FINAL REPORT

SECTION 6

ENDANGERED SPECIES ACT

OKLAHOMA DEPARTMENT OF WILDLIFE CONSERVATION

FEDERAL AID PROJECT E-6

HYDROGEOLOGY OF OZARK CAVEFISH CAVES

FINAL REPORT

STATE: Oklahoma

PROJECT NUMBER: E-6

PROJECT TYPE: Research

PROJECT TITLE: Hydrogeology of Ozark Cavefish Caves

PERIOD COVERED: June 1, 1989 - June 30, 1991

PROGRAM NARRATIVE

OBJECTIVE: The study had two objectives:

1. To refine the delineation of the groundwater recharge area for Twin Cave, an Oklahoma site for the Ozark Cavefish Amblyopsis rosae.)

2. To refine the delineation of the groundwater recharge area for Jail Cave, an Oklahoma site for the Ozark Cavefish.

EXECUTIVE SUMMARY

The Ozark cavefish (***Amblyopsis rosae***) is a federally-listed threatened species known only from a few caves in northeast Oklahoma, southwest Missouri, and northwest Arkansas.

Phase 1 of our investigations dealt with Twin, Jail, and Engelbrecht Caves (Aley and Aley, 1990). The present report, a Phase 2 investigation, deals only with Twin and Jail Caves. The primary purpose of the Phase 2 investigation was to refine the recharge area delineations for Twin and Jail Caves.

The area which contributes water to a cave system is called the cave recharge area. Cave recharge areas are delineated by introducing fluorescent tracer dyes into points where water enters the groundwater system and sampling to determine the springs and caves to which the tracer dyes move. A total of 10 dye injections were made during the Phase 1 studies. Six additional groundwater traces were conducted during the Phase 2 investigation.

Based upon our hydrogeologic work we have refined the delineation for Twin and Jail Caves. The refined recharge area for Twin Cave encompasses 2.4 square miles; the refined recharge area for Jail Cave encompasses 1.5 square miles.

Both of the delineated recharge areas were mapped to depict areas which present different magnitudes of hazards to groundwater quality within the respective caves (Aley and Aley, 1990). Three hazard classes were identified; these were High Hazard, Moderate Hazard, and Low Hazard areas. High and moderate hazard areas in the Twin Cave recharge area total 2.2 square miles (92% of the total recharge area). High and moderate hazard areas in the Jail Cave recharge area total 1.5 square miles (100% of the recharge area).

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INTRODUCTION

The Ozark cavefish (***Amblyopsis rosae***) is a federally-listed threatened species found only in a few caves in northeast Oklahoma, northwest Arkansas, and southwest Missouri. Two of the caves which provide habitat for this fish in Oklahoma are Twin Cave and Jail Cave.

Both of these caves contain underground streams and pools of water. These waters are recharged by surface precipitation. The greatest single threat to the continued existence of the cavefish in the cave waters is incidents of groundwater pollution. Any of the recharge areas for the cave waters has the potential for adversely affecting water quality in the individual caves.

Delineating the recharge area for waters in these caves is a crucial step in protecting cavefish populations. These delineations, coupled with a mapping and assessment of areas which pose water quality hazards to the caves, provides fundamental information for protecting the cavefish populations. The hazard area mapping and assessment work was completed during Phase 1 of this project (Aley and Aley, 1990).

Funding for Phase 2 work project was coordinated by The Nature Conservancy through their Tulsa, Oklahoma office. Funding sources consisted of The Nature Conservancy and the Oklahoma Department of Wildlife Conservation. The Ozark Underground Laboratory contributed some professional and analytical services to the study.

DESCRIPTION OF THE STUDY AREA

The study area includes lands in and around the recharge areas for Twin and Jail Caves. Both the caves and their recharge areas lie entirely within Delaware County, Oklahoma. The study area for Twin and Jail Caves is shown on the Chloeta and Jay 7.5 minute topographic quadrangle maps.

Both caves are located within the Boone Formation of Mississippian age. Essentially the entire study area is underlain by the Boone Formation (Miser, 1954). The Boone Formation consists of cherty limestone with chert content varying both vertically and laterally. The region is blanketed with cherty residuum, and bedrock outcrops are rare except occasionally along streams.

Most of the streams which cross the Boone Formation are losing streams. Losing streams lose surface water flow into the groundwater system in localized areas. Much of the water which enters the karst groundwater system in the area enters through these losing stream segments. Losing stream segments in the study area can recharge groundwater at rates of tens to hundreds of gallons per minute. Most of the groundwater traces which will be discussed in this report involved the introduction of tracer dyes into losing stream segments.

Groundwater flow rates in the study area are rapid. Waters can move underground for distances of several miles in only a few days. Such rapid groundwater movement involves transport along solutionally widened openings in the bedrock. Such groundwater systems provide ineffective natural cleansing for waters being transported. Because of this, food for the aquatic cave ecosystem is transported from the surface into the caves. Unfortunately, contaminants and pollutants can also be transported from the surface into the caves.

During storm events the karst groundwater system transports substantial amounts of sediment and organic material. This is evidenced by turbid waters seen in the caves during the storm periods. Streams and pools in the caves studied typically do not have strong currents during storm events; this is undoubtedly due to constrictions within portions of the solutional openings transporting the waters. These low velocities are probably essential for the cavefish (***Amblyopsis rosae***), since it is not a strong swimmer.

Soils in the area are seldom of adequate quality to support row crop agriculture. Upland and broad valley areas are used for pasture; steeper slopes are commonly poor quality oak woodland. Large poultry houses and hog houses are found on uplands and in broad valleys throughout the study area.

Settlement in the area is generally sparse except near towns and near Grand Lake. A portion of the area near Twin Cave has been subdivided into many small lots; most of these lots are not presently inhabited. Most of the subdivided area lies outside of the recharge area for Twin Cave.

METHODS

Introduction

The methods used in the present study (the Phase 2 investigation) were essentially identical with those employed in the earlier Phase 1 work in the area (Aley and Aley, 1990). The previous work in the area included seven groundwater traces designed to help delineate the recharge areas for Twin and Jail Caves plus three traces to delineate the recharge area for Engelbrecht Cave. The present study include an additional six groundwater traces.

Dye Characteristics

Three tracer dyes were used in the present study. These were fluorescein, Rhodamine WT, and Calcofluor White ST. Fluorescein and Rhodamine WT can be adsorbed on activated charcoal samplers. Calcofluor White ST, which is an optical brightener, can be adsorbed on cotton samplers.

All three of the dyes used have different properties, and each functions somewhat differently within the groundwater system. An understanding of the dyes and their properties is important to an adequate understanding of the results of our groundwater tracing program. All three of the dyes are commonly used in groundwater tracing work, and their use in this work creates no adverse impacts on health or the environment (Smart, 1984).

Fluorescein dye, (Acid Yellow 73; Color Index Constitution Number 45350) is a brilliant fluorescent yellow-green dye which has been used in groundwater tracing work since near the turn of the century. This dye has a long history of successful use in groundwater tracing in karst and fractured rock aquifers. Fluorescein dye is less subject to adsorption on soil and rock materials than is Rhodamine WT (Smart and Laidlaw, 1977; Sabatini, 1989; Sabatini and Austin, 1991). Fluorescein can be adsorbed onto activated charcoal samplers for cumulative sampling.

Rhodamine WT dye, (Acid Red 388; no assigned Color Index Constitution Number) is a reddish-orange fluorescent dye which, like fluorescein, is commonly used in hydrologic studies. Rhodamine WT is far more subject to adsorption onto soil and rock than is fluorescein. Sabatini (1989) has shown that far more water is required to flush Rhodamine WT through alluvial sands than is required to transport fluorescein dye. Similar conditions would be anticipated with the clay-rich soils of the study area and with the rock and sediment matrix of the groundwater systems associated with the two caves. Several factors affect the relative rates, yet flushing rates for fluorescein can be more than ten times faster than those for Rhodamine WT (Sabatini, 1989). One result of these differences is that groundwater tracing work done with Rhodamine WT dye routinely misses sites to which groundwater moves in karst areas (Aley, 1989). Rhodamine WT can be adsorbed onto activated charcoal samplers for cumulative sampling.

Calcofluor White ST (Fluorescence brightener 28, Color Index Constitution Number 40622) is a blue-white optical brightener commonly used as an ingredient in laundry soaps and detergents. It is sold by the manufacturer as a solution. In our experience optical brighteners (including Calcofluor White ST) is substantially more susceptible to adsorption onto soil particles than is Rhodamine WT or fluorescein. Calcofluor White ST is adsorbed onto cotton samplers for cumulative sampling.

Dye Analysis

Sampling for fluorescein and Rhodamine WT dyes used charcoal samplers. Sampling for Calcofluor White ST used cotton samplers. Charcoal samplers will not collect detectable quantities of optical brightener dyes, and cotton samplers will not collect detectable quantities of fluorescein or Rhodamine WT dyes.

The detection of fluorescein and Rhodamine WT dyes used screen samplers filled with activated carbon. An appropriate laboratory grade of activated charcoal will adsorb fluorescein and Rhodamine WT dyes. Each of our samplers was filled with approximately 4.25 grams of Fisher Scientific 6 to 14 mesh activated carbon (Fisher Product Number 5-685).

Charcoal samplers continuously adsorb some portion of the tracer dyes which pass through them; they are thus cumulative samplers. Charcoal samplers for the detection of tracer dyes were placed in flowing water at springs, surface streams, and cave streams for selected periods of time ranging from a few days to several weeks.

Waters in the two caves where we sampled were often slow moving. Prior to the start of our Phase 1 work we were concerned that sampling in very slow moving water might result in appreciably smaller dye recoveries than would sampling in more rapidly flowing waters. This would be the expected condition if the adsorption of tracer dyes were a function of the total quantity of dye passing through a sampler. To evaluate this issue, we conducted a groundwater trace through a cave stream at the Ozark Underground Laboratory, Missouri. Both fluorescein and Rhodamine WT were used. We placed one set of charcoal samplers in a riffle portion of the cave stream, and a second set where the flow rate was estimated to be less than 5% of that in the riffle. Riffle samplers which had been in place for four days showed 1.6 times more fluorescein and 1.7 times more Rhodamine WT than did samplers from the quiet-water sampling site. Shorter sampling periods showed greater variability; charcoal samplers from the riffle site always contained more of both tracer dyes than samplers from the quiet-water site.

Based upon the above-described study, it is our conclusion that effective dye sampling using charcoal samplers can be (and was) conducted in the quiet-water areas found in the caves studied. Based upon our studies, dye concentrations from the charcoal samplers in slowly moving water will typically be somewhat smaller than would be the case if the samplers could be placed in more rapidly flowing water.

When charcoal samplers were collected, new samplers were placed. Collected samplers were placed in sterile plastic bags ("Whirl-Paks") and then transported to the Ozark Underground Laboratory.

Charcoal samplers arriving at the Ozark Underground Laboratory were washed under strong jets of water to remove sediment and organic material. They were then eluted with 20 ml of a standard aqua ammonia and isopropyl alcohol solution for one hour. A sample of the resulting elutant was subjected to analysis in a Shimadzu RF-540 Spectrofluorophotometer using a synchronous scan of excitation and emission wavelengths with a 17 nm wavelength separation. Samples were analyzed using a 5 nm excitation slit and a 2 nm emission slit to insure adequate discrimination between tracer dyes and other fluorescent materials which might be present.

Fluorescence peaks were computer picked to the nearest 0.1 nm. Using this protocol for positive dye traces from Phase 1 work in the study area, fluorescein in the eluting solution has a mean peak of 517.6 nm; the general acceptable fluorescence peak range (which is the mean plus and minus two standard deviations) is from 516.3 to 518.9 nm. If background fluorescence for a station is free of fluorescence peaks, lower fluorescence peak ranges are acceptable as positive fluorescein recoveries when dye concentrations are low or when the dye is weathered. Rhodamine WT in the eluting solution has a mean peak of 570.1 nm; the general acceptable fluorescence peak range (which is the mean plus and minus two standard deviations) is from 566.5 to 573.7 nm.

Cotton samplers were used for the detection of Calcofluor White ST. The cotton used in the samplers is highly absorbant cotton which has not been optically brightened. The samplers we used consisted of cotton disks enclosed in fiberglass screening. Cotton samplers continuously adsorb some portion of the optical brightener dyes which pass through them; they are thus cumulative samplers. Cotton samplers for the detection of tracer dyes were placed in flowing water at springs, surface streams, and cave streams for selected periods of time ranging from a few days to several weeks.

When cotton samplers were collected, new samplers would be placed. Collected samplers were placed in sterile plastic bags ("Whirl-Paks") and then transported to the Ozark Underground Laboratory. Separate bags were used for cotton samplers and charcoal samplers.

Cotton samplers arriving at the Ozark Underground Laboratory were washed under strong jets of water to remove sediment and organic material. They were then examined under an ultraviolet light to identify surface areas most likely to contain optical brighteners. The samplers are then placed in a solid sample holder for analysis in a Shimadzu RF-540 Spectrofluorophotometer; any areas identified as likely to contain optical brighteners are oriented so as to be included in the analysis.

The instrument is programmed to conduct a synchronous fluorescence scan with an excitation slit of 5 nm and an emission slit of 2 nm. The separation between the excitation and emission scans is 17 nm. The emission spectrum data are plotted on an output chart by the RF-540. Separate scans are run of each side of the cotton sampler. If optical brighteners are present on the sampler there will be a distinct broad peak with a maximum ranging from about 415 to 422 nm.

Sampling Stations Used in Groundwater Traces

Table 1 identifies all dye sampling stations utilized in this study. The locations are shown on the map sheet which accompanies this report. Each of the sampling stations is briefly summarized in the following paragraphs.

Table 1. Groundwater Tracing Sampling Stations.

