Key Cave west | N | N | N | N | N | N | -- | N | N |
| AL-KEY-83 | Key Cave east | N | N | N | N | N | N | -- | N | N |
| AL-KEY-90 | O'Neal old house well | N | N | N | R | R | R | R | R | R |
| AL-KEY-92 | O'Neal Office | N | -- | N | N | N | N | N | -- | N |

Table 2.-- Test 2 dye-tracer detection sites and dates of collection of dye injected at I-2 (northwest field well)

[N, no tracer detected; P, positive tracer detection; --, detector not recovered; R, detector lost or not installed; (B) detector for background fluorescense only]

| Detector identification number | Site name | Eosine liquid (Acid Red 87) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Date of detector installation | | | | | | | | |
| | | 11/10/00 | 12/05/00 | 01/02/01 | 01/02/01 | 01/08/01 | 01/08/01 | 01/12/01 | 01/12/01 | 01/18/01 |
| | | Date of detector collection | | | | | | | | |
| | | 11/17/00 | 12/08/00 | 01/08/01 | 01/09/01 | 01/11/01 | 01/12/01 | 01/17/01 | 01/18/01 | 01/23/01 |
| AL-KEY-06 | Ram Spring | | N(B) | N(B) | -- | N | -- | N | -- | N |
| AL-KEY-16 | Rock Church well | | | N(B) | -- | N | -- | N | -- | N |
| AL-KEY-19 | O'Neal Spring #1 | | N(B) | N(B) | -- | N | -- | N | -- | N |
| AL-KEY-20 | O'Neal Spring #2 | | | N(B) | -- | -- | -- | N | -- | -- |
| AL-KEY-24 | Cypress Knee Spring | | N(B) | N(B) | -- | -- | N | N | -- | N |
| AL-KEY-27 | O'Neal Farm | | | N(B) | R | R | R | R | R | R |
| AL-KEY-42 | spring | | N(B) | N(B) | -- | -- | N | N | -- | N |
| AL-KEY-45 | spring | | | N(B) | -- | -- | N | N | -- | N |
| AL-KEY-46 | spring | | N(B) | N(B) | -- | -- | N | N | -- | -- |
| AL-KEY-67 | Cypress Creek at Highway 20 | N(B) | N(B) | N(B) | -- | N | -- | N | -- | N |
| AL-KEY-68 | Cypress Creek at County Road 14 | N(B) | N(B) | N(B) | -- | N | -- | N | -- | N |
| AL-KEY-69 | Cypress Creek at Highway 33 | N(B) | N(B) | N(B) | -- | N | R | R | R | R |
| AL-KEY-72 | Key Spring | | N(B) | N(B) | -- | -- | N | -- | N | N |
| AL-KEY-73 | Fish Camp Spring | | N(B) | N(B) | -- | -- | N | -- | N | N |
| AL-KEY-74 | spring | | N(B) | N(B) | -- | -- | N | N | -- | N |
| AL-KEY-77 | Walker well | | | | N(B) | -- | N | -- | N | N |
| AL-KEY-80 | Collier Cave north | | | N(B) | -- | -- | N | -- | N | N |
| AL-KEY-82 | Key Cave west | | | N(B) | -- | -- | N | -- | N | N |
| AL-KEY-83 | Key Cave east | | | | -- | -- | N | -- | N | N |
| AL-KEY-90 | O'Neal old house well | | | | -- | N | -- | N | -- | N |
| AL-KEY-92 | O'Neal Office | | | N(B) | -- | -- | -- | -- | N | N |

Table 2.-- Test 2 dye-tracer detection sites and dates of collection of dye injected at I-2 (northwest field well)--Continued
[N, no tracer detected; P, positive tracer detection; --, detector not recovered; R, detector lost or not installed; (B) detector for background fluorescense only]

