DETERMINATION OF THE RECHARGE AREA FOR THE RIO SPRINGS GROUNDWATER BASIN, NEAR MUNFORDVILLE, KENTUCKY: AN APPLICATION OF DYE TRACING AND POTENTIOMETRIC MAPPING FOR DELINEATION OF SPRINGHEAD AND WELLHEAD PROTECTION AREAS IN CARBONATE AQUIFERS AND KARST TERRANES

PROJECT COMPLETION REPORT

Prepared for

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SUMMARY

Dye traces and a potentiometric map based on water-wells, spring, and stream elevations were used to delineate the Rio Springs groundwater basin located east of Munfordville, Kentucky. This investigation was performed as a Springhead (Wellhead) Delineation Demonstration Project supported by the U.S. Environmental Protection Agency, Kentucky Division of Water, and the Green River Valley Water District. The results of the series of dye traces were used to iteratively revise the potentiometric maps that guided the design of successive trace tests. The rationale for various investigative techniques used and decisions made is included in this report.

The recharge area for the Rio Springs groundwater basin is approximately 4.9 $\pm$ 0.5 square miles and is shown in Plate I. The area includes groundwater drainage from an adjacent surface-water basin, Bacon Creek. Such inclusion is inferred because the boundary of the Rio Springs groundwater basin is beyond (and outside) the boundary of its surface water basin (the topographic divide) where this latter boundary can be drawn.

The long-term, sustained flow of the Rio Springs groundwater basin (its normalized base flow), as measured by its base flow discharge per square mile, is five to six times greater than that measured in any other groundwater basin in the Mammoth Cave area. This significantly greater sustained flow is a response to attenuation (damping) of aquifer response to storm-induced recharge--attenuation caused by thick masses of slumped sand and gravel that overlie most of the Rio Springs basin. The hydrogeologic properties of the sand and gravel increase the time it takes for the aquifer to respond to storms. They impart a storage that is significantly higher than that of nearby karst aquifers which lack a thick granular, non-clay mantle above the carbonate bedrock.

Normalized base flow can be used to reliably estimate the recharge area of a spring but only if its probable geology is already known. This principle, quantified during this investigation, should be widely applicable elsewhere.

The results of this investigation may be used for response to environmental emergencies, local and regional planning, resource protection through a Springhead Protection Program for the Rio Springs area, and public education.

Many results of this delineation project are relevant to the study, interpretation, and protection of water supplies in other karst terranes. These results, plus conclusions applicable to maximizing the efficiency and reliability of similar investigations elsewhere, are discussed.

INTRODUCTION

This report describes the findings of a hydrogeologic study of the Rio Springs groundwater basin, east of Munfordville, Kentucky. Rio Springs is a raw water source for the Green River Valley Water District (GRVWD). This study was conducted to define the area of recharge as part of a Karst Springhead (Wellhead) Protection Demonstration Project for public water supply springs. This hydrogeologic study was designed to delineate the recharge area of the Rio Springs groundwater basin. Tasks included the collection and review of background information, determination of physical setting, field reconnaissance, tracer-test design, tracer testing, and report generation.

A spring and the conduit network draining to it can be considered as a near-horizontal well. It follows, then, that springhead is the spring-equivalent of a wellhead.

This project completion report is written as a tutorial for technical personnel and others who may be considering establishment of a wellhead protection program in a carbonate rock terrane elsewhere. Accordingly, we have included background information to give perspective, and discussion of the rationale for why many decisions were made. However, this is not a "how-to" manual for tracing delineation of wellhead protection in non-carbonate rocks, or for organization of a wellhead protection program. The latter two topics are well described by U.S. EPA (1987, 1989).

Although many wellhead protection studies routinely include analysis of fracture-traces and lineaments as a guide to flow direction and routing of groundwater, such a study would have been irrelevant in the Rio Springs area and was not performed. In spite of the excesses described by Wise (1982, 1983), these features have been repeatedly shown to be a guide to the siting of highest-yield wells, and they do indicate the most easily recognized possible flow routes, but they are not a predictor of flow destination (Blavoux et al., 1992), or of major flow routes in carbonate aquifers. Most flow in carbonate aquifers of the Mammoth Cave/Rio Springs area is in conduits developed near-parallel to bedding planes rather than along joints. Accordingly, although much orientation data could have been acquired, analyzed, and presented, we did not consider fracture-trace and lineament analysis to be judicious, cost-efficient, or relevant to springhead delineation in the study area.

PROJECT PARTICIPANTS

Project participants included ECKENFELDER INC., Nashville, Tennessee; Quinlan & Associates, Nashville, Tennessee; Groundwater Branch, Kentucky Division of Water, Frankfort, Kentucky; the Green River Valley Water District, Cave City, Kentucky; and ATEC Associates Inc., Nashville, Tennessee. Funding for this project was supplied by the Ground Water Branch, U.S. EPA, Region IV, Atlanta, Georgia. The Kentucky Division of Water and the Green River Valley Water District also contributed personnel to work on this project. Most of the field work for this project was carried out by Joseph Ray, Kentucky Division of Water; Geary Schindel, ECKENFELDER INC.; and Tray Lyons, Green River Valley Water District. Robert Olive, Environmental Scientist, USEPA, Ground Water Branch was Project Coordinator for the EPA.

BACKGROUND INFORMATION

The GRVWD supplies more than 25,000 people with rural service connections in Hart County and portions of Green, LaRue, Barren, Metcalfe, and Edmonson Counties. It supplies water directly to Mammoth Cave National Park and to the cities of Horse Cave and Cave City, to the LaRue County Water District

(2,627 people), the Green-Taylor Water District (8,751 people), Bonnieville Water District (752 people), and the Munfordville Water District (2,627 people). Rio Springs is also the water source for the Glenbrook Trout Farm, located below the Rio Springs reservoir.

Rio Springs consists of several contiguous springs on the north side of the Green River, near the former community of Rio in Hart County, Kentucky. The springs are approximately one-half mile west of U.S. Highway 31E and one-quarter mile north of the Green River. All perennial flows are on the west bank of a small south-flowing intermittent tributary of Rocky Hollow. None of the springs are shown on the U.S. Geological Survey Canmer, Kentucky, 7.5-minute topographic map, but they are shown on Plate I of this report as Sites 6 and 7.

The stream which flows from the springs has been dammed with a concrete structure to form a small reservoir covering less than one acre. The natural spring orifices were backflooded by the reservoir and aggraded by sand. This reservoir is presently fed by seven perennial springs located on the west side of the ravine. Three of these flows comprise the major portion of Rio Springs. During high-flow conditions, a 0.6-mile long intermittent stream, draining south from the community of Linwood, conveys surface water to the reservoir. The total discharge of Rio Springs is approximately 4.8 cubic feet per second, as averaged from two measurements reported by the U.S. Geological Survey (Donald S. Mull, oral communication, June 1993). A subsequent gauging on September 3, 1993 determined a discharge of 4.4 cubic feet per second.

The Green River Valley Water District reports an average use of 500,000 gallons of water a day from Rio Springs and approximately 1,500,000 gallons a day from the Green River. However, during some months of the year, no water from Rio Springs is used by the GRVWD. The District would prefer to use additional water from Rio Springs because it requires less treatment than water from the Green River. However, there is a conflict regarding allocation of water between the GRVWD and the trout farm, which also requires a high-quality water supply.

Map coverage of the study area is available on four 7.5-minute, 1:24,000 scale topographic and geologic maps published by the U.S. Geological Survey: the Canmer, Hammonville, Hudgins, and Magnolia quadrangles. Each of the topographic and geologic maps was reviewed for the presence of surface streams, sinking streams, springs, caves, and other karst features. Most of the Canmer quadrangle and a small part of each of the other three topographic maps were assembled into a working project map which was photographically reproduced and used to plot all points possibly suitable for tracer injection and monitoring.

PREVIOUS STUDIES

Although there are no previous hydrogeologic studies of the Rio Springs basin, extensive investigations were conducted in the area adjacent to Rio Springs by James F. Quinlan and Joseph A. Ray when each was employed by the National Park Service at Mammoth Cave National Park. Those investigations north of the Green River were not completed and have not been published. Their work on groundwater basins south of the Green River has been published (Quinlan and Ray, 1989). Available information from the following organizations was also reviewed: Kentucky Division of Water, Groundwater Branch; Green River Valley Water District; U.S. Geological Survey, Kentucky District; and Kentucky Geological Survey. A map of Buckner Spring Cave was graciously provided by Dr. Joseph Saunders.

Data on dye traces in the Johnson Spring and Lanes Mill Spring groundwater basins, adjacent to the Rio Springs groundwater basin, were obtained from James F. Quinlan. Discharge and water-quality data for Rio Springs, plus well location and water-level data on 14 of the 61 wells shown on Plate I, were obtained from the U.S. Geological Survey. The Kentucky Division of Water supplied available records of water wells drilled after 1985. The National Park Service supplied water-well locations and water-level data for wells drilled before 1986. James F. Quinlan supplied information on the location of numerous springs found by him and Joseph A. Ray during pre-1986 studies.

The most recent syntheses of regional hydrogeology of the karst have been published by White and White (1989) and Quinlan et al. (1983) but neither of these original works specifically address the Rio Springs area.

A published potentiometric map at a scale of 1:250,000 (about 1 inch = 4 miles) includes the area of Plate I (Plebuch et al., 1985), but it was contoured at a 50-foot interval. For the Mammoth Cave area south of the Green River, it reproduced the

1981 version of Quinlan and Ray (1989), but partially recontoured at a 50-foot interval. [The Quinlan and Ray map averaged about 100 wells per quadrangle (approximately two per square mile) and had been published with a 20-foot contour interval.] For most of the remaining coverage of the Plebuch et al. map, there are significantly fewer wells measured per quadrangle, commonly less than 15, than were used in this report. Also, no springs are shown on it. Accordingly, the Plebuch et al. map can be used for only very general predictions. It does not include, nor can it be used to determine, boundaries of groundwater basins, or for response to environmental incidents.

GEOLOGIC SETTING

The Rio Springs groundwater basin, located in west-central Kentucky near the southeastern edge of the Illinois Basin, is in Mississippian-age limestones overlain by Mississippian and Pennsylvanian sandstones. The rocks throughout most of the map area shown in Plate I dip gently to the west at about 20 to 50 feet per mile. The north edge of Plate I coincides approximately with the axis of an anticline extending to the east; the anticline is used as the Magnolia Gas Storage Field (Moore, 1975). The stratigraphic units in the study area, from oldest to youngest, include the Salem-Warsaw, St. Louis, Site. Genevieve, and Girkin Limestones, the Big Clifty Sandstone, and the Caseyville and Tradewater Formations (mostly sandstone and conglomerate highly weathered to sand and gravel).

The Rio Springs area is a karst terrane. It is characterized by sinkholes, sinking streams (most of which are ephemeral), caves, springs, and a well-integrated subsurface drainage network. Much of the study area is a highly dissected part of the Mammoth Cave Plateau (Dicken, 1935), which is also known as the Chester Cuesta (Quinlan, 1970). The northern half of Plate I includes a sandy terrane that is known as the Brush Creek Hills (Sauer, 1927). The sand and gravel is part of the west-southwest-trending Brownsville Channel, which occupies a paleo-valley up to several hundred feet deep that is filled with Pennsylvanian sandstone, shale, and conglomerate that unconformably overlie several of the Mississippian limestone and sandstone formations. Much of this has been intensely weathered, disaggregated, and lowered during dissolutionally-induced subsidence.

All land south of the Green River is part of the Sinkhole Plain that, at Sims Bend and Davis Bend, extends up to 3 miles north of the river. All of Plate I is underlain by the same relatively pure limestones that crop out in the Mammoth Cave area and which are locally capped by the Big Clifty Sandstone.

A geologic map has been published for each of the four topographic map quadrangles listed above (Miller, 1969; Miller and Moore, 1969; Moore, 1972, 1975). These maps were spliced together and interpreted in order to determine what relationships may exist between stratigraphy, structure, and the distribution of springs.

Extensive field observations in this area, coupled with interpretation of published geologic maps, have shown that there are three lithologic controls on groundwater movement in the karst of the Rio Springs area. They are:

1. Impermeability of the Big Clifty Sandstone and associated shale. This locally preserves the caves below from erosion and dissolutional destruction, but favors the development of vertical shafts that help accomplish such destruction at the edge of ridges. The impermeability of the Big Clifty is much less important in the study area where the ridges are narrower and more highly dissected than to the west, where the beds dip slightly more steeply, dissection is less, and the ridges are wider.

2. Impermeability of the clayey, silty limestones at the top of the Salem-Warsaw Limestone and lowermost part of the overlying St. Louis Limestone, about 40 feet above their contact. Rio Springs and several other springs appear to be perched on these upper beds. Many additional springs are perched on the top of the Salem-Warsaw.

3. Recharge attenuation and storage capacity of up to several hundred feet of slumped sand and gravel (disaggregated sandstone and conglomerate) that overlie the limestones in the northern half of Plate I. This widespread sand and gravel impede rapid or direct recharge into the aquifer at sinkholes; limestone outcrops are uncommon. As a result, many of the springs have a more subdued response to storms and lower turbidity than those appreciably fed by sinking streams and sinkholes draining into open holes in limestone.

Project Hydrologic Boundary and Estimated Boundary of Basin

The preliminary project hydrologic boundary for Rio Springs and immediately adjacent groundwater basins was determined from review of the topographic and geologic maps and from interpretation of previous water-tracing studies of the region conducted by Quinlan and Ray. It was defined as the major surface and subsurface streams adjacent to Rio Springs which most probably act as a boundary for near-surface groundwater flow in the region. This boundary was identified as: Green River, to the south; Lynn Camp Creek, to the east; Laurel Branch, Brushy Fork, and Bacon Creek, to the north; and the inferred southward flowline of the dye trace from near Bolton Church to Johnson Spring, to the west. Some of these streams were known to be beyond the estimated boundary of the actual groundwater basin.

Stream incision along the Green River and the lower part of Lynn Camp Creek has exposed clayey, silty beds that perch springs at and near the contact between the St. Louis, and Salem-Warsaw. These beds and the top of the Salem-Warsaw were considered to be the basal hydrologic boundary of the near-surface aquifer.

Interpretation of the map of Buckner Spring Cave (the spring location shown on the published topographic map is about 120 feet above its actual elevation), plus the pre-project trace to Lanes Mill Spring, suggested that the actual boundary of the Buckner Spring Cave basin would be closer to Rio Springs. The orientation of Buckner Spring Cave led its mapper, Dr. Joseph Saunders, to hypothesize that the cave functioned as a high-level overflow for Rio Springs. Such a distributary could exist, but it was not demonstrated during this study.

SEARCH OF PUBLIC GROUNDWATER DATA-BASES

Dye Trace Information

The Kentucky Division of Water and the Kentucky Geological Survey had no records of dye traces in the study area. Karst researchers known to be actively working in this region of Kentucky were contacted for background information and to determine if any dye tracing was currently being conducted in the area; none was. The unpublished tracing studies by Quinlan and Ray are the only previous work known in the area.

Water Well Survey

The Kentucky Division of Water's Water-Well Drillers Program, supplied a copy of logs from two wells drilled within the area of Plate I since 1985. One well was inaccessible for measuring of water level; the other could not be found. A copy of unpublished data on well locations and water levels, based on pre-1986 field work by Quinlan and Ray and inclusive of data from the U.S. Geological Survey, was obtained from the files of the National Park Service. These data had been used by them to construct a draft potentiometric map of the region north of Green River, but more well data were needed for the Rio Springs area. That draft map guided much of the field reconnaissance for this project and was basically correct, but its contours were repeatedly modified after additional water-level data and tracing results were acquired and interpreted.

Experience has repeatedly shown that, unless a locally intensive well survey has already been made, state and federal records in many states rarely include more than about 10 percent of the wells that exist in an area. Accordingly, most of the well survey was performed by conducting a house-to-house quest for wells. The pre-1986 survey north of the Green River was part of a research program. Field work in that study yielded 0 to 12 measurable wells per day and averaged about 5, but this was a function of local stratigraphy and population density. Daily productivity of water-level data was higher in the Sinkhole Plain to the south.

When a measurable well was found, project-relevant data was recorded. Location and ground-surface elevation was estimated from the topographic map, and water level was measured with an electric tape. Data from all measurable wells was collected during low-flow conditions. Some of the wells first measured by the U.S. Geological Survey were remeasured in order to confirm the static conditions.

U.S. Geological Survey national mapping standards require that 90 percent of the elevations on a topographic map have a error of no more than half a contour interval. The practical application of this standard is ambiguous, however, unless, one has information on the statistical distribution of the errors contributory to meeting or failing the standard. But if it is assumed that: 1) the maximum possible error is half a contour interval, and 2) the study area is in a low relief, non-forested terrane such as the Sinkhole Plain where most homes and barns are shown on the topographic map, the elevation of a well can be estimated to about one-fifth of a contour interval. The two sources of error can be added to calculate the maximum error. Therefore, where the contour interval is 10 feet, the elevation of most wells can be estimated to within ± 7 feet; where the contour interval is 20 feet, twice as much.

For most of the area of Plate I, the slope of the potentiometric surface ranges from about 40 to 100 feet per mile. Therefore, the elevation "noise" on the potentiometric surface in the study area (± 7 or 14 feet, depending upon the contour interval) does not greatly affect the accuracy of the surface being contoured.

The effects of possible error induced by some of the "topography" having been locally contoured on vegetation canopy rather than on the ground surface has not been evaluated by us. It could be a problem in some of the more densely wooded parts of the study area.

The potentiometric surface in Plate I was contoured manually rather than with a computer program. The surface is subjective and was revised as tracing data became available. The working maps with the revised potentiometric contours and tracer-test results were used to guide planning and interpretation of additional tracer tests.

Public Water-Supply Resources

The Kentucky Division of Water's Water Withdrawal Program, furnished information on three water-withdrawal permits for the area: The Green River Valley Water District is permitted to remove approximately 2.6 million gallons per day (mgd) from Rio Springs and the Green River; the Glenbrook Trout Farm is permitted to use 1.446 mgd from Rio Springs; and the Powder Mill Trout Ranch, Inc., adjacent to Lynn Camp Creek and near Sites 14 and 15, near the eastern edge of Plate I, used an average of 0.735 mgd in 1992.

Compilation of Data

Data collected as part of the background study for this project were compiled onto a working map produced from the four topographic maps. These data included the injection and recovery points for the previous dye traces performed by Quinlan and Ray, locations and depths to water in domestic water wells, and the locations of springs near and within the estimated hydrologic boundary of the Rio Springs basin. These data were used to construct a potentiometric surface map and to identify areas where additional field work was required.