Station Number and Name	Location	Elevation (ft.)
1. Twin Cave Stream	SE 1/4 SE 1/4 Sec. 13, T23N, R22E	About 745
2. Jail Cave Stream	NE 1/4 SE 1/4 Sec. 20, T23N, R22E	715
3. Jail Cave Pool	NE 1/4 SE 1/4 Sec. 20, T23N, R22E	715
4. Pendergraft Spring	SE 1/4 NE 1/4 Sec. 20, T23N, R22E	715
5. Summerfield Cr. upstream of Jail Cave	SE 1/4 NE 1/4 Sec. 20, T23N, R22E	720
6. Round Spr. Hollow upstr. of Jail Cave	NE 1/4 SE 1/4 Sec. 20, T23N, R22E	715
7. Spring in Round Spr. Hollow nr. Jail Cave	SE 1/4 NE1/4 Sec. 20, T23N, R22E	712
8. Mouth of Round Spr. Hollow	SE 1/4 NE 1/4 Sec. 20, T23N, R22E	711
9. Spring pool in Summerfield Hol. downstr. of Jail Cave	SW 1/4 NE 1/4 Sec. 20, T23N, R22E	710
10. Grand Lake below dump	NW 1/4 SW 1/4 Sec. 12, T23N, R22E	740

Station 1. Twin Cave Stream. Main stream in Twin Cave. Sampling station located near the point where one must jump across the passage and climb up to enter a long, low crawlway to the remainder of the cave. Sampling station reached through the west entrance. Samplers placed at different elevations so that, during high flow events, we could recover at least one sampler if we could reach the area. ***Amblyopsis rosae*** were seen at this sampling site during the course of our study.

Station 2. Jail Cave Stream. After entering the cave follow the second major passage on the right. This leads through a short crawlway which leads to a collapse chamber from which one can climb down to the cave stream. Flow velocities are generally very low. This sampling site was sometimes inaccessible during high flows; the crawlway sometimes floods. ***Amblyopsis rosae*** was never noted at this sampling site during the course of our study.

Station 3. Jail Cave Pool. After entering the cave follow the first major passage on the right. This leads to a small pool. At high flow times it is fed by a small stream. At most other times one can note small water input points in the bottom of the pool. This sampling site was sometimes inaccessible during high flows. ***Amblyopsis rosae*** was seen at this sampling site during the course of our study.

Station 4. Pendergraft Spring. This is one of the largest springs in the area. We initially suspected that there might be hydrologic connections between this spring and waters in Jail Cave, but data collected during both Phase 1 and Phase 2 study work demonstrated that this is not the case.

Station 5. Summerfield Creek upstream of Jail Cave. A perennial streamflow segment fed by major springs located within a few hundred feet of the sampling site. Groundwater tracing demonstrates that there are hydrologic interactions between Pendergraft Spring and this sampling site. Our tracing work did not indicate any hydrologic interactions between this sampling site and waters in Jail Cave.

Station 6. Round Spring Hollow upstream of Jail Cave. This surface stream station is located upstream of Jail Cave at a county road crossing. The perennial flow at this sampling station is derived from springs about 500 feet upstream of the sampling station. Groundwater tracing work has failed to demonstrate any hydrologic interactions between these springs and the waters in Jail Cave.

Station 7. **Spring in Round Spring Hollow near Jail Cave.** Groundwater tracing during Phase 2 work demonstrated that this spring is a discharge point for waters from Jail Cave. This spring is located approximately 450 feet downstream of sampling station 6 and 250 feet upstream of station 8.

Station 8. Mouth of Round Spring Hollow. Surface stream station on Round Spring Hollow located immediately upstream of the mouth of Jail Cave Hollow. This station is located about 700 feet downstream of sampling station 6.

Station 9. Spring pool in Summerfield Creek downstream of Jail Cave. A small pool on the east side of Summerfield Creek about 250 feet downstream of the mouth of Round Spring Hollow. The pool contains watercress, which suggested that it is a spring discharge point. The spring is separated from the main channel of Summerfield Creek by a narrow bar of coarse gravel. As a result, any dye present in the waters of Summerfield Creek might also be detected at sampling station 9.

Station 10. Grand Lake below dump. This station was established in the waters of Grand Lake downstream of a small park facility for the Lakemont Shores subdivision. A large dump serving the subdivision is located upstream of this sampling station; the dump is located in the NW 1/4 SE 1/4 Section 14, T23N, R22E. This sampling station was designed to determine if waters from Trace 91-01 discharged to Grand Lake in this vicinity.

Selection of Dye Injection Sites and Related Conditions

During Phase 1 work seven groundwater traces were conducted to help delineate the recharge areas for Jail and Twin Caves. During Phase 2 work an additional six groundwater traces were conducted to refine the delineations of the recharge areas for these two caves. There are several important considerations which go into the selection of dye injection sites and decisions on when to inject dye and how much dye to inject.

The first important consideration is to select a site from which tracing results would be useful. A few of our injection sites were in locations where we anticipated that the tracers would not move to either of the caves of concern. One cannot fully delineate a recharge area for a particular spring or cave unless some dye injection sites are shown to not contribute waters to that site.

A second important consideration is an adequate supply of water. Significant volumes of water are needed for groundwater tracing. While it is sometimes possible to haul water for dye injections, there are a number of logistical problems associated with this approach. All of the groundwater traces we conducted during the Phase 2 work relied upon naturally available water supplies. In karst areas, adequate water supplies are often available only during and shortly after storm periods.

A third consideration is maximizing definitive traces while still conducting as many successive traces as possible. The more dye one uses at an injection site the greater the amount of dye recovered at the points of discharge; this could lead one to conclude that more dye is generally better. The offsetting situation is that the duration of dye pulses at discharge points increases as one uses more dye. Using more dye than the minimum necessary reduces the number of successive traces which can be conducted during a tracing season. Our study was designed to run as many dye traces as possible during as short a period as possible.

A fourth consideration is related to the nature of the dye to be used and the probable losses of the dye between the injection site and potential recovery sites. Calcofluor White ST and Rhodamine WT were used for the simpler and apparently more direct groundwater traces; Calcofluor White ST was used only for Trace 91-04. Properties of the dyes have already been discussed.

Logistical considerations (including obtaining permission to work on private lands) are obviously important. Additionally, in the study area around Twin and Jail Cave one must recognize that not all springs in the area can be sampled. Grand Lake undoubtedly inundated some springs, yet these springs still discharge waters. In several of our dye injections we did not recover any of the tracer dyes. In some cases this is because the springs to which the dyes moved are beneath Grand Lake. The volumes of water in the lake and the absence of information on where springs existed prior to creation of the lake make sampling in the lake generally impractical.

RESULTS

Description of the Groundwater Traces

The following sections will describe each of the six groundwater traces conducted during Phase 2 work. RF-540 analysis graphs of all samples are included in Appendix A.

Trace 91-01. Lakemont Dump Trace.

The dye injection site for this trace is a hazard area site missed during our Phase 1 work. Table 2 summarizes data on this groundwater trace.

The Lakemont Dump is large and much of the leachate from the dump enters the groundwater system. There are no signs directing one to the dump, yet it is clearly used by many of the residents of Lakemont Shores. It seems unlikely to us that this dump is in compliance with Oklahoma state standards for solid waste disposal facilities.

Based upon Phase 1 work, the injection site used for Trace 91-01 is just outside of the recharge area for Twin Cave, yet the boundary in this region was not based upon any nearby traces. Based upon results obtained during the Phase 2 work, this site does not contribute waters to either Jail Cave or Twin Cave. The site is outside of the recharge areas for both of these caves. The discharge point for tracer dyes from this injection site was not determined; a likely possibility is that the discharge point is covered by Grand Lake.

Trace 91-02. Pond Discharge Trace.

This trace was designed to verify the western recharge area boundary for Jail Cave as delineated in our Phase 1 work. No dye from this injection was recovered from Jail Cave or any of the sampling stations in the immediate vicinity of Jail Cave. These results demonstrate that this injection site lies outside of the recharge area for Jail Cave. Table 3 summarizes data on this groundwater trace.

Table 2. **Basic data on Groundwater Trace** 91-01

Project and Trace Number: Oklahoma cavefish habitat study. Trace 91-01

Trace Name: Lakemont Dump Trace.

Injection Location: SW 1/4 NE 1/4 Section 14, T23N, R22E., Delaware County, Oklahoma. Area shown on Chloeta 7.5 minute quadrangle map.

Description of Injection Site: Losing stream segment of unnamed hollow with large Lakemont Shores trash dump at the head of the hollow. Injection site about 200 feet downstream of the base of the dump in the flow of a small spring. All water entered subsurface within 25 feet of injection site.

Injection Elevation: 860 ft.

Estimated Flow Rate at Injection Site: 5 gallons per minute.

Date and Time of Dye Injection: March 27, 1991 at 2:25 P.M.

Tracing Agent and Amount: Rhodamine WT (20% solution). 4 pounds.

Sampling Stations: Twin Cave Stream, Jail Cave Stream, Jail Cave Pool, Pendergraft Spring, Summerfield Creek upstream of Jail Cave, Round Spring Hollow upstream of Jail Cave, Spring in Round Spring Hollow near Jail Cave, Mouth of Round Spring Hollow, Spring pool in Summerfield Creek downstream of Jail Cave, and Grand Lake below dump.

Recovery Stations: This injection site lies outside of the recharge areas for Jail Cave and Twin Cave. There were no dye recoveries from this groundwater trace.

Table 3. Basic Data on Groundwater Trace 91-02.

Project and Trace Number: Oklahoma cavefish habitat study. Trace 91-02.

Trace Name: Pond Discharge Trace.

Injection Location: NE 1/4 NW 1/4 Section 29, T23N, R22E, Delaware County, Oklahoma. Injection site located on the west side of the described 40 acres. Area shown on Chloeta 7.5 minute quadrangle map.

Description of Injection Site: Downstream of a pond in a losing stream valley.

Injection Elevation: 800 ft.

Estimated Flow Rate at Injection Site: 20 gallons per minute.

Date and Time of Dye Injection: March 27, 1991. 4:10 P.M.

Tracing Agent and Amount: Rhodamine WT. (20% solution). 2 pounds.

Sampling Stations: Twin Cave Stream, Jail Cave Stream, Jail Cave Pool, Pendergraft Spring, Summerfield Creek upstream of Jail Cave, Round Spring Hollow upstream of Jail Cave, Spring in Round Spring Hollow near Jail Cave, Mouth of Round Spring Hollow, Spring pool in Summerfield Creek downstream of Jail Cave, and Grand Lake below dump.

Recovery Stations: This injection site lies outside of the Jail Cave Recharge Area. No dye from this injection was recovered.

Trace 91-03. Spring Hollow Trace.

This trace was designed to help verify the western boundary of the delineated Twin Cave recharge area. Table 4 summarizes data on this groundwater trace.

Trace 91-03 resulted in dye recovery from Pendergraft Spring, Summerfield Creek upstream of Jail Cave, and from a spring pool on Summerfield Creek downstream of Jail Cave. No dye from injection 91-03 was recovered from either Twin or Jail Caves. It is worth noting that the wavelengths and magnitudes of the fluorescence peaks associated with Trace 91-03 were similar to those associated with Trace 89-01. These results enhance the credibility of this earlier trace.

Trace 91-04. Jail Cave Hollow Trace 2

This trace had two purposes. The first of these was to verify that downstream portions of Jail Cave Hollow contributed waters to Jail Cave. The second purpose was to aid in determining the discharge point for waters passing through Jail Cave. Table 5 summarizes data on this groundwater trace.

Trace 91-04 resulted in dye recovery from the Jail Cave Pool sampling station. Cave flooding made the Jail Cave Stream sampling station inaccessible. Trace 91-04 failed to identify the discharge point for waters passing through Jail Cave; this information was subsequently gained from Trace 91-06 (which will be discussed later). The principal discharge point for waters from Jail Cave is a small spring on Round Spring Hollow about 300 feet upstream of the mouth of Round Spring Hollow. The fact that Trace 91-04 (which used optical brightener dye) failed to identify the discharge point for Jail Cave while Trace 91-06 (which used fluorescein dye) succeeded provides valuable insight into the nature of the groundwater system existing between Jail Cave and the discharge point. Dispersed water flow through alluvium which contains substantial amounts of silts, clays, and perhaps organic matter can remove optical brighteners. In contrast, fluorescein dye can pass through such systems and be recovered in detectable quantities.

Table 4. Basic Data on Groundwater Trace 91-03.

Project and Trace Number: Oklahoma cavefish habitat study. Trace 91-03

Trace Name: Spring Hollow Trace.

Injection Location: SE 1/4 SE 1/4 Section 15, T23N, R22E, Delaware County, Oklahoma. Area shown on Chloeta 7.5 minute quadrangle map.

Description of Injection Site: Water from springs rises in streambed about 250 feet downstream of the Highway 28 crossing, then flows on the surface for several hundred feet before sinking into the groundwater system.

Injection Elevation: 860 ft.

Estimated Flow Rate at Injection Site: 30 gallons per minute.

Date and Time of Dye Injection: March 27, 1991 at 4:45 P.M.

Tracing Agent and Amount: Fluorescein. 1 pound.

Sampling Stations: Twin Cave Stream, Jail Cave Stream, Jail Cave Pool, Pendergraft Spring, Summerfield Creek upstream of Jail Cave, Round Spring Hollow upstream of Jail Cave, Spring in Round Spring Hollow near Jail Cave, Mouth of Round Spring Hollow, Spring pool in Summerfield Creek downstream of Jail Cave, and Grand Lake below dump.

Recovery Stations: Pendergraft Spring, Summerfield Creek upstream of Jail Cave, and spring pool in Summerfield Creek downstream of Jail Cave. Dye in the spring pool in Summerfield Creek downstream of Jail Cave was probably derived from Pendergraft Spring and other upstream waters.

Table 4 (con't.) Dye Tracing Results at Dye Recovery Stations
Trace 91-03

Sampling Station	Sampling Period	Emission Peak (nm)	Dye Concentration in Charcoal Packet (ppb)
Pendergraft Spr.	3/19 to 3/27/91	ND	
ditto	3/27 to 4/9	ND	
ditto	4/9 to 4/23	516.7	1.61
ditto	4/23 to 5/7	515.4	1.12
Summerfield Cr. upstr. of Jail Cave	3/19 to 3/27/91	ND	
ditto	3/27 to 4/9	ND	
ditto	4/9 to 4/23	515.7	0.477
ditto	4/23 to 5/7	514.4	0.671
Spr. Pool in Sum-merfield Cr. downstr. of Jail Cave	3/19 to 3/27/91	ND	
ditto	3/27 to 4/9	ND	
ditto	4/9 to 4/23	515.9	0.892
ditto	4/23 to 5/7	ND	

ND= None Detected. Detection limit 0.015 ppb.

Table 5. Basic Data on Groundwater Trace 91-04.

Project and Trace Number: Oklahoma cavefish habitat study. Trace 91-04

Trace Name: Jail Cave Hollow Trace 2.