| Detector identification number | Site name | Eosine liquid (Acid Red 87) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Date of detector installation | | | | | | | | |
| | | 01/23/01 | 01/29/01 | 02/02/01 | 02/06/01 | 02/13/01 | 02/22/01 | 03/02/01 | 03/02/01 | 03/15/01 |
| | | Date of detector collection | | | | | | | | |
| | | 01/29/01 | 02/02/01 | 02/06/01 | 02/13/01 | 02/22/01 | 03/02/01 | 03/14/01 | 03/15/01 | 03/28/01 |
| AL-KEY-06 | Ram Spring | N | N | N | N | N | N | N | -- | N |
| AL-KEY-16 | Rock Church well | N | N | N | N | N | N | -- | N | N |
| AL-KEY-19 | O'Neal Spring #1 | N | N | N | N | N | N | N | -- | N |
| AL-KEY-20 | O'Neal Spring #2 | -- | N | N | N | N | N | N | -- | N |
| AL-KEY-24 | Cypress Knee Spring | N | N | N | N | N | N | -- | N | N |
| AL-KEY-27 | O'Neal Farm | R | R | R | R | R | R | R | R | R |
| AL-KEY-42 | spring | N | N | N | N | N | N | -- | N | N |
| AL-KEY-45 | spring | N | N | N | N | N | N | -- | N | N |
| AL-KEY-46 | spring | N | N | N | N | N | N | -- | N | N |
| AL-KEY-67 | Cypress Creek at Highway 20 | N | -- | -- | N | -- | N | N | -- | N |
| AL-KEY-68 | Cypress Creek at County Road 14 | N | N | N | N | N | N | N | -- | N |
| AL-KEY-69 | Cypress Creek at Highway 33 | R | R | R | R | R | R | R | R | R |
| AL-KEY-72 | Key Spring | N | N | N | N | N | N | -- | N | N |
| AL-KEY-73 | Fish Camp Spring | N | N | N | N | N | N | -- | -- | N |
| AL-KEY-74 | spring | N | N | N | N | N | N | -- | N | N |
| AL-KEY-77 | Walker well | N | R | R | R | R | R | R | R | R |
| AL-KEY-80 | Collier Cave north | N | N | N | N | N | N | -- | N | N |
| AL-KEY-82 | Key Cave west | N | N | N | N | N | N | -- | N | N |
| AL-KEY-83 | Key Cave east | N | N | N | N | N | N | -- | N | N |
| AL-KEY-90 | O'Neal old house well | N | N | N | R | R | R | R | R | R |
| AL-KEY-92 | O'Neal Office | N | -- | N | N | N | N | N | -- | N |

Table 3.-- Test 3 dye-tracer detection sites and dates of collection of dye injected at I-3 (south field well)
[N, no tracer detected; P, positive tracer detection; --, detector not recovered; R, detector lost or not installed; (B) detector for background fluorescense only]

| Detector identification number | Site name | Uranine liquid (sodium fluorescein) (Acid Yellow 73) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Date of detector installation | | | | | | | | |
| | | 11/10/00 | 12/05/00 | 01/02/01 | 01/02/01 | 01/08/01 | 01/08/01 | 01/12/01 | 01/12/01 | 01/18/01 |
| | | Date of detector collection | | | | | | | | |
| | | 11/17/00 | 12/08/00 | 01/08/01 | 01/09/01 | 01/11/01 | 01/12/01 | 01/17/01 | 01/18/01 | 01/23/01 |
| AL-KEY-06 | Ram Spring | | N(B) | N(B) | -- | N | -- | N | -- | N |
| AL-KEY-16 | Rock Church well | | | N(B) | -- | N | -- | N | -- | N |
| AL-KEY-19 | O'Neal Spring #1 | | N(B) | N(B) | -- | N | -- | N | -- | N |
| AL-KEY-20 | O'Neal Spring #2 | | | N(B) | -- | -- | -- | N | -- | -- |
| AL-KEY-24 | Cypress Knee Spring | | N(B) | N(B) | -- | -- | N | N | -- | N |
| AL-KEY-27 | O'Neal Farm | | | N(B) | R | R | R | R | R | R |
| AL-KEY-42 | spring | | N(B) | N(B) | -- | -- | N | N | -- | N |
| AL-KEY-45 | spring | | | N(B) | -- | -- | N | N | -- | N |
| AL-KEY-46 | spring | | N(B) | N(B) | -- | -- | N | N | -- | -- |
| AL-KEY-67 | Cypress Creek at Highway 20 | N(B) | N(B) | N(B) | -- | N | -- | N | -- | N |
| AL-KEY-68 | Cypress Creek at County Road 14 | N(B) | N(B) | N(B) | -- | N | -- | N | -- | N |
| AL-KEY-69 | Cypress Creek at Highway 33 | N(B) | N(B) | N(B) | -- | N | R | R | R | R |
| AL-KEY-72 | Key Spring | | N(B) | N(B) | -- | -- | N | -- | N | N |
| AL-KEY-73 | Fish Camp Spring | | N(B) | N(B) | -- | -- | N | -- | N | N |
| AL-KEY-74 | spring | | N(B) | N(B) | -- | -- | N | N | -- | N |
| AL-KEY-77 | Walker well | | | | N(B) | -- | N | -- | N | N |
| AL-KEY-80 | Collier Cave north | | | N(B) | -- | -- | N | -- | N | N |
| AL-KEY-82 | Key Cave west | | | N(B) | -- | -- | N | -- | N | N |
| AL-KEY-83 | Key Cave east | | | | -- | -- | N | -- | N | N |
| AL-KEY-90 | O'Neal old house well | | | | -- | N | -- | N | -- | N |
| AL-KEY-92 | O'Neal Office | | | N(B) | -- | -- | -- | -- | N | N |