FIELD INVESTIGATIONS

General

Field reconnaissance was made of the area near the estimated hydrologic boundary not checked during the earlier studies by Quinlan and Ray. Most of this field work centered on the northern part of the map area and included Martis Branch, Tampa Branch, Laurel Branch, and Brushy Fork. Twenty-eight locations (19 springs and 9 streams) were initially identified for the placement of dye receptors (detector). One spring outside of the estimated hydrologic boundary, Handy Culvert Spring (Site No. 13 on Plate I) was monitored as a quality control procedure. It drained from the east.

Spring Survey

A spring survey was conducted in order to find springs at or within the preliminary hydrologic boundary of the study area. Springs identified during the uncompleted pre-1986 field work by Quinlan and Ray were incorporated into this survey. Additional springs were also located during field work for this project.

Only 4 of the 19 springs monitored during this study are shown on the U.S. Geological Survey topographic maps. An additional spring (James School Spring, Site No. 21) is shown on a geologic map but not on the corresponding topographic map. All other springs were found as a result of field work. Only 1 of the 19 springs found in the area may have been detectable on aerial photos. [Throughout the

Mammoth Cave area and most of the U.S., generally less than 5 percent of springs relevant to regional hydrology of karst terranes are shown on topographic maps.]

Survey for Dye-Injection Locations

Field reconnaissance for dye-injection locations, conducted near the estimated hydrologic boundary of the Rio Springs basin, was done concurrently with the spring survey. An attempt was made to identify sinkholes, sink-points (swallets) of sinking streams, and water wells that might be usable for injecting dye into the aquifer. Suitable dye-injection sites are rare in the study area; locating them required a significant field effort.

Sinkholes. Sinkholes with an opening through which water might drain readily, especially after storms, were sought during field reconnaissance and plotted on the working map. Many sinkholes drain runoff only after heavy storms. Therefore, each potential dye-injection site had to be evaluated for its accessibility by tank-trucks or other sources of water. All sinks judged to have potential as dye-injection points were also evaluated for their proximity to the estimated boundary between the Rio Springs basin and adjacent groundwater basins. A site for potential injection of dye could be technically excellent, but if it were near the probable middle of the Rio Springs basin rather than near its boundary, tracing from it was considered unnecessary.

Sinking Streams. Although there are many sinking streams in the area shown on Plate I, fewer than five of those shown as such on the 7.5-minute topographic maps occur within or adjacent to the estimated boundaries of the Rio Springs basin. These few are all ephemeral, flowing only after major storms, and they are all in locations either near the probable middle of the basin or obviously, on the basis of pre-project tracer tests, draining to other basins. Other ephemeral sinking streams exist within or adjacent to the Rio Springs basin but are not shown on the topographic maps.

One perennial sinking stream was identified for which the sink-point shifts, depending on stage height. Extensive field work was done in order to locate ephemeral streams that convey stormwater runoff to discrete sink-points. The few perennial and ephemeral sink-points found were plotted on the working map and evaluated for location relative to the estimated groundwater boundary of the Rio Springs Basin. The sink-points were further evaluated for their ease of access by a tank-truck or other source of water.

Water Wells. Several unused water wells were found during pre-project investigations by Quinlan and Ray. High priority was given during this study to finding additional unused wells suitable for injection of dye because of their accessibility and their location relative to the tentatively inferred boundary of the Rio Springs basin. Landowners were extremely cooperative. The presence of unused water wells was generally a consequence of the availability in recent years of public water from the Green River Valley Water District.

Potentiometric Mapping

There are fewer domestic water wells per square mile in the Rio Springs area than in most of the area south of Green River previously studied by Quinlan and Ray (1989). In part, this is because of the lower population density near Rio Springs, and because the thickness and loose nature of slumped sands reportedly makes it difficult for local drillers to complete a well successfully without it collapsing or producing excessive sand. An intensive house-to-house search for additional wells was made, but only five more were found.

DESIGN OF TRACER TESTS

Information obtained from the background study and field reconnaissance was used to design the tracer tests. Evaluation of these data indicated that multiple-dye traces, using up to four dyes for each series of tests, could be conducted simultaneously. The use of multiple dyes allowed for greater cost efficiency in collection, analysis, and evaluation of dye receptors (detector). Data from each series of dye tests were evaluated and additional dye-injection sites were selected. After each series of tracer tests, the location and number of monitoring sites were evaluated for their relevance to the study objectives.

Selection of Monitoring Points

Springs and streams were evaluated as potential monitoring sites for the tracer tests. Major springs were individually monitored with dye detectors. In areas where no major springs could be found, streams were monitored instead. After careful evaluation and in an effort to reduce costs, some springs were monitored at their confluence or in streams. If dyes were to be recovered, there would be time to place dye detectors in individual springs before dye cleared from the system. Twenty-eight locations, including 19 springs, were initially identified for the placement of dye detectors. Additional stream sites were added after the tests began. Plate I shows the name and location of all monitoring points used.

Selection of Dye-Injection Points

Approximately 15 potentially usable dye-injection points were identified in the study area. These included sinkholes, sinking streams, and water wells. Tracer-test injection points selected for use were those considered likely to yield access to the aquifer and to be near the suspected boundary of the Rio Springs basin, as inferred from the working draft of the potentiometric map.

Selection of Dyes

Four types of fluorescent dye were selected for use in this study. They were picked on the basis of non-toxicity, availability, analytical detectability, low cost, and ease of use. All of these dyes have been previously used as tracers and their properties have been documented in the karst-related literature. The following dyes were used:

Dye	Colour Index Generic Name
Rhodamine WT	Acid Red 388
Fluorescein (Uranine)	Acid Yellow 73
Solophenyl	Direct Yellow 96
Optical Brightener	
Burcofluor AF Solution	Fluorescent Brightening Agent 28
Tinopal CBS-X	Fluorescent Brightening Agent 351

The quantity of dyes used in this study was based on the experience of the authors in similar terranes. Factors evaluated in determining those quantities include: detection limit of the analytical method to be used for dye analysis, a desire not to induce visible coloration to spring waters or streams, and a desire not to "overload" the aquifer with dye that would persist for a much longer time than if a minimal quantity was employed (thus delaying completion of the project). The desire not to induce visible coloration to waters was a matter of aesthetics and public relations, not possible toxicity. All of the dyes used are non-toxic (non-carcinogenic, non-mutagenic, non-tumorogenic, non-teratogenic, non-poisonous, etc.), especially in the concentrations to which they were diluted and discharged at springs (Smart, 1984; Field et al., in review), and posed no threat to the quality of private or public water supplies. Non-toxic, fluorescent dyes rather than other tracing agents are used because they are safe, practical, most cost-efficient, and most easily detected tracers available.

Recovery Of Dyes in the Field

The rationale and the techniques for conducting tracer tests and methods for the analysis of dyes are discussed by Alexander and Quinlan (1992). They are summarized briefly in this report.

Dye detectors, consisting of either granular activated charcoal or non-fluorescent cotton, both of which sorb dye, are used in lieu of water samples for two reasons: economy and enhancement of dye concentration. More specifically, detectors yield an integrated sample, that barring interference from other organic compounds, is a product of continual sorption of dye, whenever dye is present in water. Therefore sampling can be weekly or biweekly rather than hourly or daily. Some tracer tests require, for various reasons, quantification of frequently collected water samples. However, most projects, including this one, are only interested in determining if dye was "present or absent" from a monitoring site. The consequent cost-savings in time, labor, materials, and analysis can be considerable. Further, the amount of dye accumulated on a detector increase with time. Charcoal, for example, when left for a week in a spring or stream that has had a constant concentration of dye, will commonly yield an elutant that has a dye-concentration of 100 to 400 times greater than ever present in the stream. Therefore, use of detectors rather than water samples enables one to sense the presence of dye that might not be detectable in a water sample.

Optical brighteners were detected with the use of non-fluorescent cotton which had been checked with an ultraviolet light before use. Both the cotton and charcoal were placed in nylon-screen bags and suspended in water from a wire attached to a concrete stand (gum drop) or wired brick. Detectors were generally changed once a week. However, the collection of detectors was dependent upon weather and access. A longer period of time between detector collections was used during the last part of the investigation.

Detectors were set, collected, analyzed, and evaluated for background concentrations of dye or dye-like substances over a period of several weeks before any dyes were put into the ground. Once it was established that there was no background, or that the background present was manageable, the final decisions could be made about what dye would be most suitable for tracing to a given site.

All sites at which dye was detected were monitored for its continued presence until the dye was either no longer detectable or was present at a concentration so low as to not interfere with the interpretation of any subsequent tracer tests. This allowed time for the dye to be possibly detected at additional sites if connections existed. Data on the frequency and duration of monitoring for each site, along with what dyes it was tested for, and whether they were present, are summarized in Appendix A.

Laboratory Analysis for Dyes

Each detector was placed in an individually marked bag in the field and shipped to the laboratory for analysis. All detectors were thoroughly washed with a high-intensity jet of tap water before being analyzed. Cotton detectors were evaluated by using an ultraviolet light over a dark, light-proof box. Cotton that was positive for brightener fluoresced a brilliant blue-white. Cotton that was positive for Solophenyl fluoresced canary yellow. The results of detector evaluation were recorded on a Tracer Test Form by date (see Appendix A). Charcoal detectors were evaluated by eluting them for one hour in a solution containing 95 percent of a 70 percent solution of isopropyl alcohol in water and 5 percent of ammonium hydroxide. The elutant was then decanted for storage in a closed, labeled glass vial until analyzed.

Laboratory analyses for fluorescein were conducted with a Turner Designs Model 10 filter fluorometer by ECKENFELDER INC. Analysis for Rhodamine WT was performed with a Turner Associates Model 111 filter fluorometer by ECKENFELDER INC. Analyses for both dyes were performed with a Shimadzu RF-540 scanning spectrofluorophotometer by Quinlan & Associates. Although it was not critical for this study, because the dye concentrations in elutant were not minimal and were well above detection limits, a scanning spectrofluorophotometer is the optimal instrument for dye analysis because it can unambiguously detect smaller concentrations of dye than a filter fluorometer and can readily and unambiguously separate three or more dyes used simultaneously. More importantly, a scanning spectrofluorophotometer can unambiguously distinguish between dyes and non-dyes that may have fluorescence which overlaps that of dyes. A filter fluorometer is an optimal instrument where one or more dyes are to be detected in a setting not likely to have industrial contaminants that may fluoresce, when fluorescein and Rhodamine WT are recovered in sub-equal quantities, or when the concentration of one dye does not exceed that of the other by more than a factor of about 20.

Documentation of Results

Results of the tracer tests are shown in Plate I. The data sheets supporting it are included in this report as Appendix A, which is comprised of Spring Survey Forms and Tracer Test Forms.

The following summaries state where and when dyes were injected and recovered, and for how long they were recovered. For details of what other sites were monitored, for when and for how long all sites were monitored, and for how long dyes were subsequently detectable, see Appendix A.

Glen Lilly Road Spring to Buckner Spring Cave (Dye Trace A). Two pounds of Rhodamine WT (20 percent solution) were injected into the Glen Lilly Road Spring on March 3, 1993. This dye was first recovered on a detector collected at Buckner Spring Cave (Site 5) on March 12, 1993. It was present for five weeks.

Charles Ash Sinkhole to Jones School Spring (Dye Trace B). Seven pounds of fluorescein were injected into the Charles Ash Sinkhole on March 3, 1993. This dye was first recovered on a detector collected at Jones School Spring (Site 21) on March 12, 1993. It was present for four weeks.

Glen Lilly Sinkhole to Rio Springs (Dye Trace C). Six and one-half pounds of Solophenyl were injected into the Glen Lilly Sinkhole on March 25, 1993. The presence of dye was first indicated on a detector collected at Rio Springs and Rio Springs East (Sites 6 and 7) on April 2, 1993. It was present for three weeks.

Bail Road Ditch Sinkhole to Bailey Falls Spring (Dye Trace D). Forty and one-half pounds (4.5 gallons) of optical brightener were injected into the Bail Road Ditch Sinkhole on March 25, 1993. This dye was first recovered on a detector collected at Bailey Falls Spring on April 2, 1993. It was present for two weeks.

Knox Creek Sinkhole (Dye Trace E). Fifteen pounds (1.75 gallons) of optical brightener were injected into the Knox Creek Sinkhole on April 24, 1993 and was not detected. The trace was repeated on June 16, 1993 using 6 pounds of another optical brightener (as a powder). Again, the dye was not detected in samples collected over a one-month period. The trace was repeated on July 16, 1993 with 3 pounds of fluorescein. This trace was repeated on March 19, 1994 with 5 pounds of fluorescein. This trace was positive at Lanes Mill Spring on March 21, 1994.

Christene Dye Well to Johnson Spring (Dye Trace F). Eleven pounds of fluorescein were injected into the Christene Dye [sic, owner's name] Well on April 24, 1993. This dye was first recovered on a detector collected from Johnson Spring on May 9, 1993. Prior to this test, a small quantity of fluorescein was present as background at this spring, but the fluorescein recovered had concentrations several orders of magnitude higher than the background, and the progressive decrease in its concentration was characteristic of tracer-test results. It was present for five weeks.

Walter Well (Dye Trace G). Twelve pounds of Rhodamine WT (20 percent solution) were injected into the Walter Well on April 24, 1993. As of August 15, 1993, this dye was not found by analysis of detectors collected on a weekly to bi-weekly basis (see section on unrecovered dyes, below). It is assumed to have flowed to Johnson Spring, as shown on Plate I.

Route 357 Sinkhole (Dye Trace H). Three pounds of Solophenyl were injected into the Route 357 Sinkhole on April 24, 1993. This dye was never recovered (see section on unrecovered dyes, below).

Unrecovered Dyes

Eight tracer tests were conducted, as shown on Plate I. Two of them, Walter Well (Site G), and Route 357 Sinkhole (Site H), were unsuccessful.

The Walter well test (Site G) was considered during its design to be a difficult one. It was thought likely that the dye might be injected into the slumped sand and gravel above the limestone rather than into it directly. Flow through slumped sand could result in a very long time of travel and sorption onto the formation matrix. Dye could be diluted to below the detection limits of the analytical instruments used. Alternatively, the dye might have been (or will be) discharged at one of the 14 small springs shown down-gradient along Bacon Creek [their discharge ranges from 0.05 to 0.2 cubic feet per second] or at other springs beyond the west edge of Plate I. The fact that dye was not detected at the Wabash Bridge (Site 28) could be a consequence of its dilution by Bacon Creek or non-discharge into it. Flow could also be partially through sand to Jones School Spring (Site 21) or even to Rio Springs (Sites 6 and 7), but, after six months, it was not yet detected in any spring. Each, some, and all of these explanations could be correct. If the test were to be repeated, a greater quantity of a different dye should be used.

The Route 357 Sinkhole test (Site H) was conducted simultaneously with that from the Christene Dye well (Site F). The rationale for this test was that the project was drawing to a close and that if Site F were to drain to Rio Springs, it would be desirable to test the other side of the inferred boundary between sites F and H. But there would not be time to do so. More dye should have been used but the results of the test from Site F makes repetition of the Route 357 Sinkhole test unnecessary. Site H most certainly flows to Johnson Spring (Site 2); the injection point at Site H is bracketed on each side by flow to this spring.

In summary of this section, and in retrospect, Site G was a known gamble and was conducted prudently. Site H was a technical and strategic decision and is now both academic, obvious, and unnecessary. These tests were not failures; there just was not sufficient time (or funding) in the project schedule to complete them by changing methodology or reinjection. On a more positive note, all other tracer tests, both those done as part of this project and those done before it, were conducted at optimal locations that allowed accurate approximation of the actual boundary of the Rio Springs groundwater basin.

CONCLUSIONS AND DISCUSSIONS

There are at least 16 important general conclusions that can be made relevant to goal attainment, predictability and accuracy of results, logistics, and interpretation of results of this project. Although some of these conclusions have also been made concerning other projects in karst terranes of Kentucky and elsewhere, they have been reinforced by the Rio Springs project and they are listed and discussed here. These conclusions are:

1. The position and configuration of the boundary of the Rio Springs groundwater basin, shown in Plate I, is based primarily on inferences from six successful tracer tests, interpretation of the configuration of the potentiometric surface, and deductions from field observations of the highest perennially flowing reaches of seepage-fed surface streams. To a far lesser extent, in part because we are aware of the fallacy of using negative evidence to prove anything, the boundary position is also influenced by the non-recovery of dye in one unsuccessful tracer test that is tentatively interpreted to have gone to somewhere other than to Rio Springs. [The rationale for this interpretation is: If some of the more than adequate amount of dye injected had reached Rio Springs, it would have been easily detected there.] We would prefer to have conducted additional tracer tests, especially within the basin, but budget and time constraints limited the number of tests that could be performed.

2. Delineation of groundwater basins in karst terranes can be done. It requires extensive field work, sometimes under difficult conditions. But groundwater tracing yields a greater quantity of highly reliable data

concerning the flow direction, velocity, destination, and sometimes routing of groundwater and pollutants in karst terranes than any other technique for investigation.

3. Delineation of the Rio Springs groundwater basin was done empirically, by tracing. It could only have been done by tracing . No analytical model or computer model now available would have been capable of doing such delineation with similar accuracy.

4. The Rio Springs groundwater basin has an area of 4.9 $\pm$0.5 square miles. This area was determined by using a compensating polar planimeter to trace its boundary. This boundary is approximate and subjective, but usable for planning, protection, and emergency response. The $\pm$0.5 square mile error is estimated.

5. Although many groundwater basins in carbonate terranes have been properly delineated -- by tracer tests performed on each side of their inferred boundary (see, for example, Quinlan and Ray, 1989) -- and tracer tests have been routinely employed by state agencies and various consultants in the delineation of numerous wellhead and springhead protection areas, we believe the Rio Springs Basin is the first springhead protection area in the U.S. to have been delineated as such and to have a published map showing the inferred relations between the boundary, the path between dye-injection and dye-recovery points, and the potentiometric surface.

6. The general dip within the Rio Spring basin is west (at about 20 to 30 feet per mile); flow within it is generally south, along the strike, as shown in Plate I. Basins to the east of it flow up-dip or along the strike. Those to the west generally flow down-dip and then along the strike. Those to the north generally flow northwest to west, along the strike.