Injection Location: SW 1/4 SE 1/4 Section 20, T23N, R22E, Delaware County, Oklahoma. Area shown on Chloeta 7.5 minute quadrangle map.

Description of Injection Site: Losing stream segment of Jail Cave Hollow about 175 feet upstream of a fenceline crossing.

Injection Elevation: 735 ft.

Estimated Flow Rate at Injection Site: 30 gallons per minute.

Date and Time of Dye Injection: April 23, 1991 at 3:30 P.M.

Tracing Agent and Amount: Calcofluor White ST (an optical brightener). 2 pounds.

Sampling Stations: Jail Cave Stream, Jail Cave Pool, Round Spring Hollow upstream of Jail Cave, Spring in Round Spring Hollow near Jail Cave, Mouth of Round Spring Hollow, and Spring pool in Summerfield Creek downstream of Jail Cave.

Recovery Stations: Jail Cave Pool. Samplers at Jail Cave Stream not accessible because of high water levels. Based upon past tracing and the recovery of dye at the Jail Cave Pool it is our conclusion that dye would also have reached the Jail Cave Stream sampling station had it been accessible.

Dye Tracing Results at Dye Recovery Stations
Trace 91-04

Sampling Station	Sampling Period	Emission Peak (nm)	Optical Brightener Concentration
Jail Cave Pool	4/23 to 5/7/91	418.4	SP
ditto	5/7 to 6/7	ND	

ND = None Detected. SP = Strongly Positive

Trace 91-05. Sinking Spring Trace.

This trace used water from a small spring which rises in the bottom of a stream channel and flows for about 15 feet before sinking again. Data on this trace are summarized in Table 6.

The dye injection site for Trace 91-05 is located about 1,900 feet northwest of the Twin Cave entrance. No dye from this injection was recovered in Twin Cave. The results from this trace and from Trace 91-01 demonstrate that most of the Lakemont Shores Subdivision lies <u>outside</u> of the Twin Cave Recharge Area.

Trace 91-06. Jail Cave Drain Trace.

This trace involved the introduction of 15 grams of fluorescein dye in a small intermittent stream in Jail Cave upstream of the Jail Cave Pool sampling station. Data on this trace are summarized in Table 7. Prior to this trace the discharge point for waters from Jail Cave was unknown.

The dye from this injection was recovered from two small springs. The first of these (identified in Table 1 as Station 7) is located on the south bank of Round Spring Hollow about 300 feet upstream of the mouth of the hollow. The second of these small springs is located on the east bank of Summerfield Creek at a point about 250 feet downstream of the mouth of Round Spring Hollow.

Table 6. **Basic Data on Groundwater Trace 91-05.**

Project and Trace Number: Oklahoma cavefish habitat study. Trace 91-05

Trace Name: Sinking Spring Trace.

Injection Location: NW 1/4 SE 1/4 Section 13, T23N, R22E, Delaware County, Oklahoma. Area shown on Chloeta 7.5 minute quadrangle map.

Description of Injection Site: Water from a spring rises in streambed and flows about 15 feet before sinking back into the groundwater system. The dye injection site is about 1,900 feet northwest of the Twin Cave entrance.

Injection Elevation: 870 ft.

Estimated Flow Rate at Injection Site: 15 gallons per minute.

Date and Time of Dye Injection: May 7, 1991 at 2:45 P.M.

Tracing Agent and Amount: Fluorescein. 1 pound.

Sampling Stations: Twin Cave Stream and Grand Lake below dump.

Recovery Stations: No dye from this trace was recovered.

Table 7. Basic Data on Groundwater Trace 91-06.

Project and Trace Number: Oklahoma cavefish habitat study. Trace 91-06

Trace Name: Jail Cave Drain Trace.

Injection Location: Within Jail Cave. NE 1/4 SE 1/4 Section 20, T23N, R22E, Delaware County, Oklahoma. Area shown on Chloeta 7.5 minute quadrangle map.

Description of Injection Site: A small intermittent stream in Jail Cave in the passage which leads to the Jail Cave Pool sampling station. The stream flows only during very wet periods.

Injection Elevation: 715 ft.

Estimated Flow Rate at Injection Site: 5 gallons per minute.

Date and Time of Dye Injection: May 7, 1991 at 3:30 P.M.

Tracing Agent and Amount: Fluorescein. 15 grams.

Sampling Stations: Jail Cave Pool, Round Spring Hollow upstream of Jail Cave, Spring in Round Spring Hollow near Jail Cave, Mouth of Round Spring Hollow, and Spring pool in Summerfield Creek downstream of Jail Cave.

Recovery Stations: Jail Cave Pool, Spring in Round Spring Hollow near Jail Cave, and Spring pool in Summerfield Creek downstream of Jail Cave.

Table 7 (con't.) Dye Tracing Results at Dye Recovery Stations
Trace 91-06

Sampling Station	Sampling Period	Emission Peak (nm)	Dye Concentration in Charcoal Packet (ppb)
Jail Cave Pool	4/9 to 6/7/91	518.1	143
ditto	5/7 to 6/7	518.3	141
Spring in Round Spr. Hollow nr. Jail Cave	5/7 to 6/7/91	518.6	461
Mouth of Round Spr. Hollow	5/7 to 6/7/91	517.7	7.73
Spring Pool in Summerfield Cr. downstr. Jail Cave	5/7 to 6/7/91	518.3	59.0

Table 8. Dye Analysis of Charcoal Packets. Station 1. Twin Cave Stream.

Sampler Placed	Sampler Recovered	Fluorescein Results			Rhodamine WT Results		
		Peak nm	Conc. ppb	Trace	Peak nm	Conc. ppb	Trace
4/23/90 *	3/19/91	517.6	43.1	90-04	ND		
4/23/90 **	3/19/91	517.9	33.7	90-04	ND		
4/23/90 @	3/19/91	517.4	3.49	90-04	ND		
3/19/91	3/27/91	ND			ND		
3/27/91	4/9/91	ND			ND		
4/9/91	4/23/91	ND			ND		
4/23/91	5/7/91	ND			ND		
4/9/91 @@	6/7/91	ND			ND		
5/7/91 @@	6/7/91	ND			ND		

* Sampler 4/23/90 to 3/19/91 in water.

** Sampler 4/23/90 to 3/19/91 halfway up mud bank and out of water on 3/19/91.

@ Sampler 4/23/90 to 3/19/91 at top of mud bank and out of water on 3/19/91.

@@ A total of 5 charcoal packets (samplers 1797-1799, 1801-1802) were placed at various elevations in the cave stream and were separately analyzed. No dye was detected in any of these samples.

ND = None Detected. Detection limit for fluorescein is 0.015 ppb. Detection limit for Rhodamine WT is 0.234 ppb.

Table 9. Dye Analysis of Charcoal Packets. Station 2. Jail Cave Stream.

Sampler Placed	Sampler Recovered	Fluorescein Results			Rhodamine WT Results		
		Peak nm	Conc. ppb	Trace	Peak nm	Conc. ppb	Trace
4/23/90	3/19/91	ND			ND		
3/19/91	3/27/91	ND			ND		
3/27/91	4/9/91	ND			ND		
4/9/91	4/23/91	ND			ND		

ND = None Detected. Detection limit for fluorescein is 0.015 ppb. Detection limit for Rhodamine WT is 0.234 ppb.

Table 11. Dye analysis of cotton samplers. Station 3. Jail Cave Pool.

Sampler Placed	Sampler Recovered	Optical Brightener Results *		
4/23/91	5/7/91	418.4nm	SP	Trace 91-04
5/7/91	6/7/91	ND		

* ND= None Detected
WP= Weakly Positive
MP= Moderately Positive
SP= Strongly Positive

Table 12. Dye Analysis of Charcoal Packets. Station 4. Pendergraft Spring.

Sampler Placed	Sampler Recovered	Fluorescein Results			Rhodamine WT Results		
		Peak nm	Conc. ppb	Trace	Peak nm	Conc. ppb	Trace
3/19/91	3/27/91	ND			ND		
3/27/91	4/9/91	ND			ND		
4/9/91	4/23/91	516.7	1.61	91-03	ND		
4/23/91	5/7/91	515.4	1.12	91-03	ND		

ND = None Detected. Detection limit for fluorescein is 0.015 ppb. Detection limit for Rhodamine WT is 0.234 ppb.

Table 13. Dye Analysis of Charcoal Packets. Station 5. Summerfield Creek Upstream of Jail Cave.

Sampler Placed	Sampler Recovered	Fluorescein Results			Rhodamine WT Results		
		Peak nm	Conc. ppb	Trace	Peak nm	Conc. ppb	Trace
3/19/91	3/27/91	ND			ND		
3/27/91	4/9/91	ND			ND		
4/9/91	4/23/91	515.7	0.477	91-03	ND		
4/23/91	5/7/91	514.4	0.671	91-03	ND		

ND = None Detected. Detection limit for fluorescein is 0.015 ppb. Detection limit for Rhodamine WT is 0.234 ppb.

Table 14. Dye Analysis of Charcoal Packets. Station 6. Round Spring Hollow Upstream of Jail Cave.

Sampler Placed	Sampler Recovered	Fluorescein Results			Rhodamine WT Results		
		Peak nm	Conc. ppb	Trace	Peak nm	Conc. ppb	Trace
4/23/90	3/19/91	ND			ND		
3/19/91	3/27/91	ND			ND		
3/27/91	4/9/91	ND			ND		
4/9/91	4/23/91	ND			ND		
4/23/91	5/7/91	ND			ND		
5/7/91	6/7/91	ND			ND		

ND = None Detected. Detection limit for fluorescein is 0.015 ppb. Detection limit for Rhodamine WT is 0.234 ppb.

Table 15. Dye analysis of cotton samplers. Station 6. Round Spring Hollow Upstream of Jail Cave.

Sampler Placed	Sampler Recovered	Optical Brightener Results *
4/23/91	5/7/91	ND
5/7/91	6/7/91	ND

* ND= None Detected
WP= Weakly Positive
MP= Moderately Positive
SP= Strongly Positive

Table 16. Dye Analysis of Charcoal Packets. Station 7. Spring in Round Spring Hollow near Jail Cave.

Sampler Placed	Sampler Recovered	Fluorescein Results			Rhodamine WT Results		
		Peak nm	Conc. ppb	Trace	Peak nm	Conc. ppb	Trace
3/19/91	3/27/91	ND			ND		
3/27/91	4/9/91	ND			ND		
4/9/91	4/23/91	ND			ND		
4/23/91	5/7/91	ND			ND		
5/7/91	6/7/91	518.6	461	91-06	ND		

ND = None Detected. Detection limit for fluorescein is 0.015 ppb. Detection limit for Rhodamine WT is 0.234 ppb.

Table 17. **Dye analysis of cotton samplers. Station 7. Spring in Round Spring Hollow near Jail Cave.**

Sampler Placed	Sampler Recovered	Optical Brightener Results *
4/23/91	5/7/91	ND
5/7/91	6/7/91	ND

* ND= None Detected
WP= Weakly Positive
MP= Moderately Positive
SP= Strongly Positive

Table 18. Dye Analysis of Charcoal Packets. Station 8. Mouth of Round Spring Hollow.

Sampler Placed	Sampler Recovered	Fluorescein Results			Rhodamine WT Results		
		Peak nm	Conc. ppb	Trace	Peak nm	Conc. ppb	Trace
3/19/91	3/27/91	ND			ND		
3/27/91	4/9/91	ND			ND		
4/9/91	4/23/91	ND			ND		
4/23/91	5/7/91	ND			ND		
5/7/91	6/7/91	517.7	7.73	91-06	ND		

ND = None Detected. Detection limit for fluorescein is 0.015 ppb. Detection limit for Rhodamine WT is 0.234 ppb.

Table 19. Dye analysis of cotton samplers. Station 8. Mouth of Round Spring Hollow.

Sampler Placed	Sampler Recovered	Optical Brightener Results *
4/23/91	5/7/91	ND
5/7/91	6/7/91	ND

* ND= None Detected
WP= Weakly Positive
MP= Moderately Positive
SP= Strongly Positive

Table 20. Dye Analysis of Charcoal Packets. Station 9. Spring Pool in Summerfield Creek Downstream of Jail Cave.

Sampler Placed	Sampler Recovered	Fluorescein Results			Rhodamine WT Results		
		Peak nm	Conc. ppb	Trace	Peak nm	Conc. ppb	Trace
3/19/91	3/27/91	ND			ND		
3/27/91	4/9/91	ND			ND		
4/9/91	4/23/91	515.9	0.892	91-03	ND		
4/23/91	5/7/91	ND			ND		
5/7/91	6/7/91	518.3	59.0	91-06	ND		

ND = None Detected. Detection limit for fluorescein is 0.015 ppb. Detection limit for Rhodamine WT is 0.234 ppb.

Table 21. Dye analysis of cotton samplers. Station 9. Spring Pool in Summerfield Creek Downstream of Jail Cave.

Sampler Placed	Sampler Recovered	Optical Brightener Results *
4/23/91	5/7/91	ND
5/7/91	6/7/91	ND

* ND= None Detected
WP= Weakly Positive
MP= Moderately Positive
SP= Strongly Positive

Table 22. Dye Analysis of Charcoal Packets. Station 10. Grand Lake Below Dump.

Sampler Placed	Sampler Recovered	Fluorescein Results			Rhodamine WT Results		
		Peak nm	Conc. ppb	Trace	Peak nm	Conc. ppb	Trace
3/27/91	4/9/91	ND			ND		
4/9/91	4/23/91	ND			ND		
4/23/91	5/7/91	ND			ND		
5/7/91	6/7/91	ND			ND		

ND = None Detected. Detection limit for fluorescein is 0.015 ppb. Detection limit for Rhodamine WT is 0.234 ppb.

Sightings of Cavefish, Cave Crayfish, and Grey Bats

During each of our visits to the caves we would spend a few minutes searching for cavefish (***Amblyopsis rosae***) and cave crayfish (species undetermined). The searches were not exhaustive. We also recorded observations on grey bats (***Myotis grisescens***) in Twin Cave.

During our March 19, 1991 field work we saw no cave crayfish nor cavefish in either of the two caves. No grey bats were noted.

During our April 9, 1991 field work we saw one cavefish in the Jail Cave pool and two cavefish in the Twin Cave stream. We also saw about 50 grey bats in Twin Cave. The bats were in the chamber where one climbs up over breakdown blocks on the route to the stream sampling station.

During our April 23, 1991 field work we saw one cavefish and one cave crayfish in the Jail Cave pool and one cave crayfish in the Twin Cave stream.