Table 3.-- Test 3 dye-tracer detection sites and dates of collection of dye injected at I-3 (south field well)--Continued
[N, no tracer detected; P, positive tracer detection; --, detector not recovered; R, detector lost or not installed; (B) detector for background fluorescense only]

| Detector identification number | Site name | Uranine liquid (sodium fluorescein) (Acid Yellow 73) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Date of detector installation | | | | | | | | |
| | | 01/23/01 | 01/29/01 | 02/02/01 | 02/06/01 | 02/13/01 | 02/22/01 | 03/02/01 | 03/02/01 | 03/15/01 |
| | | Date of detector collection | | | | | | | | |
| | | 01/29/01 | 02/02/01 | 02/06/01 | 02/13/01 | 02/22/01 | 03/02/01 | 03/14/01 | 03/15/01 | 03/28/01 |
| AL-KEY-06 | Ram Spring | N | N | N | N | N | N | N | -- | N |
| AL-KEY-16 | Rock Church well | N | N | N | N | N | N | -- | N | N |
| AL-KEY-19 | O'Neal Spring #1 | N | N | N | P | N | N | N | -- | N |
| AL-KEY-20 | O'Neal Spring #2 | -- | N | N | N | N | N | N | -- | N |
| AL-KEY-24 | Cypress Knee Spring | N | N | N | N | N | N | -- | N | N |
| AL-KEY-27 | O'Neal Farm | R | R | R | R | R | R | R | R | R |
| AL-KEY-42 | spring | N | P | P | N | N | N | -- | N | N |
| AL-KEY-45 | spring | N | N | N | N | N | N | -- | N | N |
| AL-KEY-46 | spring | N | N | N | N | N | N | -- | N | N |
| AL-KEY-67 | Cypress Creek at Highway 20 | N | -- | -- | N | -- | N | N | -- | N |
| AL-KEY-68 | Cypress Creek at County Road 14 | N | N | N | N | N | N | N | -- | N |
| AL-KEY-69 | Cypress Creek at Highway 33 | R | R | R | R | R | R | R | R | R |
| AL-KEY-72 | Key Spring | N | N | N | N | N | N | -- | N | N |
| AL-KEY-73 | Fish Camp Spring | N | N | N | P | N | N | -- | -- | N |
| AL-KEY-74 | spring | N | P | P | N | N | N | -- | N | N |
| AL-KEY-77 | Walker well | N | R | R | R | R | R | R | R | R |
| AL-KEY-80 | Collier Cave north | N | N | N | N | N | N | -- | N | N |
| AL-KEY-82 | Key Cave west | N | P | P | N | N | N | -- | N | N |
| AL-KEY-83 | Key Cave east | N | P | N | N | N | N | -- | N | N |
| AL-KEY-90 | O'Neal old house well | N | N | N | R | R | R | R | R | R |
| AL-KEY-92 | O'Neal Office | N | -- | P | P | N | N | N | -- | N |

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