7. The distribution of data points makes it likely that the boundary of much of the Rio Springs groundwater basin north of the 600-foot potentiometric contour could be shifted east or west by up to 1,000 feet. Nevertheless, we have attained a reasonably accurate representation of the probable

boundary and general flow within the Rio Springs basin. If this map were to be used for evaluating potential threats to water quality in the basin by a facility proposed within a mile beyond the boundary north of the 600-foot potentiometric contour, site-specific additional tracing would have to be done.

8. The inferred divide between groundwater draining south to the Green River and groundwater draining north and west to Bacon Creek, a tributary of the Nolin River, is locally more than two miles north of the surface water (topographic) divide between the two streams. This subsurface piracy of surface drainage is dramatically shown in the western area of Plate I where three traces that went to the south were injected significantly north of the surface-water divide, well within the surface-watershed of Bacon Creek. Although the topographic map shows blueline streams draining northwest from the topographic divide, these are actually intermittent waterways utilized only during storm events. The Green River, because of the relatively steeper gradient to it, is capturing groundwater from the flanks of Bacon Creek. [Unpublished tracing results by Quinlan and Ray show this relationship even more dramatically in the contiguous extensive area west of Plate I.] Rio Springs includes drainage from beyond the northern surface-water divide of its basin. This fact is extremely relevant to spill-response and protection of water quality.

9. The basin boundary is shown by smooth curvilinear lines. In actuality, the boundary could be irregular, even interdigitate, and it could temporarily shift in response to storms and seasonal changes in static water levels. The northern boundary of the Rio Springs groundwater basin was inferred to be nominally midway between the topographic divide (shown as a line of dots in Plate I) and the imaginary line formed by linking the highest perennially flowing segment of the easternmost five small steams (shown as arrow heads) draining to Bacon Creek. These flowing segments are fed by groundwater. Therefore, barring perching, the groundwater divide must be southeast of them. No attempt was made to locate additional highest perennially flowing stream segments west of State Highway 357.

10. Previous studies have shown that topographic maps, both in Kentucky and generally, show less than five percent of relevant springs and actual sink-points of sinking streams. Similar observations were made during this study. The topographic maps and geological maps are an essential guide for planning field work, but interpretation of them is not a substitute for field work. Field work is required for locating karst features and must be done. The field work necessary for design of a rigorous tracing plan can require use of 20 to 50 percent of a project budget. Aerial photographs are rarely useful in field work for the design of a tracer test. Most of the project-relevant karst features are too small to be recognized in photos. Alternatively, in humid climates, they are obscured by vegetation.

11. There are not enough accessible wells in the area of Plate I to accurately map the potentiometric surface. The surface shown is subjective but consistent with a prudent, skeptical interpretation of all available groundwater elevations (at springs, perennial streams, and wells) and tracing data.

12. In a karst terrane similar to the one studied, it is necessary to extend the field work at least three miles beyond the estimated boundary of the basin being studied. This is because delineation of a groundwater basin must entail partial delineation of each of the basins adjacent to it -- in fulfillment of the maxim that "A boundary is not a boundary until and unless it has been tested by traces on each side of its alleged position." Data for interpretation of the potentiometric surface of an area similar to that shown in Plate I, if it is to be reliably contoured, must also be acquired from the area at least a mile (and preferably at least two miles) beyond the map edges.

13. Dry weather significantly slowed completion of the project because of the rarity of wet weather flow; many potential sites for dye injection had no water draining into them -- except after major storms. These problems were solved by scheduling tracing during the rainy season, when flow velocities are faster, test duration is shorter and, consequently, analytical

and labor costs are less. Where water was not naturally entering the proposed injection point, alternative sources were used: siphoning by hose from a pond, injecting tap water via a garden hose from two homes on Green River Valley Water District line, and employing a 1,500-gallon tank-truck.

14. A potentiometric map, if based on an adequate amount of data (preferably about 2 wells per square mile in areas similar to the one described herein; only 0.73 wells per square mile could be measured in the area of Plate I north of the Green River), and where there are not extensive perching beds within an aquifer, is an extremely useful guide to the design of a tracer test. Nevertheless, as tracing results are acquired, the draft potentiometric map needs to be repeatedly revised in order to be consistent with tracing data. Tracing data are real; all potentiometric maps are inferential and subjective.

15. The approximate normalized base flow (NBF) of the 4.9-square-mile Rio Springs basin is 0.90 cubic feet per second per square mile (cfsm). In contrast, the approximate NBF of six other groundwater basins in the Mammoth Cave area south of Green River ranges from 0.15 to 0.20 cfsm, with a mean of 0.17. These six basins range in size from 8.8 to 190 square miles but there is no significant correlation between the area of these basins and their NBF. The NBF of what has been called conduit-flow (low-storage) karst aquifers ranges from about 0.01 to 0.2; the NBF of diffuse-flow (high-storage) karst aquifers ranges from about 0.2 to 0.4 (White, 1975). [The continuum between what have been called conduit-flow and diffuse-flow aquifers is reflected in the continuity of NBF values from 0.01 to 0.4.]* For granular aquifers, the NBF is commonly 0.5 or

*The terms *conduit flow* and *diffuse flow* have been used in at least four different senses since 1971, to refer to idealized end-members of continua describing types of discharge, recharge, flow, and storage. The consequent ambiguity of these concepts, and the ambiguity of their implied properties for the carbonate aquifers they purportedly describe, have caused much confusion, both to investigators and to regulators. Worthington et al. (1992) analyzed data in the world literature and concluded that the traditional criterion for distinguishing between types of recharge and types of flow within aquifers in temperate, climate, hardness (or its directly related surrogate, specific conductivity), was invalid. Hardness and conductivity of aquifer discharge are, instead, a measure of percentage of recharge from sinking streams. Worthington et al. (1992), followed by more. Why, then, is the NBF of the Rio Springs basin almost six times higher than the regional average? We believe this higher ratio is a consequence of differences in storage and yield of the aquifers. The five basins south of the Green River (Echo River, Pike Spring, Turnhole Spring, Lower Blue Hole, Graham Springs, and Bear Wallow) have low storage, respond rapidly to storms, and drain rapidly. The NBF of the Rio Springs basin is significantly higher for four reasons: A) Approximately 75 percent of its recharge area is sand-mantled (Miller, 1969), more than any other basin yet delineated in the Mammoth cave area; there is no sand and gravel mantle in the five basins that are compared to the Rio Springs basin. B) Open sinkholes are rare in the Rio Springs basin; they are common in the other five. C) There is relatively higher storage of available water in the thick sand and gravel that overlie the limestone. And D) the relatively non-flashy response of Rio Springs to storms occurs because there is attenuation of its rate of recharge and discharge by this sand and gravel above the limestone. They enhance the quality and yield of waters from Rio Springs, making them unique and perhaps the best in the Mammoth Cave area for use as a water supply.

16. We estimate that the inferred 4.9-square-mile area of the Rio Springs basin is accurate to within $\pm$ 10 percent. Even if its actual size were 30 percent larger than is shown (6.4 square miles), the normalized base flow would be 0.69 -- still significantly higher than the mean NBF of other basins in the Mammoth Cave area and supportive of the hypothesis that

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Quinlan et al. (1993) and Davies and Quinlan (1993), interpreted the velocities of 1,800+ tracer tests in carbonate aquifers of 25 countries and concluded that flow should be divided, on the basis of velocity, into two types, *rapid-flow* and *slow-flow*, with 0.001 meters/second being the separation value between them. This holds no matter whether flow is through conduits or through small, dissolutionally enlarged pores and joints. [This 0.001 m/s value is empirical, being based on the tracer-test velocities, rather than arbitrary.] For all these reasons, Daves and Quinlan (1993) recommended that the terms *conduit flow* and *diffuse flow* be abandoned, except to non-generically distinguish between flow within conduits and flow within pores and minimally enlarged joints. In support of the rapid-flow/slow-flow paradigm Davies (1992), Davies and Quinlan (1993), show that neither long-term, almost daily measurements of temperature variation of springs, nor similar measurements of their conductivity, can be explained by invoking conduit flow or diffuse flow (in any of the aforementioned sense of these terms). The variations can only be explained by invoking mixed proportions of rapid flow and slow flow. The bottom line: One cannot use the concepts of conduit flow or diffuse flow to validly justify decisions about springhead or wellhead protection area boundaries or groundwater monitoring strategy.

the hydrologic responses of the Rio Springs basin are damped by the effects of the thick sands that blanket most of its recharge area.

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APPENDIX A

KENTUCKY GROUNDWATER TRACING FORMS

TRACER INJECTION SITE

DRAFT

#J-

1. Name of Dye Trace (Site Location): Ash Farm Trace - Charles Ash Sinkhole
2. Date of Injection: March (Month) / 3 (Day) / 1993 (Year) Time: 10:45 (x) a.m. ( ) p.m.
3. Owner of Injection Site: Charles Ash Farm Phone: ( ) N/A
4. Quadrangle/County: Hammonville Quad, KY / Hart County
5. Elevation: 780 (x) map ( ) measured ( ) unknown
6. Latitude: 37° 22' 05" N Longitude: 85° 45' 27" W
7. Description of Injection Site:
   - ( ) sinking stream ( ) losing stream ( ) karst window (x) sinkhole
   - ( ) cave ( ) water well ( ) injection well ( ) monitoring well
   - ( ) lagoon ( ) septic system other

   Remarks
8. Formation Receiving Tracer Injection: Stc, Genevieve Limestone
9. Flow Conditions: ( ) low (X) moderate ( ) high
10. Field Conditions (precipitation, runoff, etc): runoff occurring into sinkhole

    used water from nearby pond to flush dye into sinkhole
11. Rate of Flow: 2-3 ( ) cfs (x) gpm ( ) l/s ( ) cms ( ) measured (x) estimated
    - ( ) permanent injection site ( ) intermittent
    - ( ) multiple sites possible
12. Induced Flow? ( ) no (x) yes 30-50 gal (Pre-injection) / 200 gallons (Post-injection) 120 (Elapsed Time) minutes
13. Tracing Agent:

	Color Index	% Active Ingredient	Amount
(x) Sodium Fluorescein	Acid Yellow 73	80 percent	7 pound
( ) Rhodamine WT			
( ) Optical Brightener			
( ) Direct Yellow 96			
Other			

14. Reason for Investigation: Rio Springs Wellhead delineation Project
15. Principal Investigator: Geary Schindel
16. Agency or Organization: ECKENFELDER INC.

    227 French Landing Drive (Address) Nashville (City) TN (State) 37228 (Zip)

    (615) 255-2288 (Phone) ( ) (FAX #)
17. Field Personnel: Joe Ray - Geary Schindel

IDENTIFY INJECTION SITE ON PHOTOCOPY OF TOPOGRAPHIC MAP

RECORD OF DYE TRACE

DRAFT

#R-

Project Rio Springs Wellhead Delineation Project Injection Date 03 / 03 / 93 (Month / Day / Year)

Name of Dye Trace (injection site) Charles Ash Sinkhole Tracer Fluorescein

Principal Investigator Geary Schindel Field Personnel Joe Ray - Tray Lyons

Precipitation before & during trace

ID	Location of Dye Detectors	Background	3-1	3-12	3-19	3-26	4-2	4-10			
	Duration										
1	Boiling Springs Conflu.		–	–	–	–	–	–			
2	Johnson Spring		B	–	–	–	–	–			
3	Cottrell Spring		–	–	–	–	–	–			
4	Log Spring		–	–	–	–	–	–			
5	Buckner Spring		–	–	–	–	–	–			
6	Rio Springs Conflu.		–	–	–	–	–	–			
7	Rio Springs East		–	–	–	–	–	–			
8	Rio Springs Creek		–	–	–	–	–	–			
9	Scotty Spring		–	–	–	–	–	–			
10	Lanes Mill Spring		–	–	–	–	–	–			
11	Bridge Spring		–	–	–	–	–	–			
12	Knox Creek Spring		–	–	–	–	–	–			
13	Handy Culvert Spring		–	–	–	–	–	–			
14	Powder Mill Trout Conf.		–	–	–	–	–	–			
15	Powder Mill So:: Spring		–	–	–	–	–	–			
16	Bailey Falls Spring		–	–	–	–	–	–			
17	Mystery Springs Conf.		–	–	–	–	–	–			
18	Rumble Spring		–	–	–	–	–	–			
19	Aetna Furnace at Bdg.		–	–	–	–	–	–			
20	Branch Fork at Bridge		–	++	+	+	+	+			
21	Jones School Spring		–	+++	++	++	+	+			
22	Jones School Creek		–	–	–	–	–	–			

Legend:

–	Negative Results	B	Perceptible Background (slight)
+	Positive	B+	Significant Background (problematic)
++	Very Positive	NR	Not Recovered (high water, stolen receptor, etc)
+++	Extremely Positive	L	Receptor lost
/	Receptor Not Changed	G	New or Extra Receptor Installed

Remarks: Brach Fork is downstream of Jones School Spring

Interpretation: Dye detected at Jones School Spring

DRAFT

RECORD OF DYE TRACE

#R-

Project Rio Springs Wellhead Delineation Project Injection Date 03 / 03 / 93 (Month / Day / Year)

Name of Dye Trace (injection site) Charles Ash Sinkhole Tracer Fluorescein

Principal Investigator Geary Schindel Field Personnel Joe Ray - Tray Lyons

Precipitation before & during trace

ID	Location of Dye Detectors	Back-ground	3-1	3-12	3-19	3-26	4-2	4-10			
	Duration										
23	Tampa Branch		–	–	–	–	–	–			
24	Martis Branch		–	–	–	–	–	–			
25	Gaddie Cemetery Creek		–	–	–	–	–	–			
26	Honey Run Creek		–	–	–	–	–	–			
27	Warren East Creek		–	–	–	–	–	–			
28	Bacon Ck./Wabash Bdg.		–	–	–	–	–	–			
29	Honey Run at Bridge		NM	NM	NM	NM	NM	NM			
30	Martis Branch @ Beaver Dam		NM	NM	NM	NM	NM	NM			
31	Tampa Branch East		NM	NM	NM	NM	NM	NM			
32	Tampa Branch South		NM	NM	NM	NM	NM	NM			
33	Tampa Branch at Bridge		NM	NM	NM	NM	NM	NM			

Legend:

- – Negative Results
- + Positive
- ++ Very Positive
- +++ Extremely Positive
- / Receptor Not Changed
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- L Receptor lost
- G New or Extra Receptor Installed

Remarks NM Not Monitored

Interpretation

TRACER RECOVERY SITE(S)

DRAFT

AKGWA#__________ #C-__________

1. Name of Recovery Site: Jones School Spring
2. Owner: Unknown
3. Quadrangle/County: Magnolia / Hart
4. Elevation: 600' (✓) map ( ) measured ______
5. Latitude: 37 23' 31"N Longitude: 85° 43' 38"W
6. Site Description: (✓) spring ( ) cave ( ) stream ( ) karst window ( ) water well ( ) monitoring well other______
7. Discharge at Baseflow: 2.0 CFS (Unit) (✓) est. ( ) measured
8. Background Status: ___Fluor ___Rhod ___OB ___DY ___other
9. Dye Detected: (✓) Fluor ( ) Rhod ( ) OB ( ) DY other______
10. Method of Detection: (✓) charcoal/cotton ( ) grab sample ( ) auto sampler ( ) on-site fluorometer ( ) visual other______
11. Method of Analysis: ( ) visible in elutant (✓) spectrophotometer (✓) fluorometer other______
12. Date of Detection: March / 12 / 1993 (Month / Day / Year)
13. Initial Dye Breakthrough: NA ( ) a.m. ( ) p.m.
14. Duration of Dye Curve: NA
15. Principal Investigator: Schindel
16. Field Personnel: Ray-Lyons-Schindel

AKGWA#__________ #C-__________

1. Name of Recovery Site:______
2. Owner:______
3. Quadrangle/County:______/______
4. Elevation:______ ( ) map ( ) measured ______
5. Latitude:______ Longitude:______
6. Site Description: ( ) spring ( ) cave ( ) stream ( ) karst window ( ) water well ( ) monitoring well other______
7. Discharge at Baseflow:______ ______ (Unit) ( ) est. ( ) measured
8. Background Status: ___Fluor ___Rhod ___OB ___DY ___other
9. Dye Detected: ( ) Fluor ( ) Rhod ( ) OB ( ) DY other______
10. Method of Detection: ( ) charcoal/cotton ( ) grab sample ( ) auto sampler ( ) on-site fluorometer ( ) visual other______
11. Method of Analysis: ( ) visible in elutant ( ) spectrophotometer ( ) fluorometer other______
12. Date of Detection:______/______/______ (Month / Day / Year)
13. Initial Dye Breakthrough:______ ( ) a.m. ( ) p.m.
14. Duration of Dye Curve:______
15. Principal Investigator:______
16. Field Personnel:______