During our May 7, 1991 field work we saw 2,000 to 2,500 grey bats in the room at the bottom of the entry passage in Twin Cave. The estimate is based upon a cluster of bats occupying 12 to 15 square feet of ceiling area. Common grey bat density in such clusters is about 162 bats per square foot. We were able to pass the colony without causing appreciable disturbance. We also saw one cave crayfish in the Twin Cave stream.

During our field work on June 7, 1991 we saw one cavefish, one large cave crayfish, and two small cave crayfish in the Jail Cave Pool. Also on June 7, 1991 we saw 2 cavefish and one cave crayfish in the Twin Cave stream.

DISCUSSION

Introduction

Phase 1 of our hydrologic work on cavefish population sites in Oklahoma (Aley and Aley, 1990) provided preliminary recharge area delineation data on Twin Cave, Jail Cave, and Engelbrecht Cave. The Phase 1 work included 10 groundwater traces; seven of these were associated with Twin and Jail Caves.

The Phase 2 work discussed in this report was designed to refine the delineation of the recharge areas for Twin Cave and Jail Cave. This has been accomplished. Six groundwater traces were conducted during Phase 2 work. Map Sheet 1 (in the pocket at the end of this report) depicts the delineated recharge areas for Twin and Jail Caves and shows all groundwater traces associated with this delineation work.

Delineation of the Twin Cave Recharge Area

Groundwater traces associated with the delineation of the Twin Cave Recharge Area are as follows:

89-01. Summerfield Creek at Pipeline Crossing Trace
89-04. Below Jay Sewage Lagoons Trace
90-01. Burro Spring Trace
90-03. Highway 28 Trace
90-04. Spring Pond Trace
90-05. Garbage Dump Trace
91-01. Lakemont Dump Trace
91-03. Spring Hollow Trace
91-05. Sinking Spring Trace

Traces 89-01 through 90-05 were discussed in Aley and Aley (1990). Traces 91-01 through 91-05 were conducted in conjunction with the Phase 2 investigations and will be discussed in the following paragraphs.

Trace 91-01, the Lakemont Dump Trace, failed to yield any dye to Twin Cave. The injection site was immediately downstream (and north) of the large dump which serves the Lakemont Shores subdivision. The injection site is 7,200 feet from Twin Cave. Based upon Phase 1 work (Aley and Aley, 1990) the injection site was outside the Twin Cave recharge area by about 700 feet. Based upon our refined delineation, the dye injection site is outside of the Twin Cave recharge area by about 3,200 feet.

Trace 91-01 showed that the Lakemont Dump was outside of the recharge area for Twin Cave. This trace also indicated that substantial portions of the Lakemont Shores Subdivision also lay outside of the recharge area for Twin Cave. This finding is compatible with the absence of detectable background concentrations of optical brighteners in cotton samplers placed in Twin Cave during the Phase 1 work. Optical brighteners are ingredients in laundry soaps and detergents, and for this reason are a useful indicator of sewage contamination of karst groundwater.

The discharge point for the dye from Trace 91-01 is unknown. A sampling station was established on the unnamed arm of Grand Lake which floods downstream portions of the stream basin in which the dye was introduced. No dye was detected at this sampling station. No dye from Trace 91-01 was recovered at Pendergraft Spring, in the springs feeding Summerfield Creek upstream of Pendergraft Spring, or in the springs upstream of the sampling station on Round Spring Hollow upstream of Jail Cave. It is likely that the dye from Trace 91-01 discharged into Grand Lake; it probably discharged through a spring which is submerged by the lake.

Trace 91-03, the Spring Hollow Trace, also failed to yield any dye to Twin Cave. Dye from Trace 91-03 was recovered at Pendergraft Spring, in the springs feeding Summerfield Creek upstream of Pendergraft Spring, and in a spring pool in Summerfield Creek downstream of Round Spring Hollow. Dye detected at the latter station was probably derived from waters which had discharged through Pendergraft Spring or through the springs feeding Summerfield Creek upstream of Pendergraft Spring.

The injection site for Trace 91-03 lies a short distance downstream of Oklahoma Highway 28. There is a dangerous hill and curve on the upstream segment of Highway 28; the stretch of highway is locally known for frequent accidents. Our concern that this might be a site for a significant spill in the future was one of the reasons for conducting Trace 91-03. The data clearly demonstrate that this site does not contribute water to either Twin or Jail Caves.

The injection site for Trace 91-05, the Sinking Spring Trace, is about 1,900 feet from Twin Cave. Phase 1 work included this injection site within the recharge area for Twin Cave. However, this trace demonstrated that the injection site is outside of the Twin Cave Recharge Area (or at least those portions of the Twin Cave Recharge Area lying upstream of our cave sampling station).

Traces 91-01 and 91-05 demonstrate that the majority of the Lakemont Shores Subdivision lies outside of the recharge area for Twin Cave. We have refined the delineated recharge area for Twin Cave on the map on Map Sheet 1 to reflect these new findings.

As presently delineated, the recharge area for Twin Cave encompasses 2.4 square miles. This includes 0.5 square miles of High Hazard Areas, 1.7 square miles of Moderate Hazard Areas, and 0.2 square miles of Low Hazard Areas. Southern portions of the recharge area (including those in the vicinity of the injection sites for Traces 90-01 and 90-05) appear to contribute waters to Twin Cave only during wet periods when they yield surface runoff.

The discharge point for waters from Twin Cave is still unknown. The surface valley downstream of Twin Cave is routinely dry for about a mile until a point just upstream of Grand Lake. The discharge point may be a spring near lake level or it may be a spring which is now submerged by Grand Lake. There are many small ownerships (replete with "No Trespassing" signs and apparently absent residents) in the area where the discharge spring probably exists, so we were unable to make a thorough search. A search of the area by boat would probably be the most effective approach; the spring is probably of sufficient size to be known to some fishermen.

Delineation of the Jail Cave Recharge Area

Groundwater traces associated with the delineation of the Jail Cave Recharge Area are as follows:

89-01. Summerfield Creek at Pipeline Crossing Trace
90-02. Jail Cave Hollow Trace
90-03. Highway 28 Trace
91-02. Pond Discharge Trace
91-03. Spring Hollow Trace
91-04. Jail Cave Hollow Trace 2
91-06. Jail Cave Drain Trace

Traces 89-01 through 90-03 were discussed in Aley and Aley (1990). Traces 91-02 through 91-06 were conducted in conjunction with the Phase 2 investigations and will be discussed in the following paragraphs.

Trace 91-02, the Pond Discharge Trace, involved dye injection in a major losing stream segment of the unnamed hollow immediately west of Jail Cave Hollow. No dye from this injection was recovered in Jail Cave or at any of the nearby sampling stations. This trace confirmed that the western boundary of the delineated Jail Cave Recharge Area is reasonable; it does not include the area in the vicinity of the injection site for Trace 91-02.

Trace 91-03, the Spring Hollow Trace, also failed to yield any dye to Jail Cave. Dye from Trace 91-03 was recovered at Pendergraft Spring, in the springs feeding Summerfield Creek upstream of Pendergraft Spring, and in a spring pool in Summerfield Creek downstream of Round Spring Hollow. Dye detected at the latter station was probably derived from waters which had discharged through Pendergraft Spring or through the springs feeding Summerfield Creek upstream of Pendergraft Spring. The results from Trace 91-03 were similar to those from Trace 90-03 in that there were no detectable hydrologic interactions between the waters of Jail Cave and those of Pendergraft Spring and Summerfield Creek.

Trace 91-04, Jail Cave Hollow Trace #2, was from a site 4,700 feet downstream of Jail Cave Hollow Trace #1. These two traces demonstrate that most, if not all, of the topographic basin of Jail Cave Hollow lies within the recharge area for Jail Cave.

Trace 91-06, Jail Cave Drain Trace, identified where waters from Jail Cave discharge to the surface. The tracer dyes were injected inside Jail Cave at a point near, and upstream of, the Jail Cave Pool sampling station. The dye was recovered from the following four stations:

1) Jail Cave Pool.
2) Spring in Round Spring Hollow near Jail Cave.
3) Mouth of Round Spring Hollow.
4) Spring Pool in Summerfield Creek downstream of Jail Cave.

The recovery of dye at the Jail Cave Pool sampling station was expected. However, the concentration was substantially less than the concentration recovered at the spring in Round Spring Hollow. This indicates that much of the tracer dye by-passed the Jail Cave Pool station even though it was introduced at a point only about 25 feet from that pool.

The principal recovery point for the dye from Trace 91-06 was at the spring on Round Spring Hollow near Jail Cave. Typical flow rates of this spring during the spring of 1991 were from 10 to 25 gallons per minute.

Charcoal samplers from the sampling station near the mouth of Round Spring Hollow received only about 1.5% as much dye as did the spring on Round Spring Hollow near Jail Cave. The latter sampling station is about 250 feet upstream of the sampling station near the mouth of Round Spring Hollow. These results indicate that most or all of the dye from Jail Cave which discharged to Round Spring Hollow flowed through the unnamed spring which we sampled.

The dye concentration in the charcoal sampler from the spring on Round Spring Hollow near Jail Cave was approximately 8 times greater than the concentration in the sampler from the spring pool on Summerfield Creek. The dye concentration in the sampler from the spring pool on Summerfield Creek was about 8 times greater than the concentration in the sampler from near the mouth of Round Spring Hollow. This demonstrates that the dye in the spring pool on Summerfield Creek was not derived from dyes which discharged to Round Spring Hollow. Instead, the spring pool represents a separate groundwater discharge point for waters from Jail Cave. The spring pool on Summerfield Creek discharged appreciably less dye than did the spring on Round Spring Hollow.

Dye from Trace 91-04 was recovered in the Jail Cave Pool but was not recovered at the spring on Round Spring Hollow near Jail Cave, at the mouth of Round Spring Hollow, nor at the spring pool on Summerfield Creek downstream of Jail Cave. Trace 91-06 demonstrated that the Jail Cave Pool does in fact contribute waters to these other three stations; the obvious question is, why the apparent difference in results?

Trace 91-04 used Calcofluor White ST (an optical brightener). Trace 91-06 used fluorescein. The optical brightener is much more readily adsorbed onto fine textured soil particles and rock than is fluorescein; we believe this is the explanation for the results. The results suggest there is ineffective natural adsorption between the injection site for Trace 91-04 and Jail Cave Pool, but that appreciable adsorption is present in the groundwater system between Jail Cave and spring discharge points on the nearby streams. This could explain why surface fish species are never seen in Jail Cave.

As presently delineated, the recharge area for Jail Cave encompasses 1.5 square miles. This includes 0.3 square miles of High Hazard Areas and 1.2 square miles of Moderate Hazard Areas. There are no identified

Low Hazard Areas in the Jail Cave Recharge Area. The Phase 2 work confirmed our previous delineations and indicated that no modifications were necessary.

FINDINGS AND CONCLUSIONS

1. The recharge area for Twin Cave encompasses 2.4 square miles. This area is primarily located within the topographic basin of the unnamed surface stream located south of the Twin Cave entrance.

2. Most of the Lakemont Shores Subdivision lies outside of the recharge area for Twin Cave. The dump which serves this subdivision is also located outside of the recharge area for Twin Cave.

3. The recharge area for Jail Cave encompasses 1.5 square miles. This area is located primarily within the topographic basin of Jail Cave Hollow; this is the surface stream located west of the Jail Cave entrance.

4. Waters from Jail Cave discharge to surface streams at two identified points. The major discharge point is a small spring on the south bank of Round Spring Hollow. This spring is located about 300 feet upstream of the mouth of Round Spring Hollow. The minor discharge point is a spring pool on the east bank of Summerfield Creek. This spring is located about 250 feet downstream of the mouth of Round Spring Hollow.

5. This report augments our Phase 1 report (Aley and Aley, 1990). The reader is encouraged to use both report since many issues discussed in the earlier report are not repeated in the present document.

RECOMMENDATIONS

1. The recharge area delineations and hazard area classes established in the Phase 1 and 2 studies should be used in making resource protection decisions for Twin and Jail Caves. The greatest attention should be focused on identified high hazard and moderate hazard areas.

2. Management attention should be focused on efforts to minimize groundwater quality impacts from disposal of animal wastes. Land application of wastes from hog and poultry houses is of particular concern when it occurs on lands near losing stream segments and when application is followed by precipitation events adequate to cause runoff into losing stream segments.

REFERENCES

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PREPARED BY: Thomas Aley and Catherine Aley

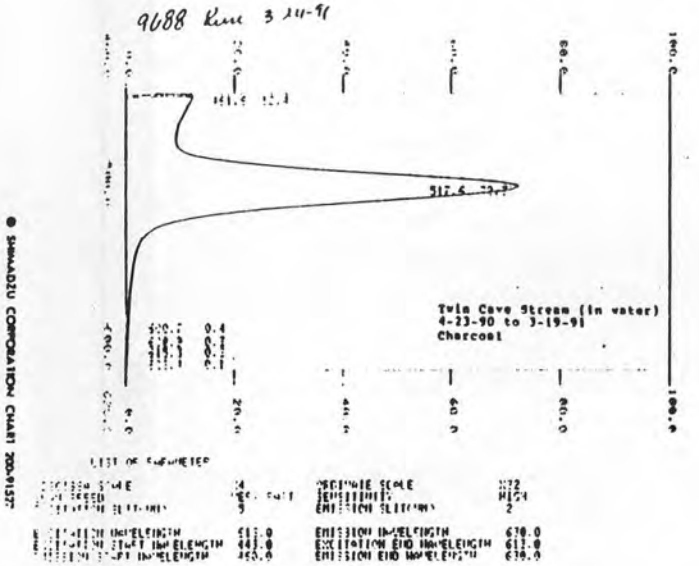
APPROVED BY: Oklahoma Department of Wildlife Conservation

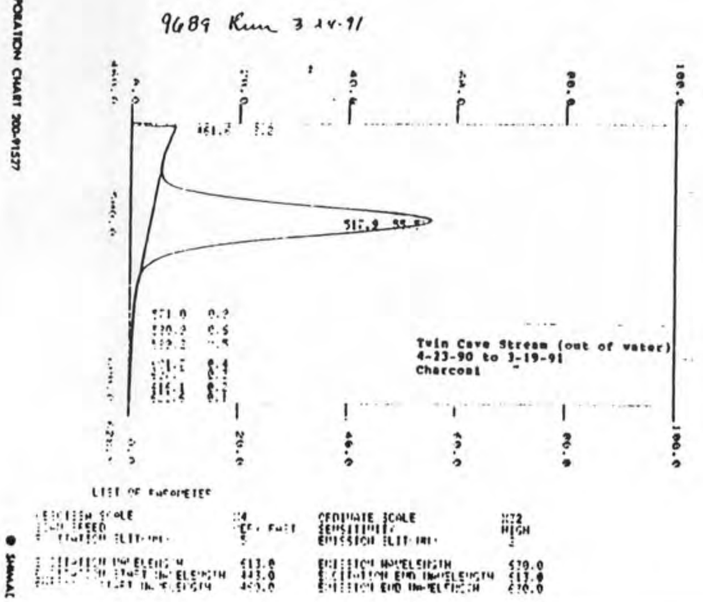
Harold E. Namminga (signature) Date 9-6-91

Harold E. Namminga
Federal Aid/Research Coordinator

APPENDIX A

This appendix includes photo-reduced copies of all RF-540 analysis charts produced in our Phase 2 study. Charts are included for both charcoal samplers and cotton samplers. This appendix provides a permanent record of all analysis work conducted during the investigation.