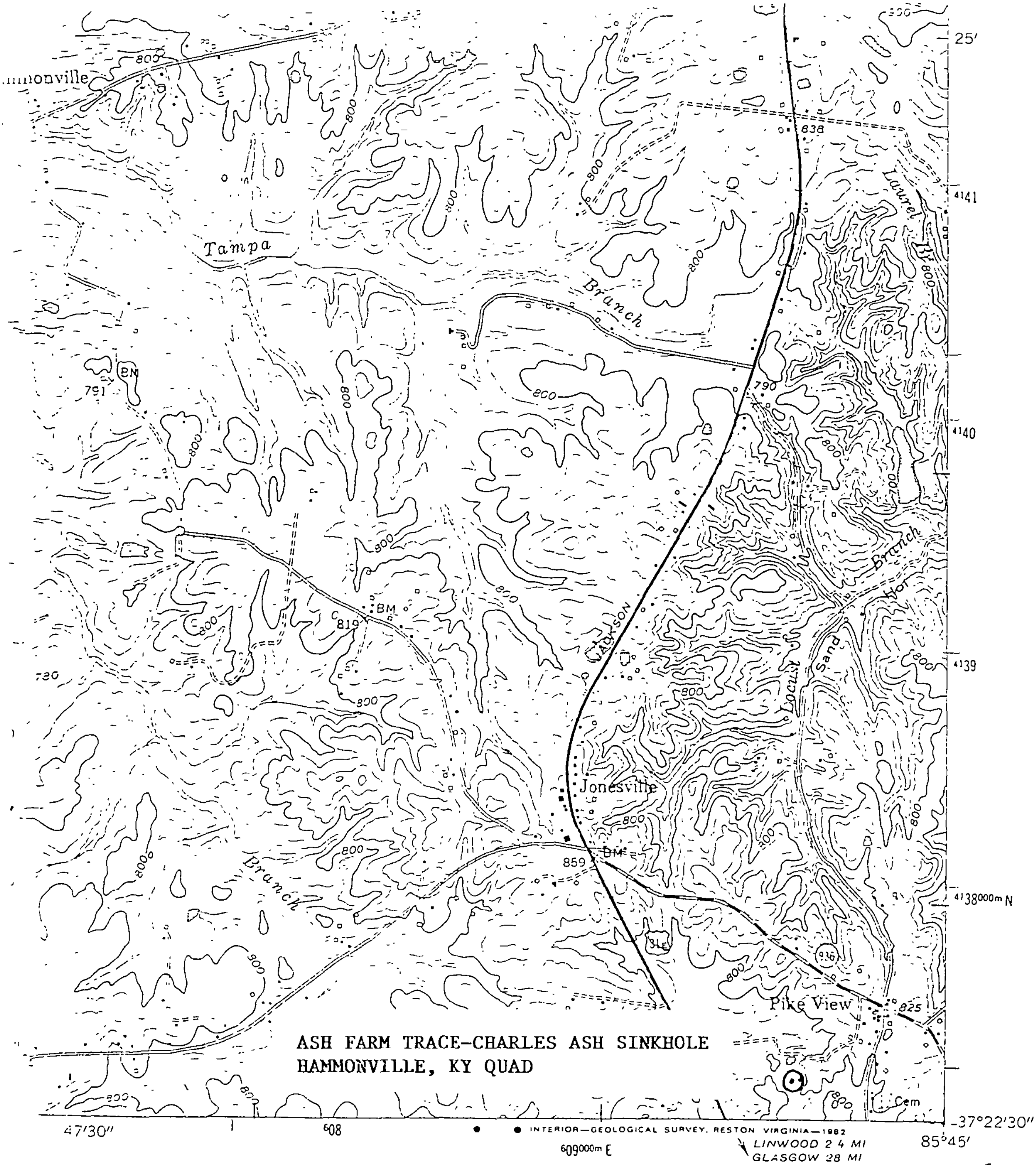
AKGWA#__________ #C-__________

1. Name of Recovery Site:______
2. Owner:______
3. Quadrangle/County:______/______
4. Elevation:______ ( ) map ( ) measured ______
5. Latitude:______ Longitude:______
6. Site Description: ( ) spring ( ) cave ( ) stream ( ) karst window ( ) water well ( ) monitoring well other______
7. Discharge at Baseflow:______ ______ (Unit) ( ) est. ( ) measured
8. Background Status: ___Fluor ___Rhod ___OB ___DY ___other
9. Dye Detected: ( ) Fluor ( ) Rhod ( ) OB ( ) DY other______
10. Method of Detection: ( ) charcoal/cotton ( ) grab sample ( ) auto sampler ( ) on-site fluorometer ( ) visual other______
11. Method of Analysis: ( ) visible in elutant ( ) spectrophotometer ( ) fluorometer other______
12. Date of Detection:______/______/______ (Month / Day / Year)
13. Initial Dye Breakthrough:______ ( ) a.m. ( ) p.m.
14. Duration of Dye Curve:______
15. Principal Investigator:______
16. Field Personnel:______

AKGWA#__________ #C-__________

1. Name of Recovery Site:______
2. Owner:______
3. Quadrangle/County:______/______
4. Elevation:______ ( ) map ( ) measured ______
5. Latitude:______ Longitude:______
6. Site Description: ( ) spring ( ) cave ( ) stream ( ) karst window ( ) water well ( ) monitoring well other______
7. Discharge at Baseflow:______ ______ (Unit) ( ) est. ( ) measured
8. Background Status: ___Fluor ___Rhod ___OB ___DY ___other
9. Dye Detected: ( ) Fluor ( ) Rhod ( ) OB ( ) DY other______
10. Method of Detection: ( ) charcoal/cotton ( ) grab sample ( ) auto sampler ( ) on-site fluorometer ( ) visual other______
11. Method of Analysis: ( ) visible in elutant ( ) spectrophotometer ( ) fluorometer other______
12. Date of Detection:______/______/______ (Month / Day / Year)
13. Initial Dye Breakthrough:______ ( ) a.m. ( ) p.m
14. Duration of Dye Curve:______
15. Principal Investigator:______
16. Field Personnel:______

IDENTIFY RECOVERY SITE(S) ON PHOTOCOPY OF TOPOGRAPHIC MAP



(HUDGINS)
3858 I SW

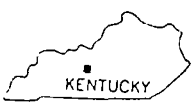
1 MILE

ROAD CLASSIFICATION

Heavy-duty — Light-duty

Medium duty — Unimproved dirt

U S Route — State Route



QUADRANGLE LOCATION

HAMMONVILLE, KY.

NE/4 MUNFORDVILLE 15′ QUADRANGLE

N 3722 5—W 8545/7 5

1954

PHOTOREVISED 1982

DMA 3858 IV NE-SERIES V853

TRACER INJECTION SITE

DRAFT

#J-________

1. Name of Dye Trace (Site Location): Glen Lilly Road Spring

2. Date of Injection: March / 3 / 1993 (Month / Day / Year) Time: 1:10 ( ) a.m. (X) p.m.

3. Owner of Injection Site: Royce Noe Phone: (502) 528-5730

4. Quadrangle/County: CANMER / Hart County

5. Elevation: 750 feet (X) map ( ) measured ________ ( ) unknown

6. Latitude: 37° 20' 12" N Longitude: 85° 46' 39" W

7. Description of Injection Site:

   (X) sinking stream ( ) losing stream ( ) karst window ( ) sinkhole
   ( ) cave ( ) water well ( ) injection well ( ) monitoring well
   ( ) lagoon ( ) septic system other ________

   Remarks ________

8. Formation Receiving Tracer Injection: Ste. Genevieve Limestone

9. Flow Conditions: ( ) low (X) moderate ( ) high ________

10. Field Conditions (precipitation, runoff, etc): water flows from small spring beneath shelf of rock and sinks at base of small sinkhole.

11. Rate of Flow: 5-7 ( ) cfs (XX) gpm ( ) l/s ( ) cms ( ) measured ( ) estimated

    ( ) permanent injection site ( ) intermittent
    ( ) multiple sites possible ________

12. Induced Flow? (XX) no ( ) yes ____ / ____ (Pre-injection / Post-injection) ____ minutes (Elapsed Time)

13. Tracing Agent:

Tracing Agent	Color Index	% Active Ingredient	Amount
( ) Sodium Fluorescein			
(X) Rhodamine WT	Acid Red 388	20 percent	2 pounds
( ) Optical Brightener			
( ) Direct Yellow 96			
Other ________			

14. Reason for Investigation: Rio Springs Wellhead Delineation Project

15. Principal Investigator: Geary Schindel

16. Agency or Organization: ECKENFELDER INC.

    227 French Landing Drive (Address) Nashville (City) TN (State) 37228 (Zip)

    (615) 255-2370 (Phone) ( ) ________ (FAX #)

17. Field Personnel: Joe Ray - Geary Schindel

IDENTIFY INJECTION SITE ON PHOTOCOPY OF TOPOGRAPHIC MAP

DRAFT

RECORD OF DYE TRACE

#R-

Project Rio Springs Wellhead Delineation Project Injection Date 03 / 03 / 93 (Month / Day / Year)

Name of Dye Trace (injection site) Glen Lilly Road Spring Tracer Rhodamine WT

Principal Investigator Geary Schindel Field Personnel Joe Ray - Tray Lyons

Precipitation before & during trace

ID	Location of Dye Detectors	Back-ground	Results								
	Date		3-12	3-19	3-26	4-2	4-10		3	3/1/93	
	Duration								background		
1	Boiling Springs Conflu.		—	—	—	—	—		—		
2	Johnson Spring		—	—	—	—	—		—		
3	Cottrell Spring		—	—	—	—	—		—		
4	Log Spring		—	—	—	—	—		—		
5	Buckner Spring		+++	++	+	+	+		—		
6	Rio Springs Conflu.		—	—	—	—	—		—		
7	Rio Springs East		—	—	—	—	—		—		
8	Rio Springs Creek		—	—	—	—	—		—		
9	Scotty Spring		—	—	—	—	—		—		
10	Lanes Mill Spring		—	—	—	—	—		—		
11	Bridge Spring		—	—	—	—	—		—		
12	Knox Creek Spring		—	—	—	—	—		—		
13	Handy Culvert Spring		—	—	—	—	—		—		
14	Powder Mill Trout Conf.		—	—	—	—	—		—		
15	Powder Mill So. Spring		—	—	—	—	—		—		
16	Bailey Falls Spring		—	—	—	—	—		—		
17	Mystery Springs Conf.		—	—	—	—	—		—		
18	Rumble Spring		—	—	—	—	—		—		
19	Aetna Furnace at Bdg.		—	—	—	—	—		—		
20	Branch Fork at Bridge		—	—	—	—	—		—		
21	Jones School Spring		—	—	—	—	—		—		
22	Jones School Creek		—	—	—	—	—		—		

Legend:

—	Negative Results	B	Perceptible Background (slight)
+	Positive	B +	Significant Background (problematic)
+ +	Very Positive	NR	Not Recovered (high water, stolen receptor, etc)
+ + +	Extremely Positive	L	Receptor lost
/	Receptor Not Changed	G	New or Extra Receptor Installed

Remarks

Interpretation Dye Detected at Buckner Spring Cave

DRAFT

RECORD OF DYE TRACE

#R-

Project Rio Springs Wellhead Delineation Project Injection Date 03 / 03 / 93 (Month / Day / Year)

Name of Dye Trace (injection site) Glen Lilly Road Spring Tracer Rhodamine WT

Principal Investigator Geary Schindel Field Personnel Joe Ray - Tray Lyons

Precipitation before & during trace

ID	Location of Dye Detectors	Back-ground	3-12	3-19	3-26	4-2	4-10		Background		
	Duration										
23	Tampa Branch		–	–	–	–	–		–		
24	Martis Branch		–	–	–	–	–		–		
25	Gaddie Cemetery Creek		–	–	–	–	–		–		
26	Honey Run Creek		–	–	–	–	–		–		
27	Warren East Creek		–	–	–	–	–		–		
28	Bacon Ck./Wabash Bdg.		–	–	–	–	–		–		
29	Honey Run at Bridge		NM	→	→	→	→				
30	Martis Branch @ Beaver	Dam	NM	→	→	→	→				
31	Tampa Branch East		NM	→	→	→	→				
32	Tampa Branch South		NM	→	→	→	→				
33	Tampa Branch at Bridge		NM	→	→	→	→				

Legend:

- – Negative Results
- \+ Positive
- \+ + Very Positive
- \+ + + Extremely Positive
- / Receptor Not Changed
- B Perceptible Background (slight)
- B + Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- L Receptor lost
- G New or Extra Receptor Installed

Remarks NM Not Monitored

Interpretation

DRAFT

TRACER RECOVERY SITE(S)

AKGWA#______________________ #C-__________

1. Name of Recovery Site: Buckner Spring Cave
2. Owner: Unknown
3. Quadrangle/County: Canmer / Hart
4. Elevation: 540 (✓) map ( ) measured ______
5. Latitude: 37° 18' 47" N Longitude: 85° 48' 14" W
6. Site Description: (✓) spring (✓) cave ( ) stream ( ) karst window ( ) water well ( ) monitoring well other______
7. Discharge at Baseflow: .75-1 CFS (Unit) (✓) est ( ) measured
8. Background Status: ___Fluor ___Rhod ___OB ___DY ___ other
9. Dye Detected: ( ) Fluor (X) Rhod ( ) OB ( ) DY other______
10. Method of Detection: (X) charcoal/cotton ( ) grab sample ( ) auto sampler ( ) on-site fluorometer ( ) visual other______
11. Method of Analysis: ( ) visible in elutant (✓) spectrophotometer (✓) fluorometer other______
12. Date of Detection: March / 12 / 1993 (Month / Day / Year)
13. Initial Dye Breakthrough: N/A ( ) a.m. ( ) p.m.
14. Duration of Dye Curve: N/A
15. Principal Investigator: Schindel
16. Field Personnel: Lyons-Schindel-Ray

AKGWA#______________________ #C-__________

1. Name of Recovery Site:______
2. Owner:______
3. Quadrangle/County:______ /______
4. Elevation:______ ( ) map ( ) measured ______
5. Latitude:______ Longitude:______
6. Site Description: ( ) spring ( ) cave ( ) stream ( ) karst window ( ) water well ( ) monitoring well other______
7. Discharge at Baseflow:______ ______ (Unit) ( ) est. ( ) measured
8. Background Status: ___Fluor ___Rhod ___OB ___DY ___ other
9. Dye Detected: ( ) Fluor ( ) Rhod ( ) OB ( ) DY other______
10. Method of Detection: ( ) charcoal/cotton ( ) grab sample ( ) auto sampler ( ) on-site fluorometer ( ) visual other______
11. Method of Analysis: ( ) visible in elutant ( ) spectrophotometer ( ) fluorometer other______
12. Date of Detection:______ /______ /______ (Month / Day / Year)
13. Initial Dye Breakthrough:______ ( ) a.m. ( ) p.m.
14. Duration of Dye Curve:______
15. Principal Investigator:______
16. Field Personnel:______

AKGWA#______________________ #C-__________

1. Name of Recovery Site:______
2. Owner:______
3. Quadrangle/County:______ /______
4. Elevation:______ ( ) map ( ) measured ______
5. Latitude:______ Longitude:______
6. Site Description: ( ) spring ( ) cave ( ) stream ( ) karst window ( ) water well ( ) monitoring well other______
7. Discharge at Baseflow:______ ______ (Unit) ( ) est. ( ) measured
8. Background Status: ___Fluor ___Rhod ___OB ___DY ___ other
9. Dye Detected: ( ) Fluor ( ) Rhod ( ) OB ( ) DY other______
10. Method of Detection: ( ) charcoal/cotton ( ) grab sample ( ) auto sampler ( ) on-site fluorometer ( ) visual other______
11. Method of Analysis: ( ) visible in elutant ( ) spectrophotometer ( ) fluorometer other______
12. Date of Detection:______ /______ /______ (Month / Day / Year)
13. Initial Dye Breakthrough:______ ( ) a.m. ( ) p.m.
14. Duration of Dye Curve:______
15. Principal Investigator:______
16. Field Personnel:______

AKGWA#______________________ #C-__________

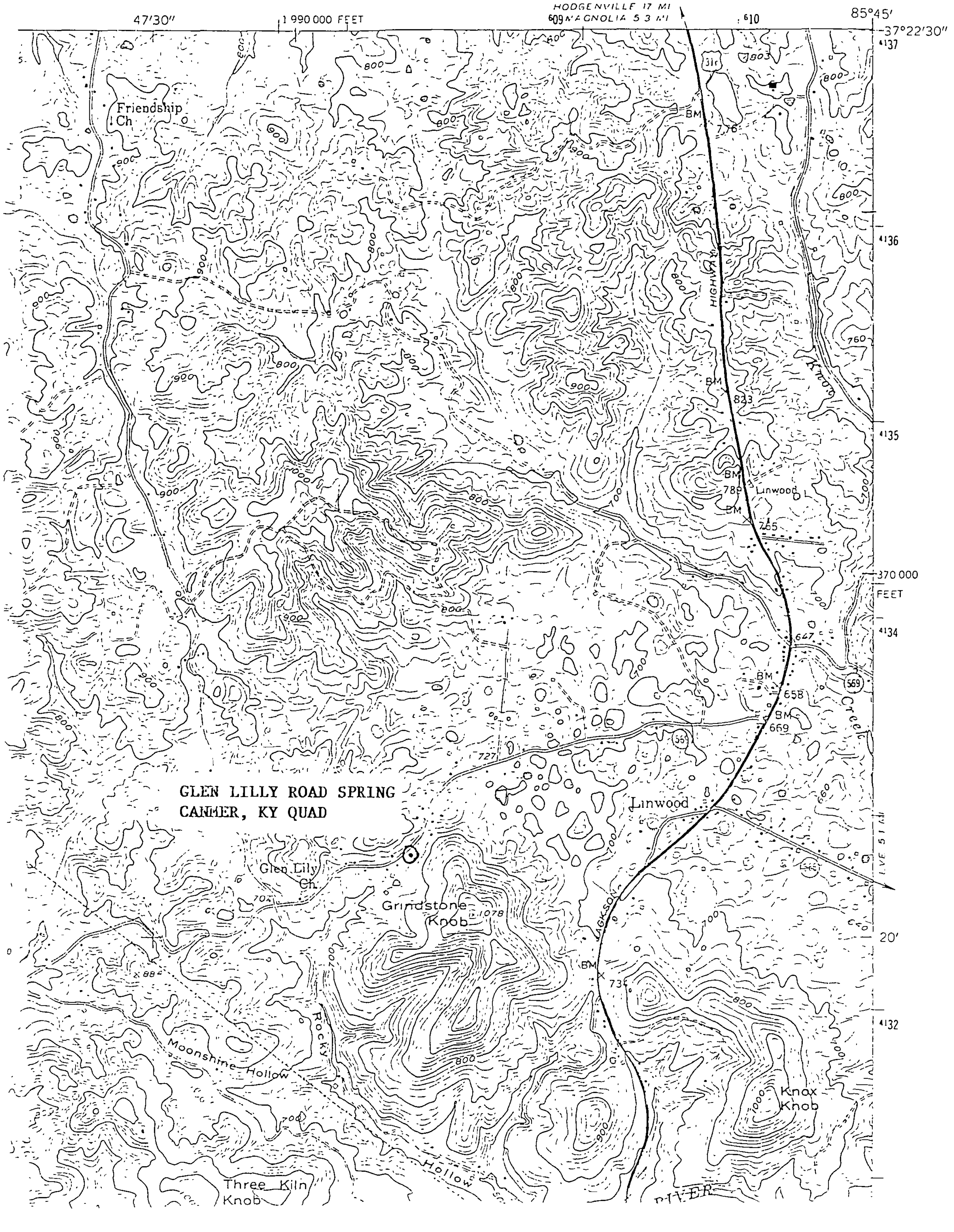
1. Name of Recovery Site ______
2. Owner:______
3. Quadrangle/County:______ /______
4. Elevation:______ ( ) map ( ) measured ______
5. Latitude:______ Longitude:______
6. Site Description: ( ) spring ( ) cave ( ) stream ( ) karst window ( ) water well ( ) monitoring well other______
7. Discharge at Baseflow:______ ______ (Unit) ( ) est ( ) measured
8. Background Status: ___Fluor ___Rhod ___OB ___DY ___ other
9. Dye Detected: ( ) Fluor ( ) Rhod ( ) OB ( ) DY other______
10. Method of Detection: ( ) charcoal/cotton ( ) grab sample ( ) auto sampler ( ) on-site fluorometer ( ) visual other______
11. Method of Analysis. ( ) visible in elutant ( ) spectrophotometer ( ) fluorometer other______
12. Date of Detection:______ /______ /______ (Month / Day / Year)
13. Initial Dye Breakthrough.______ ( ) a.m. ( ) p.m.
14. Duration of Dye Curve:______
15. Principal Investigator:______
16. Field Personnel:______

IDENTIFY RECOVERY SITE(S) ON PHOTOCOPY OF TOPOGRAPHIC MAP

CANMER QUADRANGLE
KENTUCKY—HART CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)
SE/4 MUNFORDVILLE 15' QUADRANGLE

RD

3858 I NW (MAGNOLI



TRACER INJECTION SITE

DRAFT

#J-

1. Name of Dye Trace (Site Location): Glen Lilly Sink
2. Date of Injection: March (Month) / 25 (Day) / 1993 (Year) Time: 12:40 ( ) a.m. (XX) p.m.
3. Owner of Injection Site: N/A Phone: ( )
4. Quadrangle/County: Canmer Quad., KY / Hart Co.
5. Elevation: 890 (XX) map ( ) measured ( ) unknown
6. Latitude: 37° 21' 06" N Longitude: 85° 47' 12" W
7. Description of Injection Site:
   - (XX) sinking stream ( ) losing stream ( ) karst window ( ) sinkhole
   - ( ) cave ( ) water well ( ) injection well ( ) monitoring well
   - ( ) lagoon ( ) septic system other

   Remarks
8. Formation Receiving Tracer Injection: Girkin Formation
9. Flow Conditions: ( ) low (XX) moderate ( ) high
10. Field Conditions (precipitation, runoff, etc): Dye injected after rain on previous day - hard rain on evening after trace.
11. Rate of Flow: 10-15 ( ) cfs (XX) gpm ( ) l/s ( ) cms ( ) measured (XX) estimated
    - ( ) permanent injection site (XX) intermittent
    - ( ) multiple sites possible
12. Induced Flow? (X) no ( ) yes ______ / ______ (Pre-injection / Post-injection) ______ minutes (Elapsed Time)
13. Tracing Agent:

	Color Index	% Active Ingredient	Amount
( ) Sodium Fluorescein			
( ) Rhodamine WT			
( ) Optical Brightener			
(XX) Direct Yellow 96		unknown	6.5 lbs
Other	Solophenyl (formerly	marketed as Diphenyl	Brilliant Flavine TGF)

14. Reason for Investigation: Rio Springs Wellhead delineation Project
15. Principal Investigator: Geary Schindel
16. Agency or Organization: ECKENFELDER INC.

    227 French Landing Drive (Address) Nashville (City) TN (State) 37228 (Zip)

    (615) 255-2288 (Phone) ( ) (FAX #)
17. Field Personnel: Joe Ray - Geary Schindel

IDENTIFY INJECTION SITE ON PHOTOCOPY OF TOPOGRAPHIC MAP

DRAFT

RECORD OF DYE TRACE

#R-

Project Rio Springs Wellhead Delineation Project Injection Date 03 / 25 / 93 (Month / Day / Year)

Name of Dye Trace (injection site) Glen Lilly Sinkhole Tracer Solophenyl DY96

Principal Investigator Geary Schindel Field Personnel Joe Ray - Tray Lyons

Precipitation before & during trace

ID	Location of Dye Detectors	Back-ground	3/19	3-26	4-2	4-10	4-17				
		Duration									
			Results								
1	Boiling Springs Conflu.		–	–	–	–	–				
2	Johnson Spring		–	–	–	–	–				
3	Cottrell Spring		–	–	–	–	–				
4	Log Spring		–	–	–	–	–				
5	Buckner Spring		–	–	–	–	–				
6	Rio Springs Conflu.		–	–	+++	+	+				
7	Rio Springs East		–	–	++	+	–				
8	Rio Springs Creek		–	–	–	–	–				
9	Scotty Spring		–	–	–	–	–				
10	Lanes Mill Spring		–	–	–	–	–				
11	Bridge Spring		–	–	–	–	–				
12	Knox Creek Spring		–	–	–	–	–				
13	Handy Culvert Spring		–	–	–	–	–				
14	Powder Mill Trout Conf.		–	–	–	–	–				
15	Powder Mill So. Spring		–	–	–	–	–				
16	Bailey Falls Spring		–	–	–	–	–				
17	Mystery Springs Conf.		–	–	–	–	–				
18	Rumble Spring		–	–	–	–	–				
19	Aetna Furnace at Bdg.		–	–	–	–	–				
20	Branch Fork at Bridge		–	–	–	–	–				
21	Jones School Spring		–	–	–	–	–				
22	Jones School Creek		–	–	–	–	–				

Legend:

- – Negative Results
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- / Receptor Not Changed
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- L Receptor lost
- G New or Extra Receptor Installed

Remarks Rio Springs East is overflow for Rio Springs. Rio Springs East is intermittent discharge spring

Interpretation Dye detected at Rio Springs & ~~B~~ Rio Springs East

DRAFT

RECORD OF DYE TRACE

#R- ____________________

Project: Rio Springs Wellhead Delineation Project Injection Date: 03 / 25 / 93 (Month / Day / Year)

Name of Dye Trace (injection site): Glen Lilly Sinkhole Tracer: Solophenyl DY 96

Principal Investigator: Geary Schindel Field Personnel: Joe Ray - Tray Lyons

Precipitation before & during trace: ____________________

		Date	3-19	3-26	4-2	4-10	4-17				
		Duration									
ID	Location of Dye Detectors	Back-ground	Results								
23	Tampa Branch		—	—	—	—	—				
24	Martis Branch		—	—	—	—	—				
25	Gaddie Cemetery Creek		—	—	—	—	—				
26	Honey Run Creek		—	—	—	—	—				
27	Warren East Creek		—	—	—	—	—				
28	Bacon Ck./Wabash Bdg.		—	—	—	—	—				
29	Honey Run at Bridge										
30	Martis Branch @ Beaver Dam										
31	Tampa Branch East										
32	Tampa Branch South										
33	Tampa Branch at Bridge										

Legend:

—	Negative Results	B	Perceptible Background (slight)
+	Positive	B +	Significant Background (problematic)
+ +	Very Positive	NR	Not Recovered (high water, stolen receptor, etc)
+ + +	Extremely Positive	L	Receptor lost
/	Receptor Not Changed	G	New or Extra Receptor Installed

Remarks ____________________

Interpretation ____________________

DRAFT

TRACER RECOVERY SITE(S)

AKGWA# ______ #C- ______

1. Name of Recovery Site: Rio Springs
2. Owner: Green River Valley Water District
3. Quadrangle/County: Canmer / Hart
4. Elevation: 540 (X) map ( ) measured ______
5. Latitude: 37 19 27'N Longitude: 85 46' 18"W
6. Site Description:
   (✓) spring ( ) cave ( ) stream ( ) karst window
   ( ) water well ( ) monitoring well other ______
7. Discharge at Baseflow: 5-6 CFS (Unit) (✓) est. ( ) measured
8. Background Status: ___ Fluor ___ Rhod ___ OB ___ DY ___ other
9. Dye Detected: ( ) Fluor ( ) Rhod ( ) OB (X) DY
   other ______
10. Method of Detection:
    (X) charcoal/cotton ( ) grab sample ( ) auto sampler
    ( ) on-site fluorometer ( ) visual other ______
11. Method of Analysis:
    ( ) visible in elutant ( ) spectrophotometer ( ) fluorometer
    other UV Light
12. Date of Detection: April / 2 / 1993 (Month / Day / Year)
13. Initial Dye Breakthrough: N/A ( ) a.m. ( ) p.m.
14. Duration of Dye Curve: N/A
15. Principal Investigator: Schindel
16. Field Personnel: Lyons - Ray - Schindel

AKGWA# ______ #C- ______

1. Name of Recovery Site: ______
2. Owner: ______
3. Quadrangle/County: ______ / ______
4. Elevation: ______ ( ) map ( ) measured ______
5. Latitude: ______ Longitude: ______
6. Site Description:
   ( ) spring ( ) cave ( ) stream ( ) karst window
   ( ) water well ( ) monitoring well other ______
7. Discharge at Baseflow: ______ ______ (Unit) ( ) est. ( ) measured
8. Background Status: ___ Fluor ___ Rhod ___ OB ___ DY ___ other
9. Dye Detected: ( ) Fluor ( ) Rhod ( ) OB ( ) DY
   other ______
10. Method of Detection:
    ( ) charcoal/cotton ( ) grab sample ( ) auto sampler
    ( ) on-site fluorometer ( ) visual other ______
11. Method of Analysis:
    ( ) visible in elutant ( ) spectrophotometer ( ) fluorometer
    other ______
12. Date of Detection: ______ / ______ / ______ (Month / Day / Year)
13. Initial Dye Breakthrough: ______ ( ) a.m. ( ) p.m.
14. Duration of Dye Curve: ______
15. Principal Investigator: ______
16. Field Personnel: ______

AKGWA# ______ #C- ______

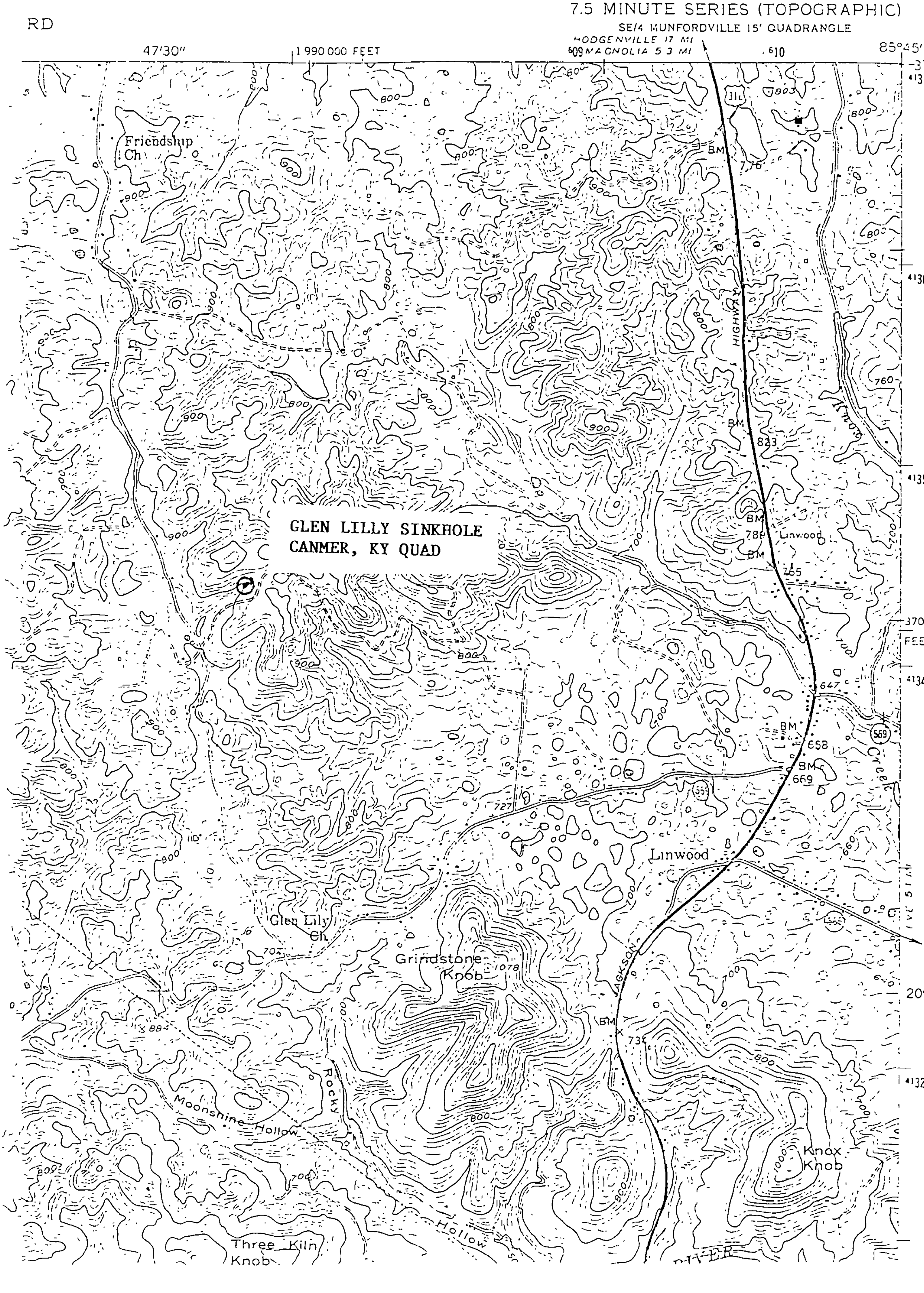
1. Name of Recovery Site: ______
2. Owner: ______
3. Quadrangle/County: ______ / ______
4. Elevation: ______ ( ) map ( ) measured ______
5. Latitude: ______ Longitude: ______
6. Site Description:
   ( ) spring ( ) cave ( ) stream ( ) karst window
   ( ) water well ( ) monitoring well other ______
7. Discharge at Baseflow: ______ ______ (Unit) ( ) est. ( ) measured
8. Background Status: ___ Fluor ___ Rhod ___ OB ___ DY ___ other
9. Dye Detected: ( ) Fluor ( ) Rhod ( ) OB ( ) DY
   other ______
10. Method of Detection:
    ( ) charcoal/cotton ( ) grab sample ( ) auto sampler
    ( ) on-site fluorometer ( ) visual other ______
11. Method of Analysis:
    ( ) visible in elutant ( ) spectrophotometer ( ) fluorometer
    other ______
12. Date of Detection: ______ / ______ / ______ (Month / Day / Year)
13. Initial Dye Breakthrough: ______ ( ) a.m. ( ) p.m.
14. Duration of Dye Curve: ______
15. Principal Investigator: ______
16. Field Personnel: ______

AKGWA# ______ #C- ______

1. Name of Recovery Site: ______
2. Owner: ______
3. Quadrangle/County: ______ / ______
4. Elevation: ______ ( ) map ( ) measured ______
5. Latitude: ______ Longitude: ______
6. Site Description:
   ( ) spring ( ) cave ( ) stream ( ) karst window
   ( ) water well ( ) monitoring well other ______
7. Discharge at Baseflow: ______ ______ (Unit) ( ) est. ( ) measured
8. Background Status: ___ Fluor ___ Rhod ___ OB ___ DY ___ other
9. Dye Detected: ( ) Fluor ( ) Rhod ( ) OB ( ) DY
   other ______
10. Method of Detection:
    ( ) charcoal/cotton ( ) grab sample ( ) auto sampler
    ( ) on-site fluorometer ( ) visual other ______
11. Method of Analysis:
    ( ) visible in elutant ( ) spectrophotometer ( ) fluorometer
    other ______
12. Date of Detection: ______ / ______ / ______ (Month / Day / Year)
13. Initial Dye Breakthrough: ______ ( ) a.m. ( ) p.m.
14. Duration of Dye Curve: ______
15. Principal Investigator: ______
16. Field Personnel: ______

IDENTIFY RECOVERY SITE(S) ON PHOTOCOPY OF TOPOGRAPHIC MAP

CANMER QUADRANGLE
KENTUCKY—HART CO
7.5 MINUTE SERIES (TOPOGRAPHIC)
SE/4 MUNFORDVILLE 15' QUADRANGLE



TRACER INJECTION SITE

DRAFT

#J-

1. Name of Dye Trace (Site Location): Bail Road Ditch

2. Date of Injection: March (Month) / 25 (Day) / 1993 (Year) Time: 2:20 ( ) a.m. (x) p.m.

3. Owner of Injection Site: County Highway Dept. Right of Way Phone: ( )

4. Quadrangle/County: Hudgins Quad., KY / Hart County

5. Elevation: 730 ft (x) map ( ) measured ( ) unknown

6. Latitude: 37° 21' 44" N Longitude: 85° 44' 27" W

7. Description of Injection Site:
   - (x) sinking stream ( ) losing stream ( ) karst window ( ) sinkhole
   - ( ) cave ( ) water well ( ) injection well ( ) monitoring well
   - ( ) lagoon ( ) septic system other

   Remarks Placed dye in water sinking in ditch along N side of road

8. Formation Receiving Tracer Injection: Ste. Genevieve Limestone

9. Flow Conditions: ( ) low (x) moderate ( ) high

10. Field Conditions (precipitation, runoff, etc): Dye injected after rain on previous day - hard rain after trace

11. Rate of Flow: 1 to 3 ( ) cfs (x) gpm ( ) l/s ( ) cms ( ) measured (x) estimated
    - ( ) permanent injection site (x) intermittent
    - ( ) multiple sites possible

12. Induced Flow? (x) no ( ) yes ____ (Pre-injection) / ____ (Post-injection) ____ (Elapsed Time) minutes

13. Tracing Agent:

	Color Index	% Active Ingredient	Amount
( ) Sodium Fluorescein			
( ) Rhodamine WT			
(x) Optical Brightener	Fluorescent Brightening Agent 28		40.5 pounds
( ) Direct Yellow 96			
Other			

14. Reason for Investigation: Rio Springs Wellhead Delineation Project

15. Principal Investigator: Geary Schindel

16. Agency or Organization: ECKENFELDER INC.

    227 French Landing Drive (Address) Nashville (City) TN (State) 37228 (Zip)

    (615) 255-228 (Phone) (615) 256-8332 (FAX #)

17. Field Personnel: Joe Ray - Geary Schindel

IDENTIFY INJECTION SITE ON PHOTOCOPY OF TOPOGRAPHIC MAP

DRAFT

RECORD OF DYE TRACE

#R-

Project Rio Springs Wellhead Delineation Project Injection Date 03 / 25 / 93 (Month / Day / Year)

Name of Dye Trace (injection site) Bail Road Ditch Sinkhole Tracer Optical Brightener