9688 Run 3-24-91
Twin Cave Stream (in water)
4-23-90 to 3-19-91
Charcoal
517.6
LIST OF PARAMETER
SHIMADZU CORPORATION CHART 200-91527


9689 Run 3-24-91
Twin Cave Stream (out of water)
4-23-90 to 3-19-91
Charcoal
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LIST OF PARAMETER
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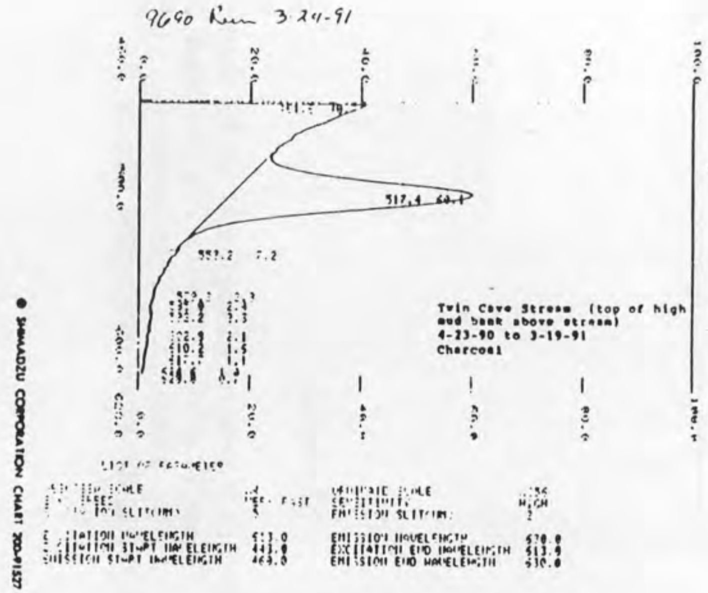
9690 Run 3-24-91
Twin Cave Stream (top of high mud bank above stream)
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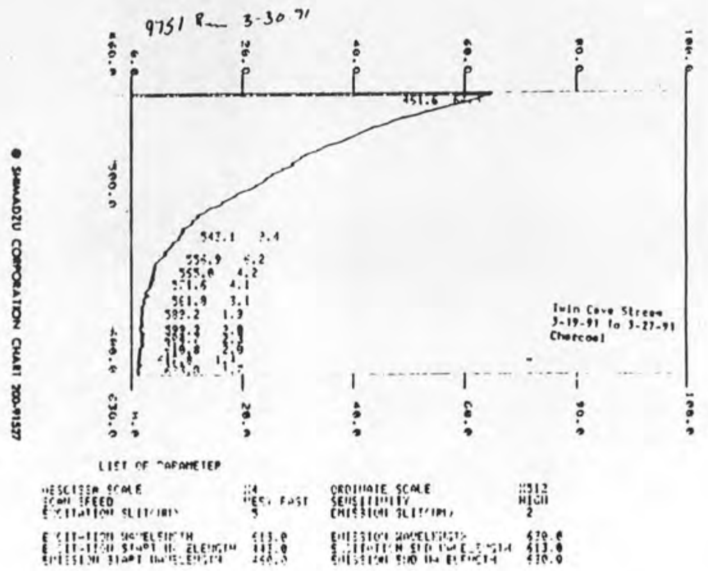
Charcoal
517.4
LIST OF PARAMETER
SHIMADZU CORPORATION CHART 200-91527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Twin Cave Stream
3-19-91 to 3-27-91
Charcoal
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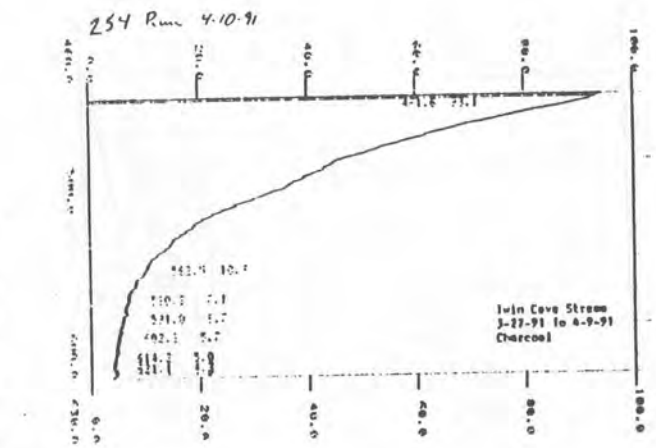

LIST OF PARAMETER

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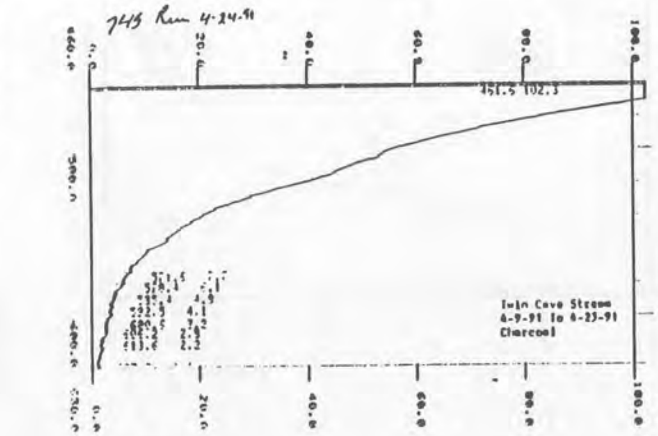
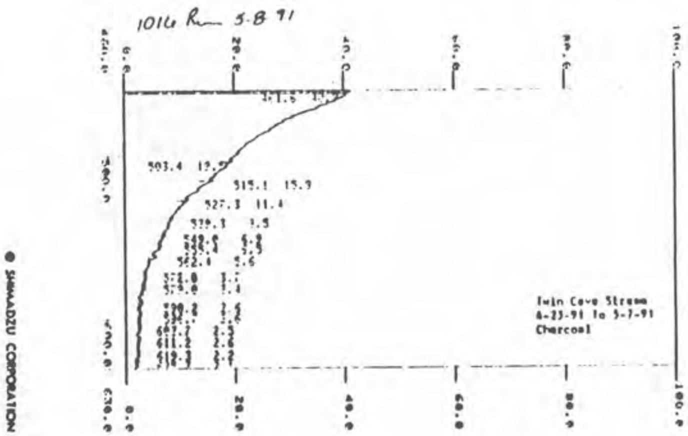
EXCITATION WAVELENGTH 513.0 | EMISSION WAVELENGTH 570.0
EXCITATION START WAVELENGTH 443.0 | EXCITATION END WAVELENGTH 613.0
EMISSION START WAVELENGTH 460.0 | EMISSION END WAVELENGTH 630.0



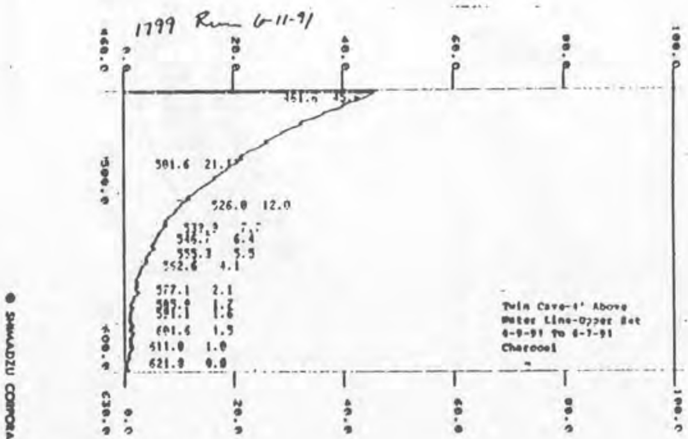
LIST OF PARAMETER

ABSCISSA SCALE X4 | ORDINATE SCALE X512
SCAN SPEED VERY FAST | SENSITIVITY HIGH
EXCITATION SLIT(NM) 5 | EMISSION SLIT(NM) 2
EXCITATION WAVELENGTH 513.0 | EMISSION WAVELENGTH 570.0
EXCITATION START WAVELENGTH 443.0 | EXCITATION END WAVELENGTH 613.0
EMISSION START WAVELENGTH 460.0 | EMISSION END WAVELENGTH 630.0



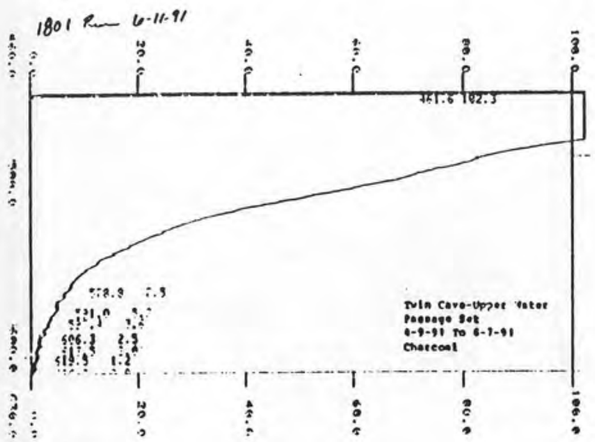
LIST OF PARAMETER

ABSCISSA SCALE X4 | ORDINATE SCALE X512
SCAN SPEED VERY FAST | SENSITIVITY HIGH
EXCITATION SLIT(NM) 5 | EMISSION SLIT(NM) 2
EXCITATION WAVELENGTH 513.0 | EMISSION WAVELENGTH 570.0
EXCITATION START WAVELENGTH 443.0 | EXCITATION END WAVELENGTH 613.0
EMISSION START WAVELENGTH 450.0 | EMISSION END WAVELENGTH 630.0



LIST OF PARAMETER

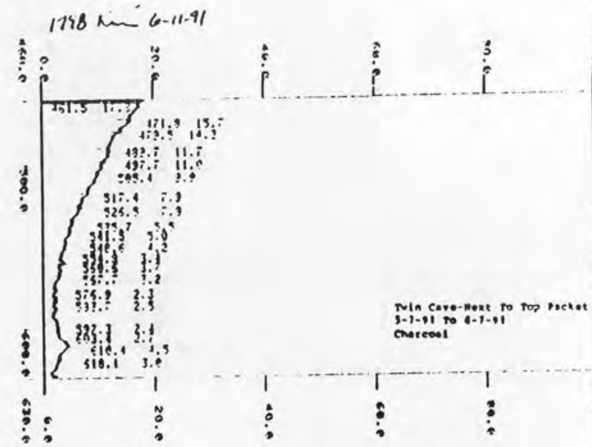
ABSCISSA SCALE X4 | ORDINATE SCALE X512
SCAN SPEED VERY FAST | SENSITIVITY HIGH
EXCITATION SLIT(NM) 5 | EMISSION SLIT(NM) 2
EXCITATION WAVELENGTH 513.0 | EMISSION WAVELENGTH 570.0
EXCITATION START WAVELENGTH 443.0 | EXCITATION END WAVELENGTH 613.0
EMISSION START WAVELENGTH 460.0 | EMISSION END WAVELENGTH 630.0



LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	513.0	EMISSION WAVELENGTH	630.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	513.0
EMISSION START WAVELENGTH	460.0	EMISSION END WAVELENGTH	630.0

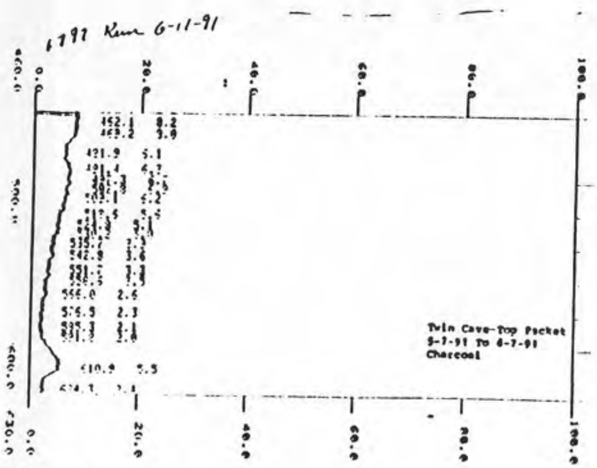
SHIMADZU CORPORATION CHART 200-91577



LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	513.0	EMISSION WAVELENGTH	630.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	513.0
EMISSION START WAVELENGTH	450.0	EMISSION END WAVELENGTH	630.0

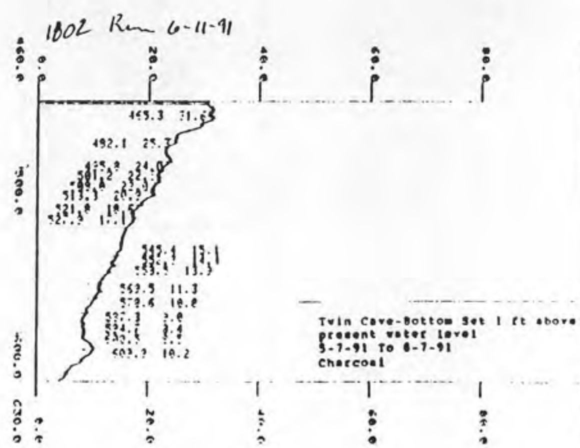
SHIMADZU CORPORATION CHART 200-91577



LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	513.0	EMISSION WAVELENGTH	530.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	513.0
EMISSION START WAVELENGTH	460.0	EMISSION END WAVELENGTH	630.0