Principal Investigator Geary Schindel Field Personnel Joe Ray - Tray Lyons

Precipitation before & during trace

ID	Location of Dye Detectors	Background	3-19	3-26	4-2	4-10	4-17				
	Duration										
			Results								
1	Boiling Springs Conflu.		—	—	—	—	—				
2	Johnson Spring		—	—	—	—	—				
3	Cottrell Spring		—	—	—	—	—				
4	Log Spring		—	—	—	—	—				
5	Buckner Spring		—	—	—	—	—				
6	Rio Springs Conflu.		—	—	—	—	—				
7	Rio Springs East		—	—	—	—	—				
8	Rio Springs Creek		—	—	—	—	—				
9	Scotty Spring		—	—	—	—	—				
10	Lanes Mill Spring		—	—	—	—	—				
11	Bridge Spring		—	—	—	—	—				
12	Knox Creek Spring		—	—	—	—	—				
13	Handy Culvert Spring		—	—	—	—	—				
14	Powder Mill Trout Conf.		—	—	—	—	—				
15	Powder Mill So. Spring		—	—	—	—	—				
16	Bailey Falls Spring		—	—	++	+	—				
17	Mystery Springs Conf.		—	—	—	—	—				
18	Rumble Spring		—	—	—	—	—				
19	Aetna Furnace at Bdg.		B	—	—	—	—				
20	Branch Fork at Bridge		—	—	—	—	—				
21	Jones School Spring		—	—	—	—	—				
22	Jones School Creek		—	—	—	—	—				

Legend:

—	Negative Results	B	Perceptible Background (slight)
+	Positive	B +	Significant Background (problematic)
+ +	Very Positive	NR	Not Recovered (high water, stolen receptor, etc)
+ + +	Extremely Positive	L	Receptor lost
/	Receptor Not Changed	G	New or Extra Receptor Installed

Remarks

Interpretation Dye detected at Bailey Falls Spring

DRAFT

RECORD OF DYE TRACE

#R- ____________

Project Rio Springs Wellhead Delineation Project Injection Date 03 / 25 / 93 (Month / Day / Year)

Name of Dye Trace (injection site) Bail Road Ditch Sinkhole Tracer Optical Brightener

Principal Investigator Geary Schindel Field Personnel Joe Ray - Tray Lyons

Precipitation before & during trace ____________

ID	Location of Dye Detectors	Background	Results								
		Date	3-19	3-26	4-2	4-10	4-17				
		Duration									
23	Tampa Branch		—	—	—	—	—				
24	Martis Branch		—	—	—	—	—				
25	Gaddie Cemetery Creek		—	—	—	—	—				
26	Honey Run Creek		—	—	—	—	—				
27	Warren East Creek		—	—	—	—	—				
28	Bacon Ck./Wabash Bdg.		—	—	—	—	—				
29	Honey Run at Bridge										
30	Martis Branch @ Beaver Dam										
31	Tampa Branch East										
32	Tampa Branch South										
33	Tampa Branch at Bridge										

Legend:

—	Negative Results	B	Perceptible Background (slight)
+	Positive	B +	Significant Background (problematic)
+ +	Very Positive	NR	Not Recovered (high water, stolen receptor, etc)
+ + +	Extremely Positive	L	Receptor lost
/	Receptor Not Changed	G	New or Extra Receptor Installed

Remarks ____________

Interpretation ____________

DRAFT

TRACER RECOVERY SITE(S)

AKGWA# ______ #C- ______

1. Name of Recovery Site: Bailey Falls Spring
2. Owner: Unknown
3. Quadrangle/County: Hudgins / Hart
4. Elevation: 560 (✓) map ( ) measured ______
5. Latitude: 37°21'11"N Longitude: 85°42'41"W
6. Site Description:
   (✓) spring ( ) cave ( ) stream ( ) karst window
   ( ) water well ( ) monitoring well other ______
7. Discharge at Baseflow: 1-2 CFS (Unit) (✓) est. ( ) measured
8. Background Status: ___ Fluor ___ Rhod ___ OB ___ DY ___ other
9. Dye Detected: ( ) Fluor ( ) Rhod (✓) OB ( ) DY
   other ______
10. Method of Detection:
    (✓) charcoal/cotton ( ) grab sample ( ) auto sampler
    ( ) on-site fluorometer ( ) visual other ______
11. Method of Analysis:
    ( ) visible in elutant ( ) spectrophotometer ( ) fluorometer
    other UV Light
12. Date of Detection: April / 2 / 1993 (Month / Day / Year)
13. Initial Dye Breakthrough: N/A ( ) a.m. ( ) p.m.
14. Duration of Dye Curve: N/A
15. Principal Investigator: Schindel
16. Field Personnel: Lyons - Ray - Schindel

AKGWA# ______ #C- ______

1. Name of Recovery Site: ______
2. Owner: ______
3. Quadrangle/County: ______ / ______
4. Elevation: ______ ( ) map ( ) measured ______
5. Latitude: ______ Longitude: ______
6. Site Description:
   ( ) spring ( ) cave ( ) stream ( ) karst window
   ( ) water well ( ) monitoring well other ______
7. Discharge at Baseflow: ______ ______ (Unit) ( ) est. ( ) measured
8. Background Status: ___ Fluor ___ Rhod ___ OB ___ DY ___ other
9. Dye Detected: ( ) Fluor ( ) Rhod ( ) OB ( ) DY
   other ______
10. Method of Detection:
    ( ) charcoal/cotton ( ) grab sample ( ) auto sampler
    ( ) on-site fluorometer ( ) visual other ______
11. Method of Analysis:
    ( ) visible in elutant ( ) spectrophotometer ( ) fluorometer
    other ______
12. Date of Detection: ______ / ______ / ______ (Month / Day / Year)
13. Initial Dye Breakthrough: ______ ( ) a.m. ( ) p.m.
14. Duration of Dye Curve: ______
15. Principal Investigator: ______
16. Field Personnel: ______

AKGWA# ______ #C- ______

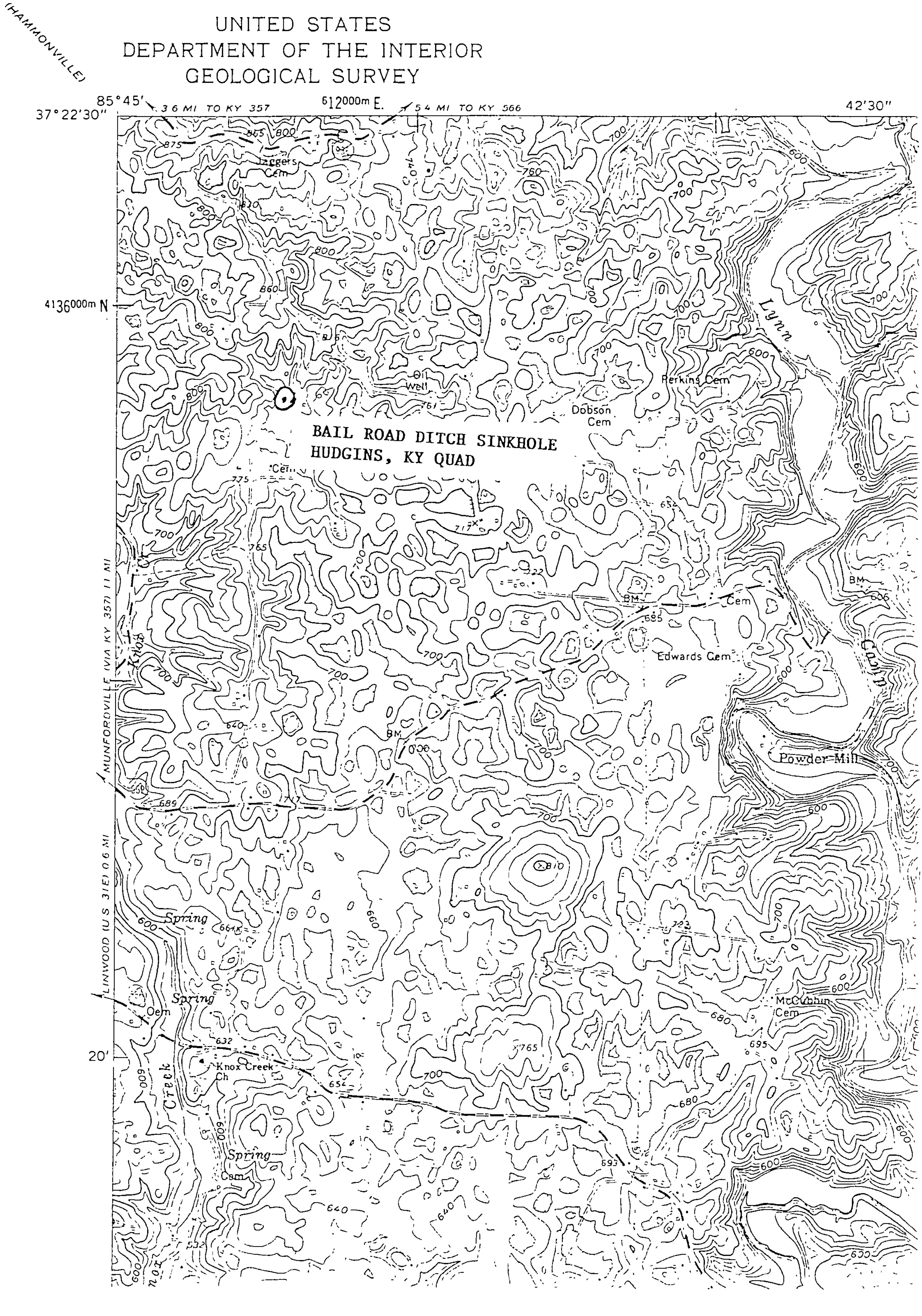
1. Name of Recovery Site: ______
2. Owner: ______
3. Quadrangle/County: ______ / ______
4. Elevation: ______ ( ) map ( ) measured ______
5. Latitude: ______ Longitude: ______
6. Site Description:
   ( ) spring ( ) cave ( ) stream ( ) karst window
   ( ) water well ( ) monitoring well other ______
7. Discharge at Baseflow: ______ ______ (Unit) ( ) est. ( ) measured
8. Background Status: ___ Fluor ___ Rhod ___ OB ___ DY ___ other
9. Dye Detected: ( ) Fluor ( ) Rhod ( ) OB ( ) DY
   other ______
10. Method of Detection:
    ( ) charcoal/cotton ( ) grab sample ( ) auto sampler
    ( ) on-site fluorometer ( ) visual other ______
11. Method of Analysis:
    ( ) visible in elutant ( ) spectrophotometer ( ) fluorometer
    other ______
12. Date of Detection: ______ / ______ / ______ (Month / Day / Year)
13. Initial Dye Breakthrough: ______ ( ) a.m. ( ) p.m.
14. Duration of Dye Curve: ______
15. Principal Investigator: ______
16. Field Personnel: ______

AKGWA# ______ #C- ______

1. Name of Recovery Site: ______
2. Owner: ______
3. Quadrangle/County: ______ / ______
4. Elevation: ______ ( ) map ( ) measured ______
5. Latitude: ______ Longitude: ______
6. Site Description:
   ( ) spring ( ) cave ( ) stream ( ) karst window
   ( ) water well ( ) monitoring well other ______
7. Discharge at Baseflow: ______ ______ (Unit) ( ) est. ( ) measured
8. Background Status: ___ Fluor ___ Rhod ___ OB ___ DY ___ other
9. Dye Detected: ( ) Fluor ( ) Rhod ( ) OB ( ) DY
   other ______
10. Method of Detection:
    ( ) charcoal/cotton ( ) grab sample ( ) auto sampler
    ( ) on-site fluorometer ( ) visual other ______
11. Method of Analysis:
    ( ) visible in elutant ( ) spectrophotometer ( ) fluorometer
    other ______
12. Date of Detection: ______ / ______ / ______ (Month / Day / Year)
13. Initial Dye Breakthrough: ______ ( ) a.m. ( ) p.m.
14. Duration of Dye Curve: ______
15. Principal Investigator: ______
16. Field Personnel: ______

IDENTIFY RECOVERY SITE(S) ON PHOTOCOPY OF TOPOGRAPHIC MAP

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY



TRACER INJECTION SITE

DRAFT

#J- ____________________

1. Name of Dye Trace (Site Location): Knox Creek Sink
2. Date of Injection: April (Month) / 24 (Day) / 1993 (Year) Time: 1:15 ( ) a.m. (x) p.m.
3. Owner of Injection Site: County Highway Right of Way Phone: ( )
4. Quadrangle/County: Canmer Quad., KY / Hart County
5. Elevation: 690 feet (x) map ( ) measured ____ ( ) unknown
6. Latitude: 37° 21' 36" N Longitude: 85° 45' 11" W
7. Description of Injection Site:
   - ( ) sinking stream ( ) losing stream ( ) karst window (x) sinkhole
   - ( ) cave ( ) water well ( ) injection well ( ) monitoring well
   - ( ) lagoon ( ) septic system other ____

   Remarks Water injected into sinkhole in bed of Knox Creek
8. Formation Receiving Tracer Injection: Ste. Genevieve - St. Louis Limestone
9. Flow Conditions: (x) low ( ) moderate ( ) high
10. Field Conditions (precipitation, runoff, etc): Cool, clear day - No precipitation
11. Rate of Flow: 100 ( ) cfs (x) gpm ( ) l/s ( ) cms ( ) measured (x) estimated
    - ( ) permanent injection site ( ) intermittent
    - ( ) multiple sites possible
12. Induced Flow? ( ) no (x) yes 1,000 gal (Pre-injection) / 500 (Post-injection) 15 (Elapsed Time) minutes
13. Tracing Agent:

	Color Index	% Active Ingredient	Amount
( ) Sodium Fluorescein			
( ) Rhodamine WT			
(x) Optical Brightener	Fluorescent Brightening Agent 28		15 pounds
( ) Direct Yellow 96			
Other			

14. Reason for Investigation: Rio Springs Wellhead Delineation Project
15. Principal Investigator: Geary Schindel
16. Agency or Organization: ECKENFELDER INC.

    227 French Landing Drive (Address) Nashville (City) TN (State) 37228 (Zip)

    (615) 256-2288 (Phone) (615) 256-8332 (FAX #)
17. Field Personnel: Joe Ray - Geary Schindel

IDENTIFY INJECTION SITE ON PHOTOCOPY OF TOPOGRAPHIC MAP

DRAFT

RECORD OF DYE TRACE

#R-

Project Rio Springs Wellbead Delineation Project Injection Date 04 / 24 / 93 (Month / Day / Year)

Name of Dye Trace (injection site) *Knox Creek Sinkhole* Tracer *Optical Brightner*

Principal Investigator Geary Schindel Field Personnel Joe Ray - Tray Lyons

Precipitation before & during trace

ID	Location of Dye Detectors	Background	4-23	5-1	5-9	5-16	5-28	6-19	6-26	7/23	7/31
	Duration										
			Results								
1	Boiling Springs Conflu.		—	—	—	—	—	—	—	—	—
2	Johnson Spring		—	—	—	—	—	—	—	—	—
3	Cottrell Spring		—	—	—	—	—	—	—	—	—
4	Log Spring		—	—	—	—	—	—	—	—	—
5	Buckner Spring		—	—	—	—	—	—	—	—	—
6	Rio Springs Conflu.		—	—	—	—	—	—	—	—	—
7	Rio Springs East		—	—	—	—	—	—	—	—	—
8	Rio Springs Creek		—	—	—	—	—	—	—	—	—
9	Scotty Spring		—	—	—	—	—	—	—	—	—
10	Lanes Mill Spring		—	—	—	—	—	—	—	—	—
11	Bridge Spring		—	—	—	—	—	—	—	—	—
12	Knox Creek Spring		—	—	—	—	—	—	—	—	—
13	Handy Culvert Spring		—	—	—	—	—	—	—	—	—
14	Powder Mill Trout Conf.		—	—	—	—	—	—	—	—	—
15	Powder Mill So[illegible] Spring		—	—	—	—	—	—	—	—	—
16	Bailey Falls Spring		—	—	—	—	—	—	—	—	—
17	Mystery Springs Conf.		—	—	NM	NM	NM	NM	NM	NM	NM
18	Rumble Spring		—	—	NM	NM	NM	NM	NM	NM	NM
19	Aetna Furnace at Bdg.		—	—	NM	NM	NM	NM	NM	NM	NM
20	Branch Fork at Bridge		—	—	NM	NM	NM	NM	NM	NM	NM
21	Jones School Spring		—	—	—	—	—	—	—	—	—
22	Jones School Creek		—	—	—	—	—	—	—	—	—

Legend:

- — Negative Results
- \+ Positive
- \+ + Very Positive
- \+ + + Extremely Positive
- / Receptor Not Changed
- B Perceptible Background (slight)
- B + Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- L Receptor lost
- G New or Extra Receptor Installed

Remarks *Dye not detected. Additional optical Brightner was injected on June 16. and Fluorescein injected on July 16.*

Interpretation *See Report*

DRAFT

RECORD OF DYE TRACE

#R-

Project Rio Springs Wellhead Delineation Project Injection Date 04 / 24 / 93 (Month / Day / Year)

Name of Dye Trace (injection site) Knox Creek Tracer Optical Brightener

Principal Investigator Geary Schindel Field Personnel Joe Ray - Tray Lyons

Precipitation before & during trace

ID	Location of Dye Detectors	Background	4-23	5-1	5-9	5-16	5-22	6-19	6-26	7-23	7-31
	Duration										
23	Tampa Branch		—	—	NM	NM	NM	NM	NM	NM	NM
24	Martis Branch		—	—	NM	NM	NM	NM	NM	NM	NM
25	Gaddie Cemetery Creek		—	NM	NM	NM	NM	NM	NM	NM	NM
26	Honey Run Creek		—	NM	NM	NM	NM	NM	NM	NM	NM
27	Warren East Creek		—	—	—	—	—	—	—	—	—
28	Bacon Ck./Wabash Bdg.		—	—	—	—	—	—	—	—	—
29	Honey Run at Bridge		—	—	—	—	—	—	—	—	—
30	Martis Branch @ Beaver Dam		NM	—	—	—	—	—	—	—	—
31	Tampa Branch East		NM	—	—	—	—	—	—	—	—
32	Tampa Branch South		NM	—	—	—	—	—	—	—	—
33	Tampa Branch at Bridge		NM	—	—	—	—	—	—	—	—

Legend:

—	Negative Results	B	Perceptible Background (slight)
+	Positive	B +	Significant Background (problematic)
+ +	Very Positive	N R	Not Recovered (high water, stolen receptor, etc)
+ + +	Extremely Positive	L	Receptor lost
/	Receptor Not Changed	G	New or Extra Receptor Installed

Remarks NM Not monitored

Interpretation

TRACER INJECTION SITE

1. Name of Dye Trace (Site Location): Knox Creek Sink # ____ (Year – Trace # – Initials)

2. Date of Injection: March (Month) / 19 (Day) / 94 (Year) Time: 1:00 ( ) a.m. (x) p.m.

3. Owner of Injection Site: County Highway Right of Way Phone: ( ) ____

4. Quadrangle/County: Canmer Quad., Ky / ____

5. Elevation: 690 (x) map ( ) measured 6. Latitude: 37 21' 36" N Longitude: 87 45' 11" W

7. Description of Injection Site:

(x) sinking stream ( ) sinkhole ( ) water well ( ) injection well
( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
( ) lagoon ( ) cave stream ( ) other

Remarks: Sinkhole in dry stream bed of Knox Creek

8. Formation Receiving Tracer Injection: Ste. Genevieve – St. Louis Limestone

9. Flow Conditions: (x) low ( ) moderate ( ) high

10. Induced Flow? ( ) no (x) yes 1,500 (Pre-injection) / 1,500 (Post-injection) 39 (Elapsed Time) minutes

11. Tracing Agent: Amt 5 lbs (x) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 ( ) other ____

RECORD OF DYE TRACE

Principal Investigator: G. Schindel Field Personnel: G. Schindel, Joe Ray

Precipitation before & during trace: Heavy rain night after trace, Appro. 1.5 inches

ID	Location of Dye Receptors	Date	3/12	3/18	3/21											
		Duration														
		Background	Results													
6	Rio Springs		–	–	–											
10	Lanes Mill		–	–	+++											
11	Bridge Spring		–	–	–											
12	Knox Creek Spring		–	–	–											
13	Handy Culvert Spring		–	–	–											
14	Powder Mill Trout Sp.		–	–	–											
16	Baily Falls		–	–	–											
21	Jones School Sp		–	–	–											
22	Brushy Fork		–	–	–											
33	Tampa Branch at Bdg		–	–	–											
34	Mouth of Knox Creek		–	–	–											
35	Green River at Rio Sp		–	–	–											

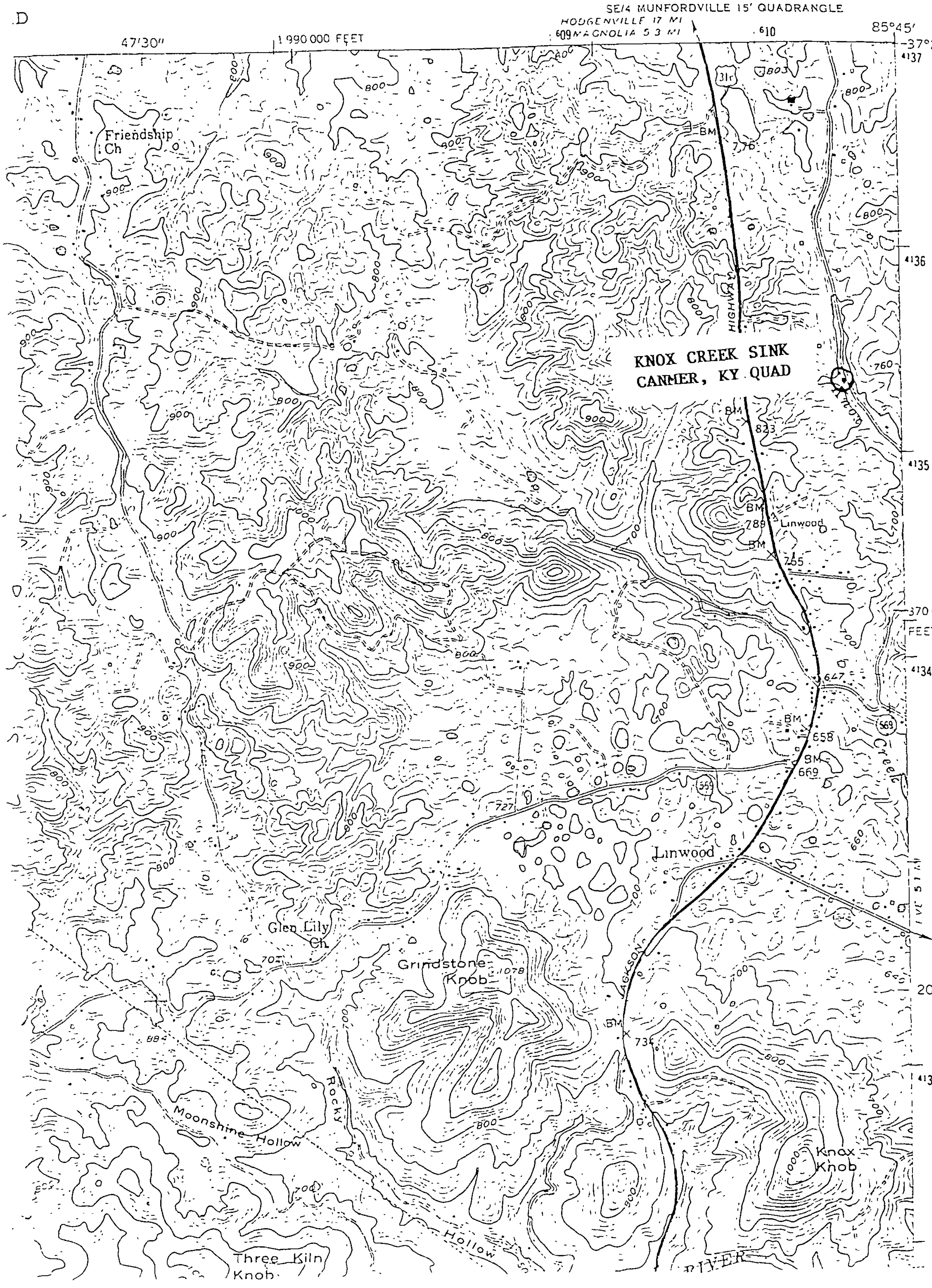
Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed

Remarks Interpretation: Dye was injected during low flow condition, recovered during high flow flow conditions.

Please identify injection and recovery sites on photocopy of topographic map.

CANMER QUADRANGLE
KENTUCKY—HART CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)
SE/4 MUNFORDVILLE 15' QUADRANGLE

3858 I NW (MAGNOLIA)



TRACER INJECTION SITE

DRAFT

#J-

1. Name of Dye Trace (Site Location): Christene Dye Well

2. Date of Injection: April (Month) / 24 (Day) / 1993 (Year) Time: 3:45 ( ) a.m. (XX) p.m.

3. Owner of Injection Site: Christene Dye Phone: ( )

4. Quadrangle/County: Canmer Quad., KY / Hart

5. Elevation: 830' (XX) map ( ) measured ( ) unknown

6. Latitude: 37° 21' 59" N Longitude: 85° 47' 43" W

7. Description of Injection Site:
   ( ) sinking stream ( ) losing stream ( ) karst window ( ) sinkhole
   ( ) cave (X) water well ( ) injection well ( ) monitoring well
   ( ) lagoon ( ) septic system other

   Remarks Abandoned Private Water Well

8. Formation Receiving Tracer Injection: Girken Formation/Ste. Genevieve Limestone

9. Flow Conditions: (X) low ( ) moderate ( ) high

10. Field Conditions (precipitation, runoff, etc): Cool clear day - no precipitation

11. Rate of Flow: 3 ( ) cfs (XX) gpm ( ) l/s ( ) cms (XX) measured ( ) estimated
    (XX) permanent injection site ( ) intermittent
    ( ) multiple sites possible

12. Induced Flow? ( ) no (X) yes 30 gallons (Pre-injection) / 300 gallons (Post-injection) 100 (Elapsed Time) minutes

13. Tracing Agent:

	Color Index	% Active Ingredient	Amount
(X) Sodium Fluorescein	Acid Yellow 73	80 percent	11 lbs
( ) Rhodamine WT			
( ) Optical Brightener			
( ) Direct Yellow 96			
Other			

14. Reason for Investigation: Rio Springs Wellhead Delineation Project

15. Principal Investigator: Geary Schindel

16. Agency or Organization: ECKENFELDER INC.

    227 French Landing Drive (Address) Nashville (City) TN (State) 37228 (Zip)

    (615) 255-2288 (Phone) ( ) (FAX #)

17. Field Personnel: Joe Ray - Geary Schindel

IDENTIFY INJECTION SITE ON PHOTOCOPY OF TOPOGRAPHIC MAP

DRAFT

RECORD OF DYE TRACE

#R- ______________________

Project Rio Springs Wellhead Delineation Project Injection Date 04 / 24 / 93
(Month / Day / Year)

Name of Dye Trace (injection site) Christene Dye Well Tracer Fluorescein

Principal Investigator Geary Schindel Field Personnel Joe Ray - Tray Lyons

Precipitation before & during trace ______________________

ID	Location of Dye Detectors	Background	4-23	5-1	5-9	5-16	5-22	6-19	6-26	7-23
	Duration									
			Results							
1	Boiling Springs Conflu.		—	—	—	—	—	—	—	—
2	Johnson Spring		—	—	+++	++	++	++	+1	—
3	Cottrell Spring		—	—	—	—	—	—	—	—
4	Log Spring		—	—	—	—	—	—	—	—
5	Buckner Spring		—	—	—	—	—	—	—	—
6	Rio Springs Conflu.		—	—	—	—	—	—	—	—
7	Rio Springs East		—	—	—	—	—	—	—	—
8	Rio Springs Creek		—	—	—	—	—	—	—	—
9	Scotty Spring		—	—	—	—	—	—	—	—
10	Lanes Mill Spring		—	—	—	—	—	—	—	—
11	Bridge Spring		—	—	—	—	—	—	—	—
12	Knox Creek Spring		—	—	—	—	—	—	—	—
13	Handy Culvert Spring		—	—	—	—	—	—	—	—
14	Powder Mill Trout Conf.		—	—	—	—	—	—	—	—
15	Powder Mill So[illegible] Spring		—	—	—	—	—	—	—	—
16	Bailey Falls Spring		—	—	—	—	—	—	—	—
17	Mystery Springs Conf.		—	—	NM →					
18	Rumble Spring		—	—	NM →					
19	Aetna Furnace at Bdg.		—	—	NM →					
20	Branch Fork at Bridge		—	—	NM →					
21	Jones School Spring		—	—	—	—	—	—	—	—
22	Jones School Creek		—	—	—	—	—	—	—	—

Legend:

- — Negative Results
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- / Receptor Not Changed
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- L Receptor lost
- G New or Extra Receptor Installed

Remarks NM = Not Monitored

Interpretation ______________________

DRAFT

RECORD OF DYE TRACE

#R-

Project Rio Springs Wellhead Delineation Project Injection Date 04 / 24 / 93 (Month / Day / Year)

Name of Dye Trace (injection site) Christene Dye Well Tracer Fluorescein

Principal Investigator Geary Schindel Field Personnel Joe Ray - Tray Lyons

Precipitation before & during trace

ID	Location of Dye Detectors	Back-ground	4-23	5-1	5-9	5-16	5-22	6-19	6-26	7-23
		Duration								
23	Tampa Branch		—	—	NM	→	→	→	→	→
24	Martis Branch		—	—	NM	→	→	→	→	→
25	Gaddie Cemetery Creek		—	NM	NM	→	→	→	→	→
26	Honey Run Creek		—	NM	NM	→	→	→	→	→
27	Warren East Creek		—	—	—	—	—	—	—	—
28	Bacon Ck./Wabash Bdg.		—	—	—	—	—	—	—	—
29	Honey Run at Bridge		—	—	—	—	—	—	—	—
30	Martis Branch @ Beaver Dam		—	—	—	—	—	—	—	—
31	Tampa Branch East		—	—	—	—	—	—	—	—
32	Tampa Branch South		—	—	—	—	—	—	—	—
33	Tampa Branch at Bridge		—	—	—	—	—	—	—	—

Legend:

- — Negative Results
- \+ Positive
- \+ + Very Positive
- \+ + + Extremely Positive
- / Receptor Not Changed
- B Perceptible Background (slight)
- B + Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- L Receptor lost
- G New or Extra Receptor Installed

Remarks

Interpretation Dye detected at Major Johnson Spring

TRACER RECOVERY SITE(S)

DRAFT

AKGWA# ______ #C- ______

1. Name of Recovery Site: Major Johnson Spring
2. Owner: City of Munfordville
3. Quadrangle/County: Canmer / Hart
4. Elevation: 500 (✓) map ( ) measured ______
5. Latitude: 37°30' 59"N Longitude: 85 50 54 W
6. Site Description:
   (✓) spring ( ) cave ( ) stream ( ) karst window
   ( ) water well ( ) monitoring well other ______
7. Discharge at Baseflow: 6-8 CFS (Unit) (✓) est. ( ) measured
8. Background Status: ___Fluor ___Rhod ___OB ___DY ___ other
9. Dye Detected: (✓) Fluor ( ) Rhod ( ) OB ( ) DY
   other ______
10. Method of Detection:
    (✓) charcoal/cotton ( ) grab sample ( ) auto sampler
    ( ) on-site fluorometer ( ) visual other ______
11. Method of Analysis:
    (✓) visible in elutant (✓) spectrophotometer (✓) fluorometer
    other ______
12. Date of Detection: May / 9 / 1993 (Month / Day / Year)
13. Initial Dye Breakthrough: NA ( ) a.m. ( ) p.m.
14. Duration of Dye Curve: NA
15. Principal Investigator: Schindel
16. Field Personnel: Lyons - Ray - Schindel

______

AKGWA# ______ #C- ______

1. Name of Recovery Site: ______
2. Owner: ______
3. Quadrangle/County: ______ / ______
4. Elevation: ______ ( ) map ( ) measured ______
5. Latitude: ______ Longitude: ______
6. Site Description:
   ( ) spring ( ) cave ( ) stream ( ) karst window
   ( ) water well ( ) monitoring well other ______
7. Discharge at Baseflow: ______ ______ (Unit) ( ) est. ( ) measured
8. Background Status: ___Fluor ___Rhod ___OB ___DY ___ other
9. Dye Detected: ( ) Fluor ( ) Rhod ( ) OB ( ) DY
   other ______
10. Method of Detection:
    ( ) charcoal/cotton ( ) grab sample ( ) auto sampler
    ( ) on-site fluorometer ( ) visual other ______
11. Method of Analysis:
    ( ) visible in elutant ( ) spectrophotometer ( ) fluorometer
    other ______
12. Date of Detection: ______ / ______ / ______ (Month / Day / Year)
13. Initial Dye Breakthrough: ______ ( ) a.m. ( ) p.m.
14. Duration of Dye Curve: ______
15. Principal Investigator: ______
16. Field Personnel: ______

______

AKGWA# ______ #C- ______

1. Name of Recovery Site: ______
2. Owner: ______
3. Quadrangle/County: ______ / ______
4. Elevation: ______ ( ) map ( ) measured ______
5. Latitude: ______ Longitude: ______
6. Site Description:
   ( ) spring ( ) cave ( ) stream ( ) karst window
   ( ) water well ( ) monitoring well other ______
7. Discharge at Baseflow: ______ ______ (Unit) ( ) est. ( ) measured
8. Background Status: ___Fluor ___Rhod ___OB ___DY ___ other
9. Dye Detected: ( ) Fluor ( ) Rhod ( ) OB ( ) DY
   other ______
10. Method of Detection:
    ( ) charcoal/cotton ( ) grab sample ( ) auto sampler
    ( ) on-site fluorometer ( ) visual other ______
11. Method of Analysis:
    ( ) visible in elutant ( ) spectrophotometer ( ) fluorometer
    other ______
12. Date of Detection: ______ / ______ / ______ (Month / Day / Year)
13. Initial Dye Breakthrough: ______ ( ) a.m. ( ) p.m.
14. Duration of Dye Curve: ______
15. Principal Investigator: ______
16. Field Personnel: ______

______

AKGWA# ______ #C- ______

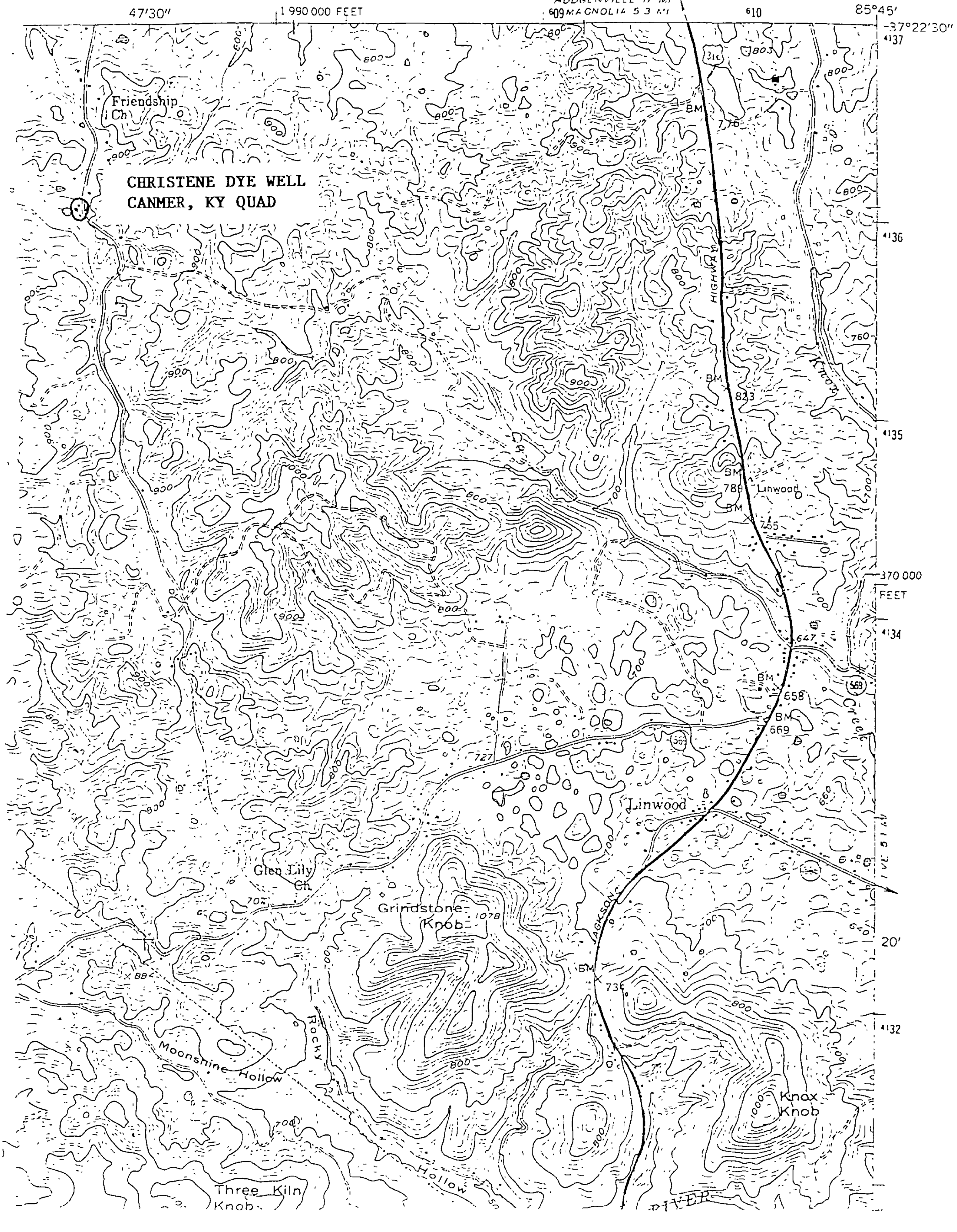
1. Name of Recovery Site: ______
2. Owner: ______
3. Quadrangle/County: ______ / ______
4. Elevation: ______ ( ) map ( ) measured ______
5. Latitude: ______ Longitude: ______
6. Site Description:
   ( ) spring ( ) cave ( ) stream ( ) karst window
   ( ) water well ( ) monitoring well other ______
7. Discharge at Baseflow: ______ ______ (Unit) ( ) est. ( ) measured
8. Background Status: ___Fluor ___Rhod ___OB ___DY ___ other
9. Dye Detected: ( ) Fluor ( ) Rhod ( ) OB ( ) DY
   other ______
10. Method of Detection:
    ( ) charcoal/cotton ( ) grab sample ( ) auto sampler
    ( ) on-site fluorometer ( ) visual other ______
11. Method of Analysis:
    ( ) visible in elutant ( ) spectrophotometer ( ) fluorometer
    other ______
12. Date of Detection: ______ / ______ / ______ (Month / Day / Year)
13. Initial Dye Breakthrough: ______ ( ) a.m. ( ) p.m.
14. Duration of Dye Curve: ______
15. Principal Investigator: ______
16. Field Personnel: ______