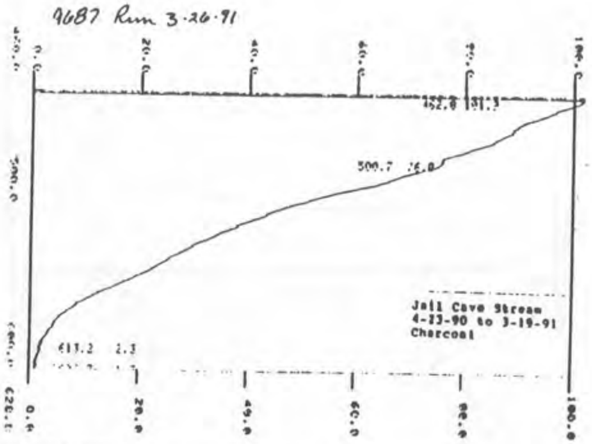
SHIMADZU CORPORATION CHART 200-91577



LIST OF PARAMETER

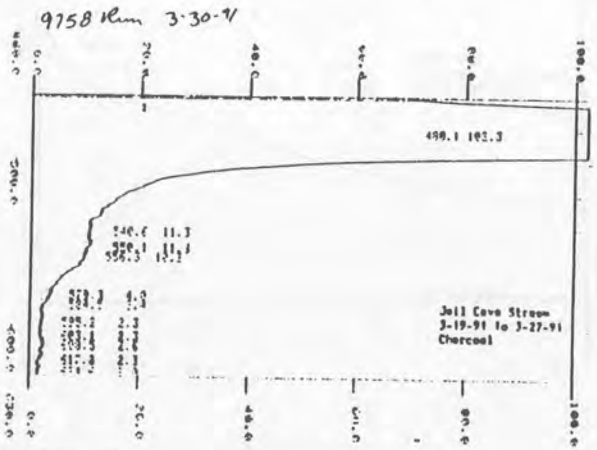
ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	513.0	EMISSION WAVELENGTH	630.0

SHIMADZU CORPORATION CHART



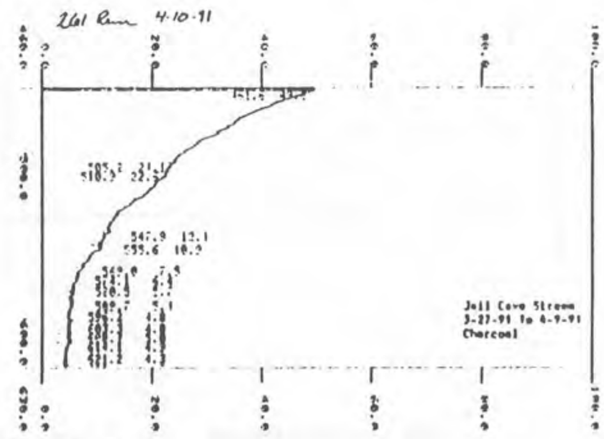
LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X256
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	513.0	EMISSION WAVELENGTH	670.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	513.0
EMISSION START WAVELENGTH	460.0	EMISSION END WAVELENGTH	630.0



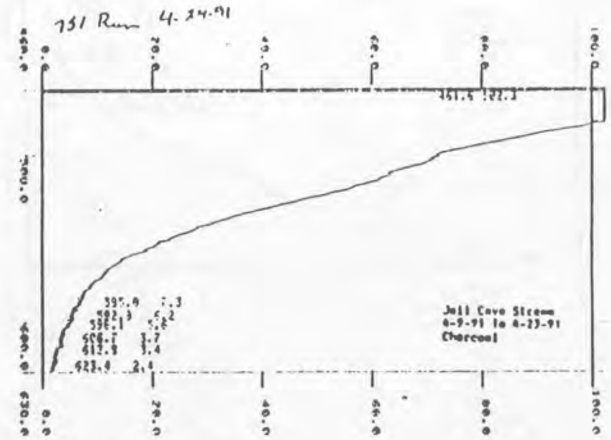
LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	[illegible]
EXCITATION WAVELENGTH	513.0	EMISSION WAVELENGTH	[illegible]
EXCITATION START WAVELENGTH	443.0	EXCITATION END	[illegible]
EMISSION START WAVELENGTH	460.0	EMISSION E[illegible]	[illegible]30.0



LIST OF PARAMETER

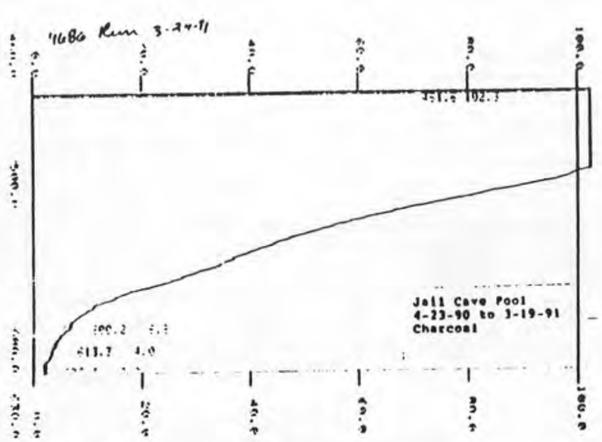
ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	513.0	EMISSION WAVELENGTH	570.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	513.0
EMISSION START WAVELENGTH	460.0	EMISSION END WAVELENGTH	630.0



LIST OF PARAMETER

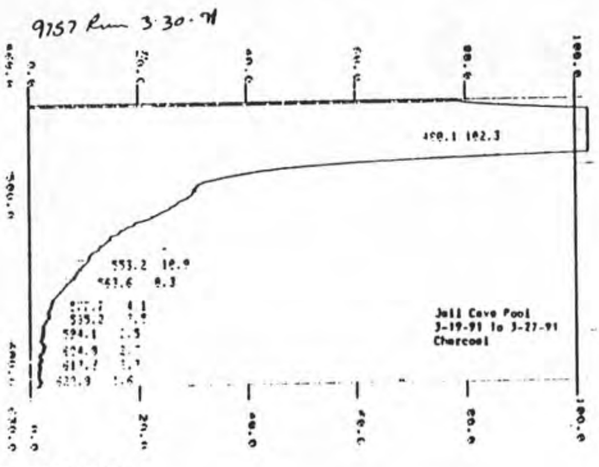
ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	513.0	EMISSION WAVELENGTH	570.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	513.0
EMISSION START WAVELENGTH	460.0	EMISSION END WAVELENGTH	630.0

● SHIMADZU CORPORATION CHART 200-91527



LIST OF PARAMETER

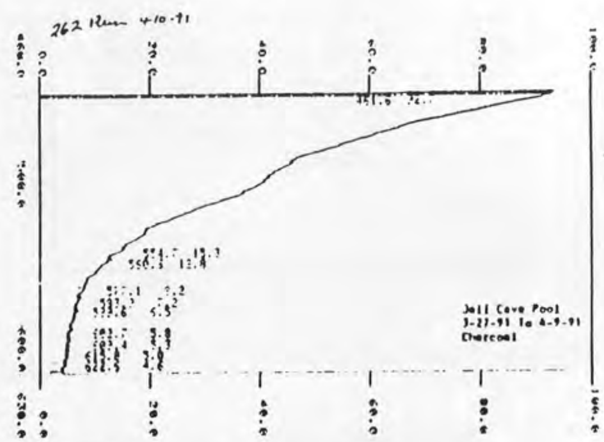
ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	513.0	EMISSION WAVELENGTH	570.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	513.0
EMISSION START WAVELENGTH	460.0	EMISSION END WAVELENGTH	630.0



LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	513.0	EMISSION WAVELENGTH	570.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	513.0
EMISSION START WAVELENGTH	460.0	EMISSION END WAVELENGTH	630.0

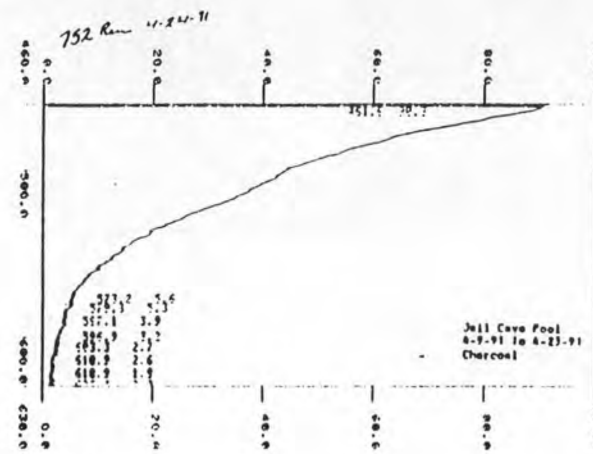
● SHIMADZU CORPORATION CHART 200-91527



LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	513.0	EMISSION WAVELENGTH	570.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	513.0
EMISSION START WAVELENGTH	460.0	EMISSION END WAVELENGTH	630.0

● SHIMADZU CORPORATION CHART 200-91527

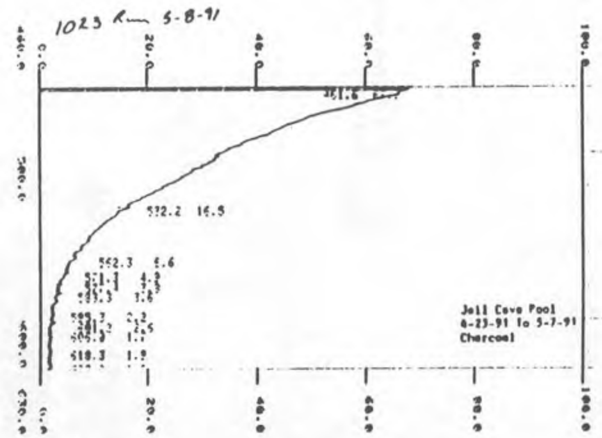


LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	[illegible]	EMISSION WAVELENGTH	570.0
EXCITATION START WAVELENGTH	[illegible]	EXCITATION END WAVELENGTH	513.0
EMISSION START WAVELENGTH	[illegible]	EMISSION END WAVELENGTH	[illegible]

● SHIMADZU CORPORATION CHART 200-91527

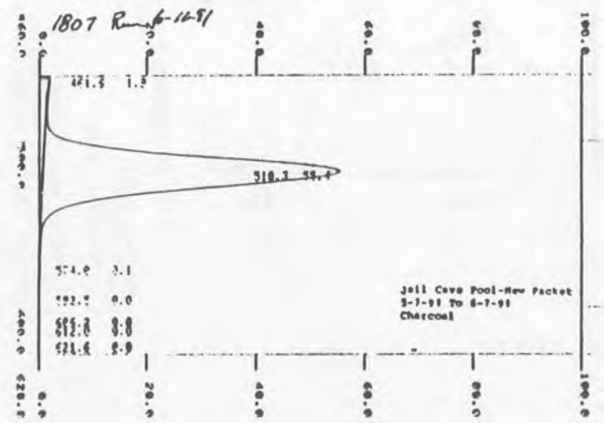
CORPORATION CHART 200-91527



LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	613.0	EMISSION WAVELENGTH	530.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	613.0
EMISSION START WAVELENGTH	460.0	EMISSION END WAVELENGTH	570.0

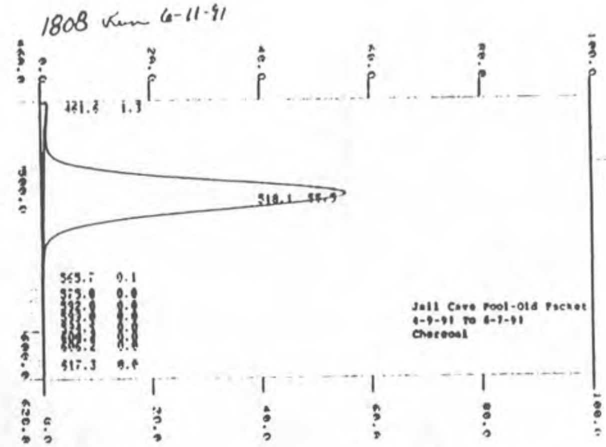
● SHIMAD ADZU CORPORATION CHART 200-91527



LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X8
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	613.0	EMISSION WAVELENGTH	570.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	613.0
EMISSION START WAVELENGTH	460.0	EMISSION END WAVELENGTH	630.0

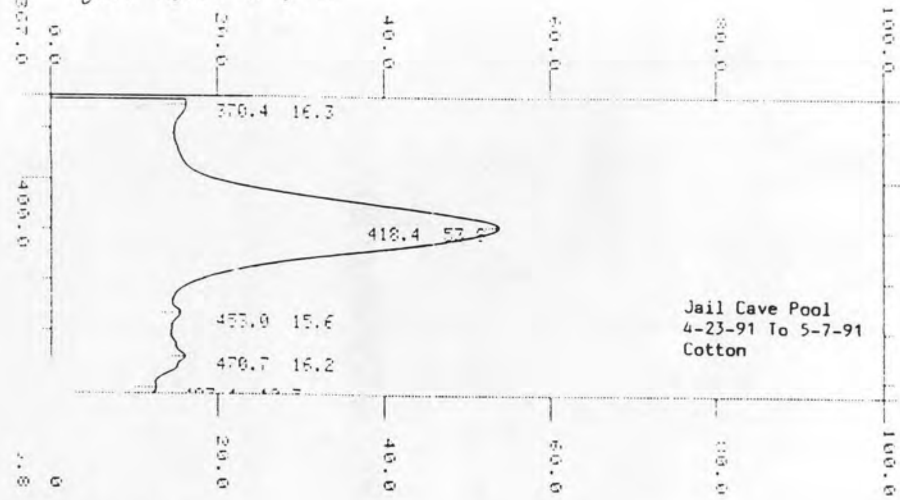
● SHIMADZU CORPORATION CHART 200-91527



LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X8
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	613.0	EMISSION WAVELENGTH	570.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	613.0
EMISSION START WAVELENGTH	460.0	EMISSION END WAVELENGTH	630.0