______

IDENTIFY RECOVERY SITE(S) ON PHOTOCOPY OF TOPOGRAPHIC MAP

CANMER QUADRANGLE
KENTUCKY—HART CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)
SE/4 MUNFORDVILLE 15' QUADRANGLE

3858 I NW (MAGNOLIA)



TRACER INJECTION SITE

DRAFT

#J-

1. Name of Dye Trace (Site Location): Walter's Well
2. Date of Injection: April (Month) / 24 (Day) / 1993 (Year) Time: 12:12 ( ) a.m. (x) p.m.
3. Owner of Injection Site: Ms. Walter Phone: ( )
4. Quadrangle/County: Hammonville, KY / Hart County
5. Elevation: 845 feet (x) map ( ) measured ( ) unknown
6. Latitude: 37° 23' 18" N Longitude: 85° 45' 25" W
7. Description of Injection Site:
   - ( ) sinking stream ( ) losing stream ( ) karst window ( ) sinkhole
   - ( ) cave (x) water well ( ) injection well ( ) monitoring well
   - ( ) lagoon ( ) septic system other

   Remarks Abandoned private water supply well - casing buried below ground
8. Formation Receiving Tracer Injection: Beaver Bend and Paoli Limestone - Slumped Sandstone
9. Flow Conditions: (x) low ( ) moderate ( ) high
10. Field Conditions (precipitation, runoff, etc): Cool, clear day - no precipitation - well buried behind house beneath concrete slab, approximately 2 to 3 feet below ground
11. Rate of Flow: ( ) cfs ( ) gpm ( ) l/s ( ) cms ( ) measured ( ) estimated
    - ( ) permanent injection site ( ) intermittent
    - ( ) multiple sites possible
12. Induced Flow? ( ) no (x) yes 75 gal (Pre-injection) / 440 gal (Post-injection) 140 (Elapsed Time) minutes
13. Tracing Agent:

	Color Index	% Active Ingredient	Amount
( ) Sodium Fluorescein			
(x) Rhodamine WT	Acid Red 388	20 percent	12 lbs
( ) Optical Brightener			
( ) Direct Yellow 96			
Other			

14. Reason for Investigation: Rio Springs Wellhead Delineation Project
15. Principal Investigator: Geary Schindel
16. Agency or Organization: ECKENFELDER INC.

    227 French Landing Drive (Address) Nashville (City) TN (State) 37228 (Zip)

    (615) 255-2288 (Phone) (615) 256-8332 (FAX #)
17. Field Personnel: Joe Ray - Geary Schindel

IDENTIFY INJECTION SITE ON PHOTOCOPY OF TOPOGRAPHIC MAP

DRAFT

RECORD OF DYE TRACE

#R- ____________

Project Rio Springs Wellhead Delineation Project Injection Date 04 / 24 / 93 (Month / Day / Year)

Name of Dye Trace (injection site) Walter Well Tracer Rhodamine WT

Principal Investigator Geary Schindel Field Personnel Joe Ray - Tray Lyons

Precipitation before & during trace ____________

ID	Location of Dye Detectors	Background	4-23	5-1	5-9	5-16	5-28	6-19	6-26	7-23	7/31
	Duration										
			Results								
1	Boiling Springs Conflu.		—	—	—	—	—	—	—	—	—
2	Johnson Spring		—	—	—	—	—	—	—	—	—
3	Cottrell Spring		—	—	—	—	—	—	—	—	—
4	Log Spring		—	—	—	—	—	—	—	—	—
5	Buckner Spring		—	—	—	—	—	—	—	—	—
6	Rio Springs Conflu.		—	—	—	—	—	—	—	—	—
7	Rio Springs East		—	—	—	—	—	—	—	—	—
8	Rio Springs Creek		—	—	—	—	—	—	—	—	—
9	Scotty Spring		—	—	—	—	—	—	—	—	—
10	Lanes Mill Spring		—	—	—	—	—	—	—	—	—
11	Bridge Spring		—	—	—	—	—	—	—	—	—
12	Knox Creek Spring		—	—	—	—	—	—	—	—	—
13	Handy Culvert Spring		—	—	—	—	—	—	—	—	—
14	Powder Mill Trout Conf.		—	—	—	—	—	—	—	—	—
15	Powder Mill So[illegible] Spring		—	—	—	—	—	—	—	—	—
16	Bailey Falls Spring		—	—	— —	—	—	—	—	—	—
17	Mystery Springs Conf.		—	—	NM	→	→	→	→	→	→
18	Rumble Spring		—	—	NM	→	→	→	→	→	→
19	Aetna Furnace at Bdg.		—	—	NM	→	→	→	→	→	→
20	Branch Fork at Bridge		—	—	NM	→	→	→	→	→	→
21	Jones School Spring		—	—	—	—	—	—	—	—	—
22	Jones School Creek		—	—	—	—	—	—	—	—	—

Legend:

—	Negative Results	B	Perceptible Background (slight)
+	Positive	B +	Significant Background (problematic)
+ +	Very Positive	NR	Not Recovered (high water, stolen receptor, etc)
+ + +	Extremely Positive	L	Receptor lost
/	Receptor Not Changed	G	New or Extra Receptor Installed

Remarks NM = Not Monitored

Interpretation See Report

DRAFT

RECORD OF DYE TRACE

#R- ____________

Project Rio Springs Wellhead Delineation Project Injection Date 04 / 24 / 93 (Month / Day / Year)

Name of Dye Trace (injection site) Walter Well Tracer Rhodamine WT

Principal Investigator Geary Schindel Field Personnel Joe Ray - Tray Lyons

Precipitation before & during trace ____________

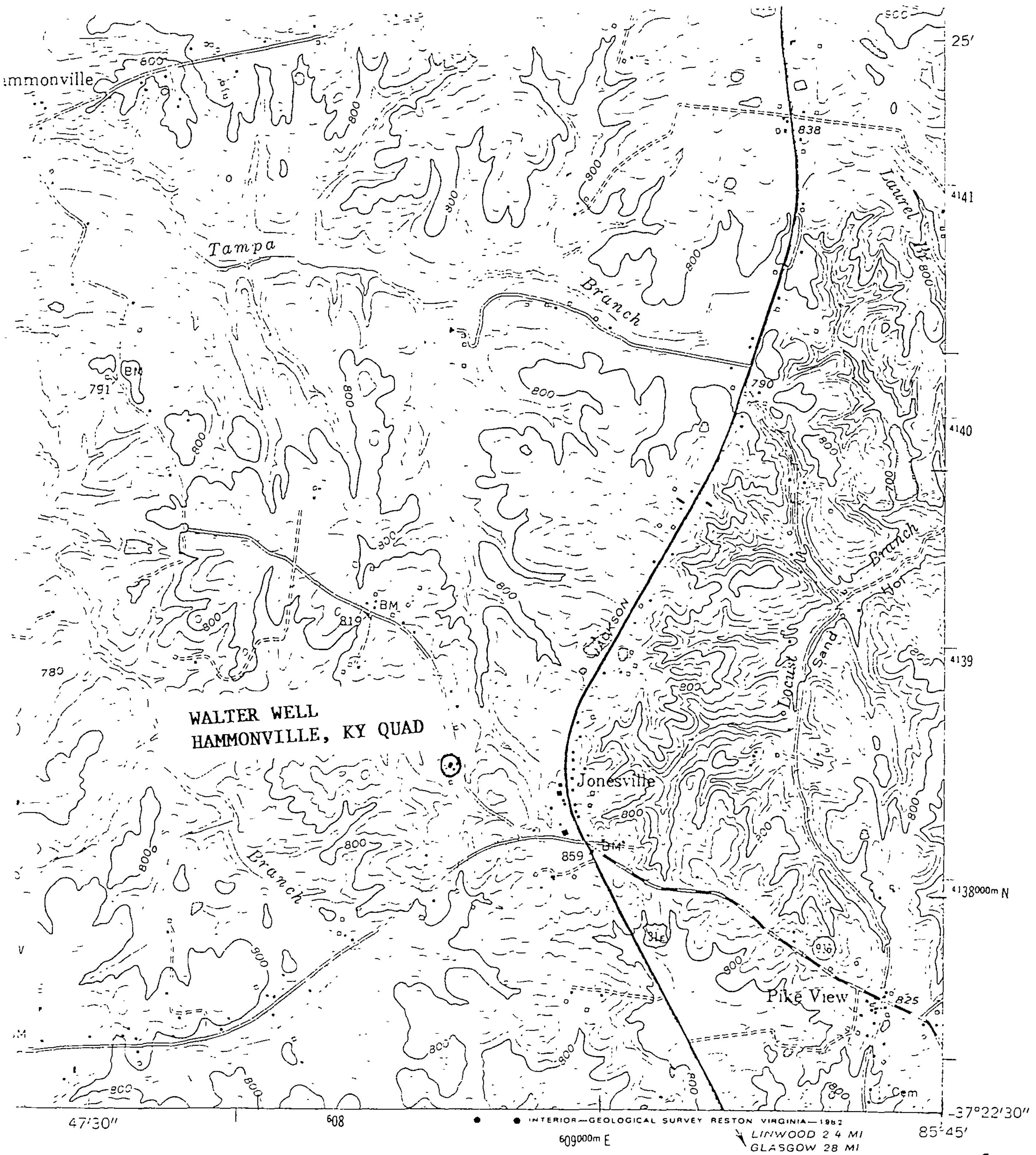
ID	Location of Dye Detectors	Background	4-23	5-1	5-9	5-16	5-28	6-19	6-26	7-23	7-31
	Duration										
			Results								
23	Tampa Branch		—	~	NM	————→					
24	Martis Branch		—	—	NM	————→					
25	Gaddie Cemetery Creek		—	NM	NM	————→					
26	Honey Run Creek		—	NM	NM	————→					
27	Warren East Creek		—	—	—	—	—	—	—	—	—
28	Bacon Ck./Wabash Bdg.		—	—	—	—	—	—	—	—	—
29	Honey Run at Bridge		—	—	—	—	—	—	—	—	—
30	Martis Branch @ Beaver Dam		—	—	—	—	—	—	—	—	—
31	Tampa Branch East		—	—	—	—	—	—	—	—	—
32	Tampa Branch South		—	—	—	—	—	—	—	—	—
33	Tampa Branch at Bridge		—	—	—	—	—	—	—	—	—

Legend:

- — Negative Results
- \+ Positive
- \+ + Very Positive
- \+ + + Extremely Positive
- / Receptor Not Changed
- B Perceptible Background (slight)
- B + Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- L Receptor lost
- G New or Extra Receptor Installed

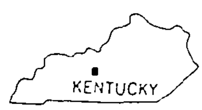
Remarks NM - Not Monitored

Interpretation ____________



ROAD CLASSIFICATION

Heavy-duty	Light-duty
Medium duty	Unimproved dirt
U. S. Route	State Route



QUADRANGLE LOCATION

HAMMONVILLE, KY.

NE/4 MUNFORDVILLE 15′ QUADRANGLE
N 3722.5—W 8545/7.5

1954
PHOTOREVISED 1982
DMA 3858 IV NE–SERIES V853

TRACER INJECTION SITE

DRAFT

#J-

1. Name of Dye Trace (Site Location): Route 357 Sinkhole
2. Date of Injection: April (Month) / 24 (Day) / 1993 (Year) Time: 11:00 (X) a.m. ( ) p.m.
3. Owner of Injection Site: Unknown Phone: ( )
4. Quadrangle/County: Canmer, Ky Quad. ~~Hart~~ / Hart County
5. Elevation: 780 feet (X) map ( ) measured ( ) unknown
6. Latitude: Longitude:
7. Description of Injection Site:
   - ( ) sinking stream ( ) losing stream ( ) karst window (X) sinkhole
   - ( ) cave ( ) water well ( ) injection well ( ) monitoring well
   - ( ) lagoon ( ) septic system other

   Remarks
8. Formation Receiving Tracer Injection: Girkin Formation
9. Flow Conditions: (X) low ( ) moderate ( ) high
10. Field Conditions (precipitation, runoff, etc):
11. Rate of Flow: 1-3 ( ) cfs (X) gpm ( ) l/s ( ) cms ( ) measured (X) estimated
    - ( ) permanent injection site (X) intermittent
    - ( ) multiple sites possible
12. Induced Flow? (X) no ( ) yes ____ Pre-injection / ____ Post-injection ____ Elapsed Time minutes
13. Tracing Agent:

	Color Index	% Active Ingredient	Amount
( ) Sodium Fluorescein			
( ) Rhodamine WT			
( ) Optical Brightener			
(X) Direct Yellow 96	Solophenyl		3 lbs
Other			

14. Reason for Investigation: Rio Springs Wellhead Delineation Project
15. Principal Investigator: Geary Schindel
16. Agency or Organization: ECKENFELDER INC.

    227 French Landing Drive (Address) Nashville (City) TN (State) 37228 (Zip)

    (615) 255-2288 (Phone) ( ) (FAX #)
17. Field Personnel: Joe Ray-Geary Schindel

IDENTIFY INJECTION SITE ON PHOTOCOPY OF TOPOGRAPHIC MAP

DRAFT

RECORD OF DYE TRACE

#R-

Project Rio Springs Wellhead Delineation Project Injection Date 04 / 24 / 93 (Month / Day / Year)

Name of Dye Trace (injection site) Route 357 Sinkhole Tracer Solophenyl-DY 96

Principal Investigator Geary Schindel Field Personnel Joe Ray - Tray Lyons

Precipitation before & during trace

ID	Location of Dye Detectors	Background	4-23	5-1	5-9	5-16	5-29	6-19		
	Duration									
1	Boiling Springs Conflu.		—	—	—	—	—	—		
2	Johnson Spring		—	—	—	—	—	—		
3	Cottrell Spring		—	—	—	—	—	—		
4	Log Spring		—	—	—	—	—	—		
5	Buckner Spring		—	—	—	—	—	—		
6	Rio Springs Conflu.		—	—	—	—	—	—		
7	Rio Springs East		—	—	—	—	—	—		
8	Rio Springs Creek		—	—	—	—	—	—		
9	Scotty Spring		—	—	—	—	—	—		
10	Lanes Mill Spring		—	—	—	—	—	—		
11	Bridge Spring		—	—	—	—	—	—		
12	Knox Creek Spring		—	—	—	—	—	—		
13	Handy Culvert Spring		—	—	—	—	—	—		
14	Powder Mill Trout Conf.		—	—	—	—	—	—		
15	Powder Mill So. Spring		—	—	—	—	—	—		
16	Bailey Falls Spring		—	—	—	—	—	—		
17	Mystery Springs Conf.		—	—	NM	→	→	→		
18	Rumble Spring		—	—	NM	→	→	→		
19	Aetna Furnace at Bdg.		—	—	NM	→	→	→		
20	Branch Fork at Bridge		—	—	NM	→	→	→		
21	Jones School Spring		—	—	—	—	—	—		
22	Jones School Creek		—	—	—	—	—	—		

Legend:

- — Negative Results
- \+ Positive
- \+ + Very Positive
- \+ + + Extremely Positive
- / Receptor Not Changed
- B Perceptible Background (slight)
- B + Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- L Receptor lost
- G New or Extra Receptor Installed

Remarks

Interpretation Insufficient amount of dye used. See Report.

DRAFT

RECORD OF DYE TRACE

#R-

Project Rio Springs Wellhead Delineation Project Injection Date ____ / ____ / ____ (Month / Day / Year)

Name of Dye Trace (injection site) ____________ Tracer ____________

Principal Investigator Geary Schindel Field Personnel Joe Ray - Tray Lyons

Precipitation before & during trace ____________

ID	Location of Dye Detectors	Back-ground	4-23	5-1	5-9	5-16	5-29	6-19			
		Duration									
23	Tampa Branch		–	–	NM	→	→	→			
24	Martis Branch		–	–	NM	→	→	→			
25	Gaddie Cemetery Creek		–	NM	NM	→	→	→			
26	Honey Run Creek		–	NM	NM	→	→	→			
27	Warren East Creek		–	–	–	–	–	–			
28	Bacon Ck./Wabash Bdg.		–	–	–	–	–	–			
29	Honey Run at Bridge		–	–	–	–	–	–			
30	Martis Branch @ Beaver Dam		–	–	–	–	–	–			
31	Tampa Branch East		–	–	–	–	–	–			
32	Tampa Branch South		–	–	–	–	–	–			
33	Tampa Branch at Bridge		–	–	–	–	–	–			

Legend:

–	Negative Results	B	Perceptible Background (slight)
+	Positive	B+	Significant Background (problematic)
++	Very Positive	NR	Not Recovered (high water, stolen receptor, etc)
+++	Extremely Positive	L	Receptor lost
/	Receptor Not Changed	G	New or Extra Receptor Installed

Remarks ____________

Interpretation ____________

PAGE NOT

AVAILABLE

DIGITALLY