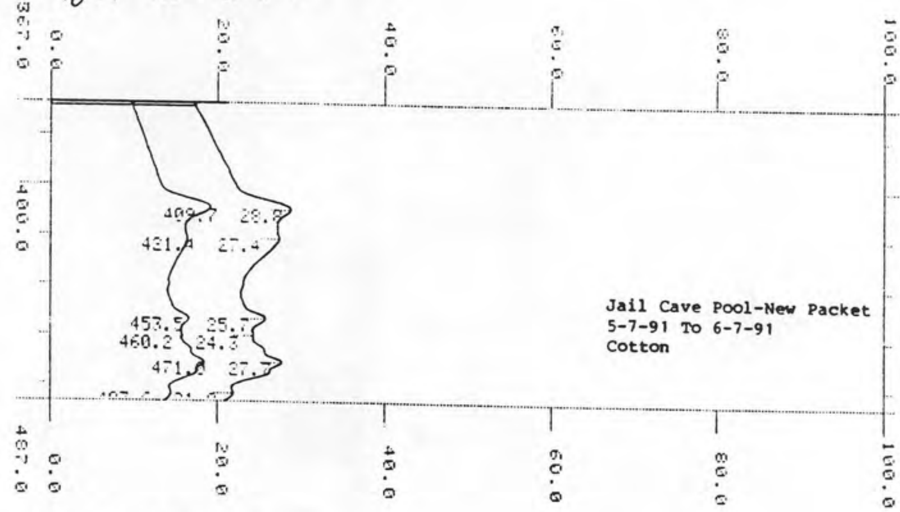
1029 Run 5-8-91



LIST OF PARAMETER

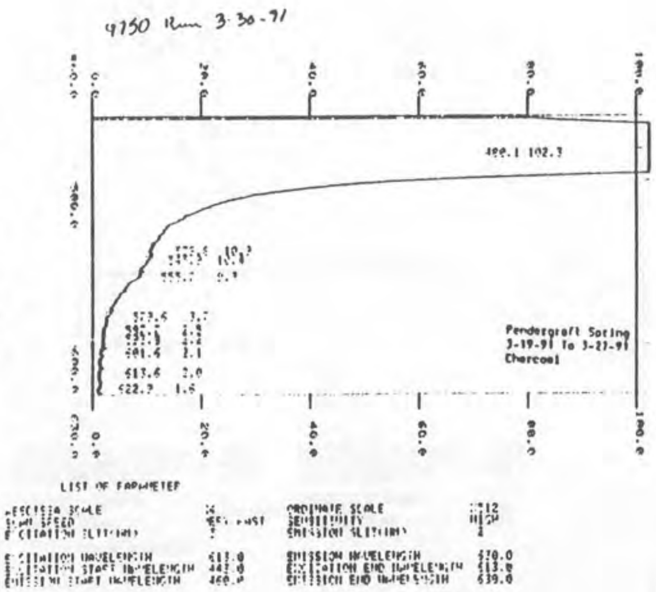
ABSCISSA SCALE	X4	ORDINATE SCALE	X4
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	3
EXCITATION WAVELENGTH	470.0	EMISSION WAVELENGTH	487.0
EXCITATION START WAVELENGTH	350.0	EXCITATION END WAVELENGTH	470.0
EMISSION START WAVELENGTH	367.0	EMISSION END WAVELENGTH	487.0

1814 Run 6-11-91



LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X16
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	3
EXCITATION WAVELENGTH	470.0	EMISSION WAVELENGTH	487.0
EXCITATION START WAVELENGTH	350.0	EXCITATION END WAVELENGTH	470.0
EMISSION START WAVELENGTH	367.0	EMISSION END WAVELENGTH	487.0



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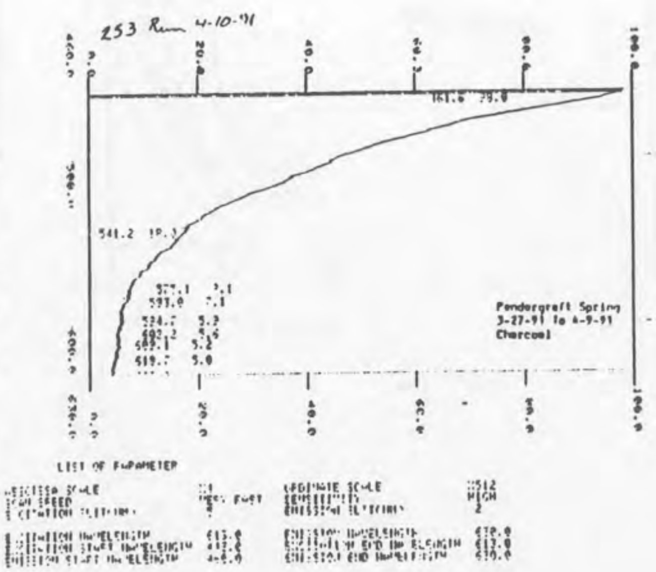
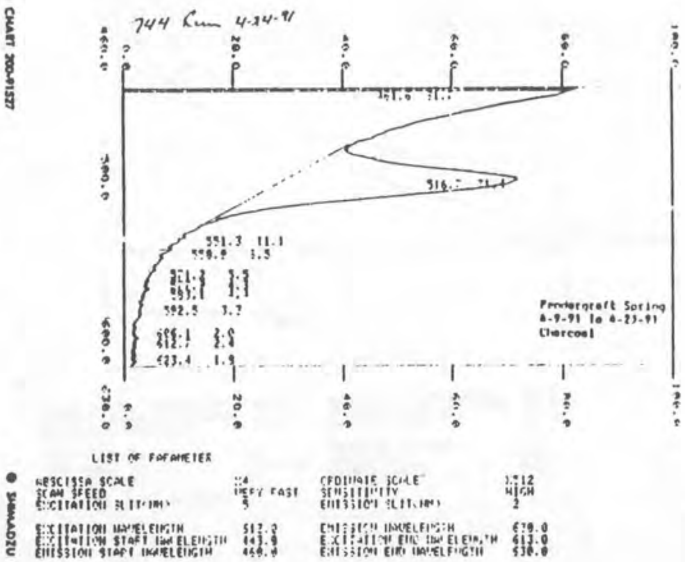
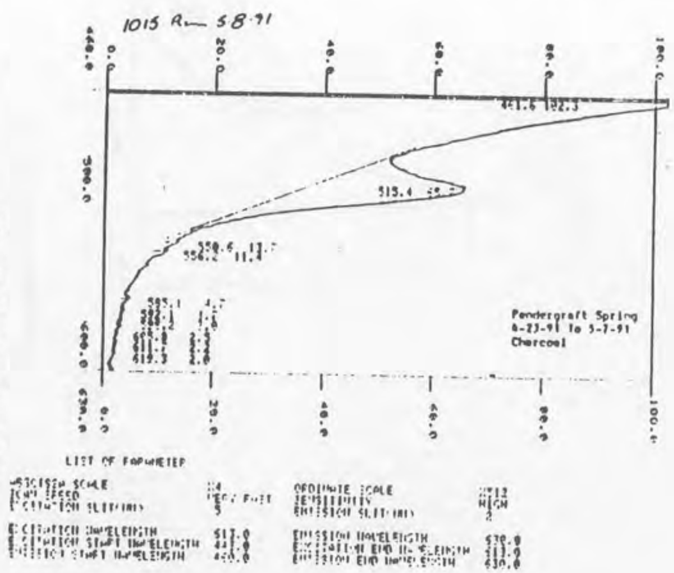


● SHIMADZU CORPORATION CHART 200-91527



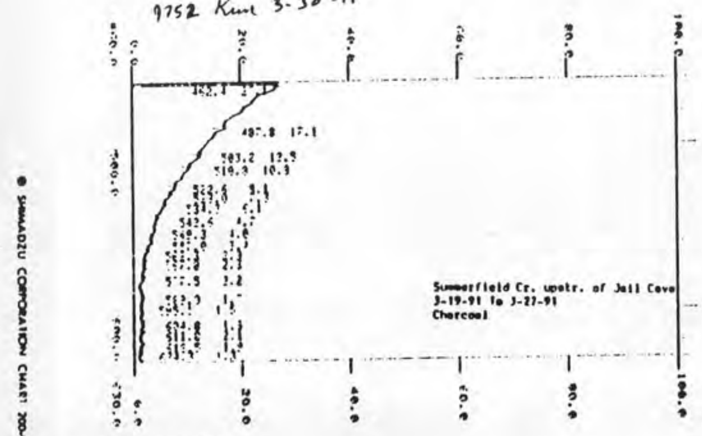
RATION CHART 200-91527

● SHIMADZU CORPC



● SHIMADZU CORPORATION CHART 200-91527

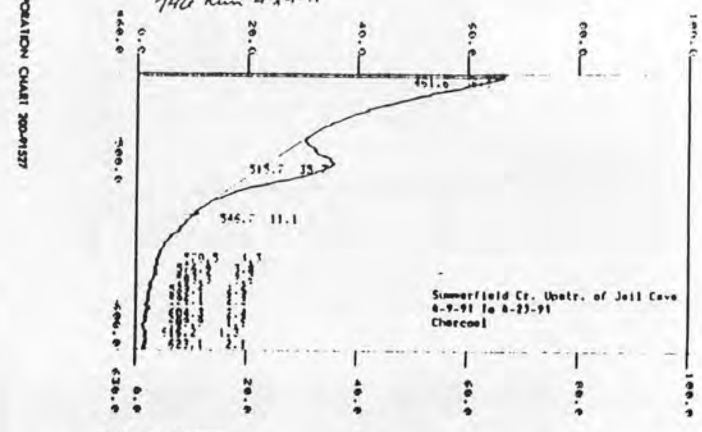
9752 Run 3-30-91



LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	513.0	EMISSION WAVELENGTH	570.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	513.0
EMISSION START WAVELENGTH	460.0	EMISSION END WAVELENGTH	630.0

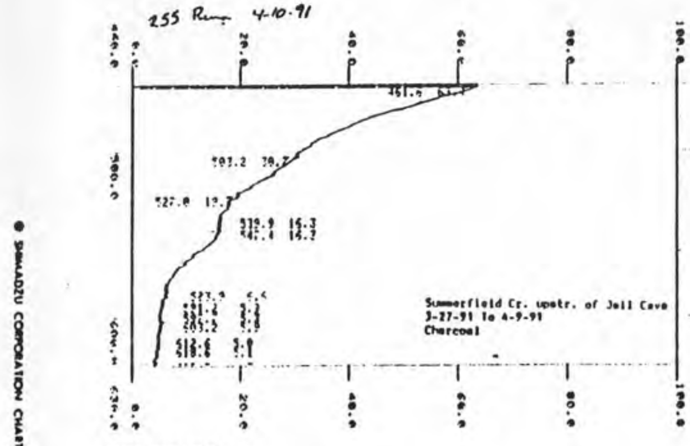
740 Run 4-24-91



LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	513.0	EMISSION WAVELENGTH	570.0
EXCITATION START WAVELENGTH	447.0	EXCITATION END WAVELENGTH	613.0
EMISSION START WAVELENGTH	465.0	EMISSION END WAVELENGTH	630.0

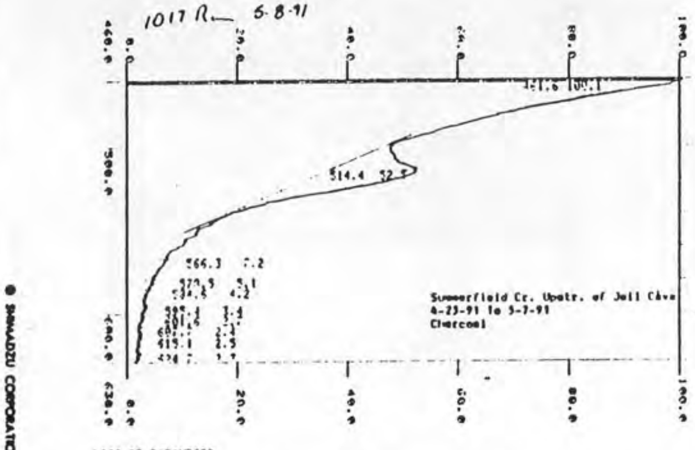
255 Run 4-10-91



LIST OF PARAMETER

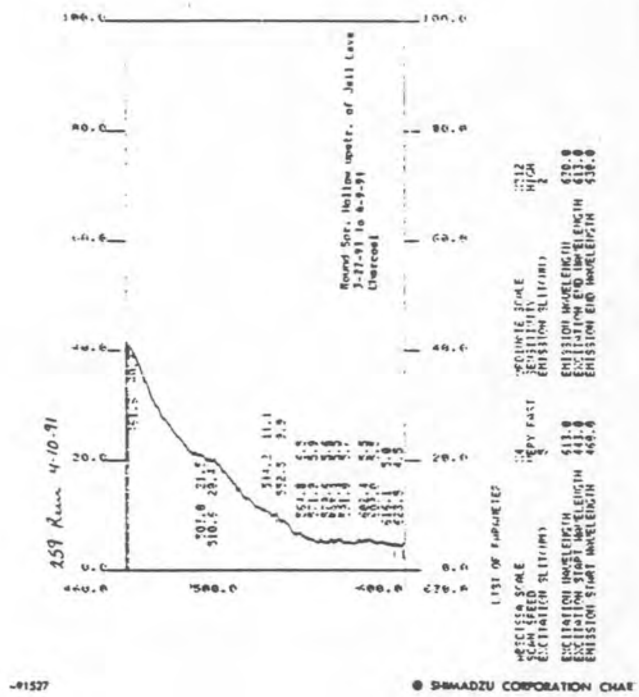
ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	513.0	EMISSION WAVELENGTH	570.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	513.0
EMISSION START WAVELENGTH	460.0	EMISSION END WAVELENGTH	630.0

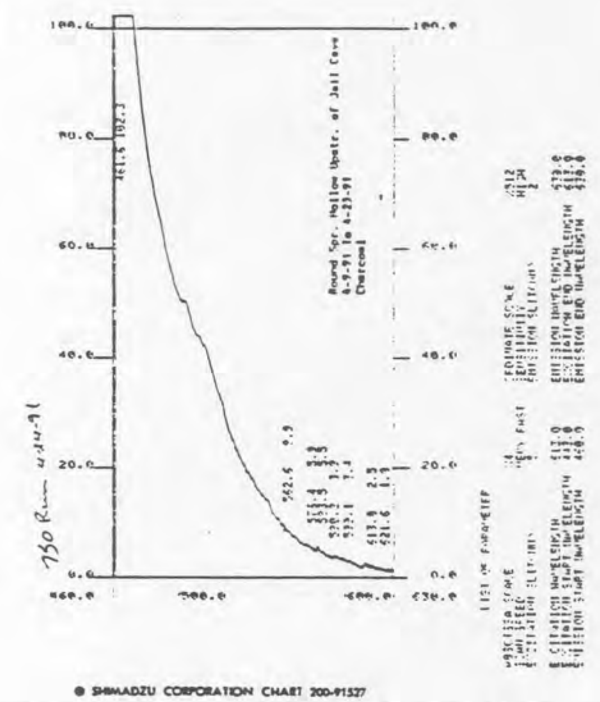
1017 Run 5-8-91

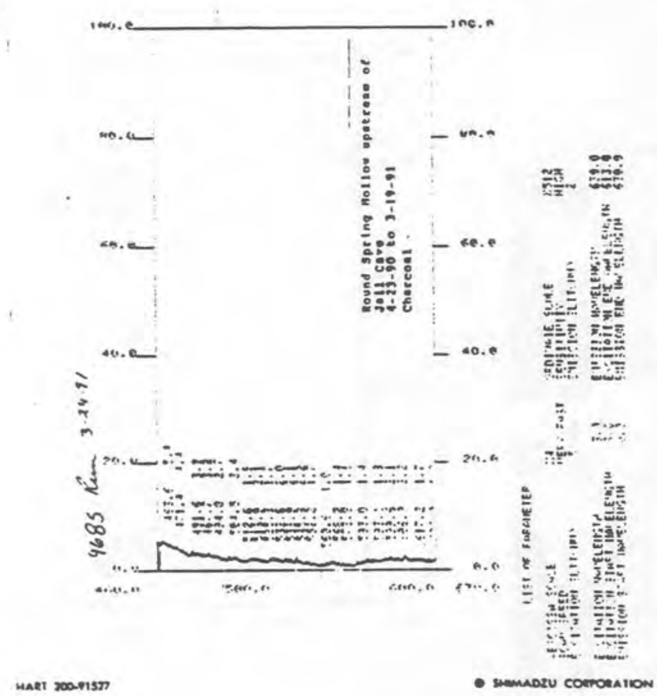


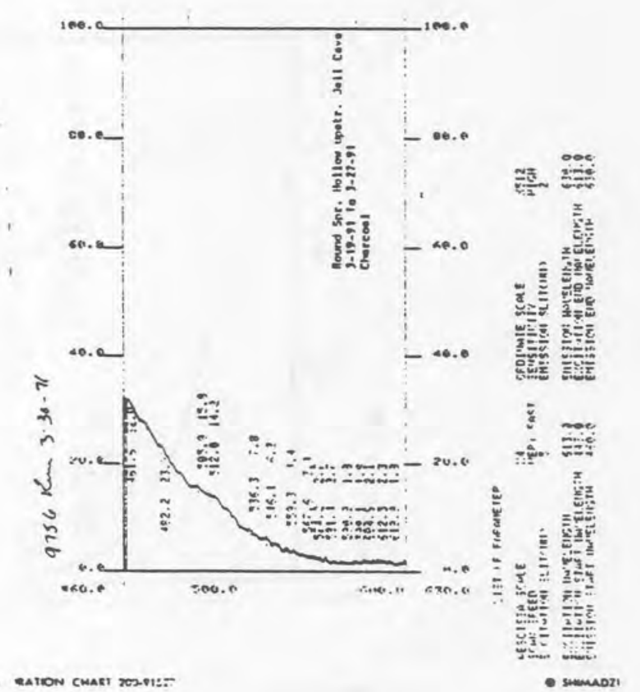
LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	513.0	EMISSION WAVELENGTH	570.0
EXCITATION START WAVELENGTH	442.0	EXCITATION END WAVELENGTH	613.0
EMISSION START WAVELENGTH	466.0	EMISSION END WAVELENGTH	630.0

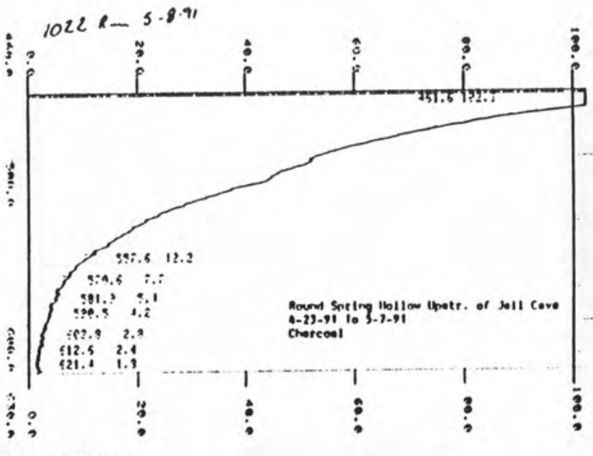

Round Spr. Hollow upstr. of Jell Cave
3-27-91 to 4-9-91
Charcoal
259 Run 4-10-91
LIST OF PARAMETER
500.0
600.0
SHIMADZU CORPORATION CHART


Round Spr. Hollow Upstr. of Jell Cave
4-9-91 to 4-23-91
Charcoal
750 Run 4-24-91
500.0
600.0
SHIMADZU CORPORATION CHART 200-91527


Round Spring Hollow upstream of
Jell Cave
4-23-90 to 3-19-91
Charcoal
9685 Run 3-24-91
LIST OF PARAMETER
500.0
600.0
HART 200-91527


Round Spr. Hollow upstr. Jell Cave
3-19-91 to 3-27-91
Charcoal
9756 Run 3-30-91
500.0
SHIMADZU CORPORATION CHA

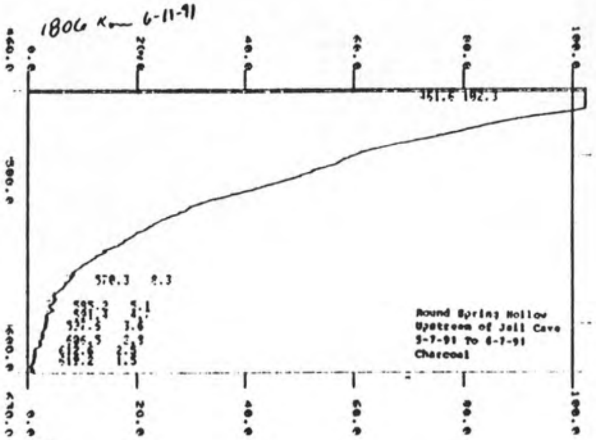
1022 R— 5-8-91



LIST OF PARAMETER

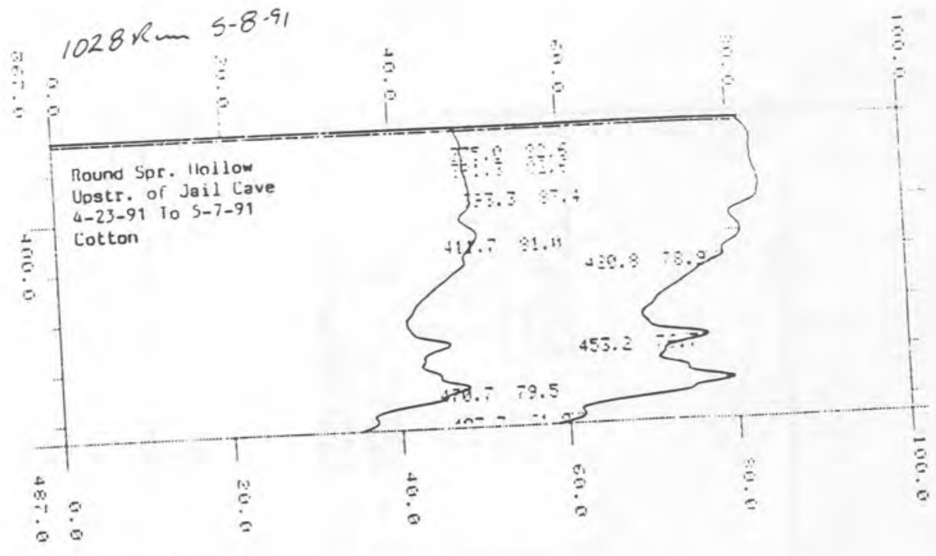
ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	613.0	EMISSION WAVELENGTH	570.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	613.0
EMISSION START WAVELENGTH	460.0	EMISSION END WAVELENGTH	630.0

1806 K— 6-11-91



LIST OF PARAMETER

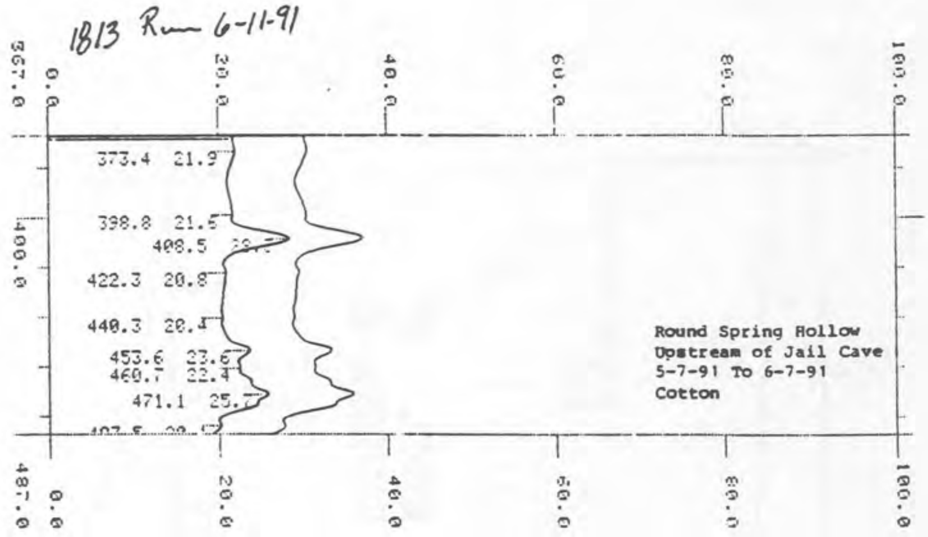
ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	613.0	EMISSION WAVELENGTH	570.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	613.0
EMISSION START WAVELENGTH	460.0	EMISSION END WAVELENGTH	630.0



LIST OF PARAMETER

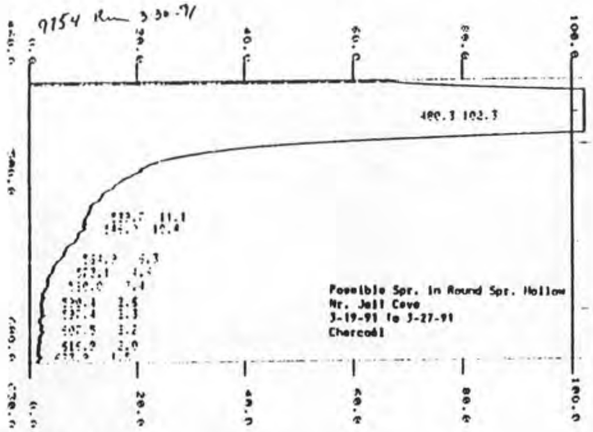
ABSCISSA SCALE	X4	ORDINATE SCALE	X16
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	470.0	EMISSION WAVELENGTH	487.0
EXCITATION START WAVELENGTH	350.0	EXCITATION END WAVELENGTH	470.0
EMISSION START WAVELENGTH	367.0	EMISSION END WAVELENGTH	487.0

.RT 200-91527



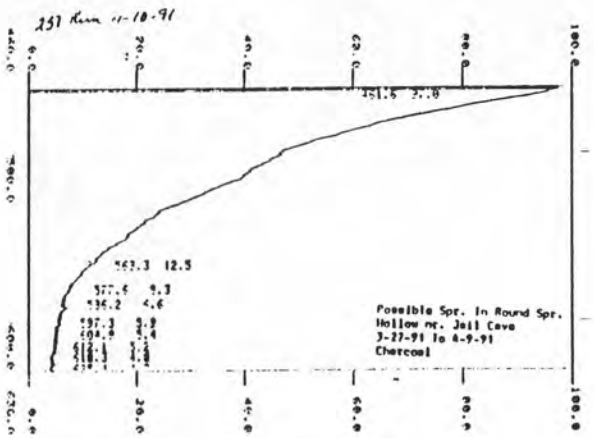
LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X16
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	470.0	EMISSION WAVELENGTH	487.0
EXCITATION START WAVELENGTH	350.0	EXCITATION END WAVELENGTH	470.0
EMISSION START WAVELENGTH	367.0	EMISSION END WAVELENGTH	487.0



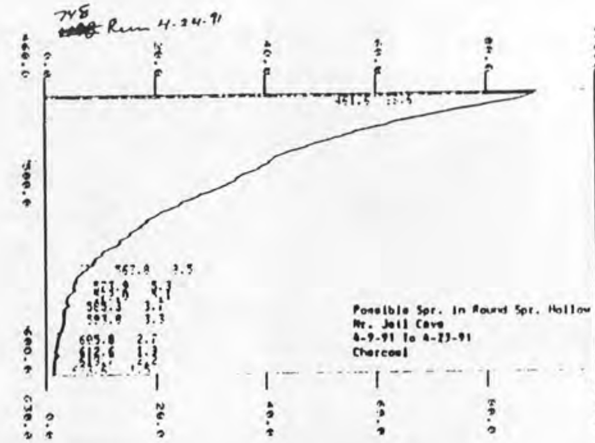
LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	613.0	EMISSION WAVELENGTH	630.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	613.0
EMISSION START WAVELENGTH	460.0	EMISSION END WAVELENGTH	629.0



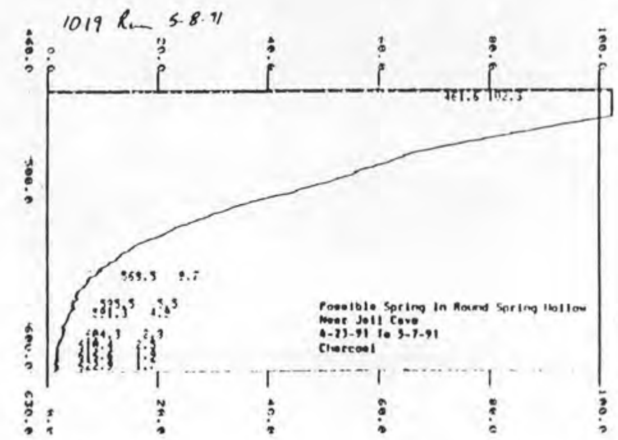
LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	613.0	EMISSION WAVELENGTH	630.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	613.0
EMISSION START WAVELENGTH	460.0	EMISSION END WAVELENGTH	630.0



LIST OF PARAMETER

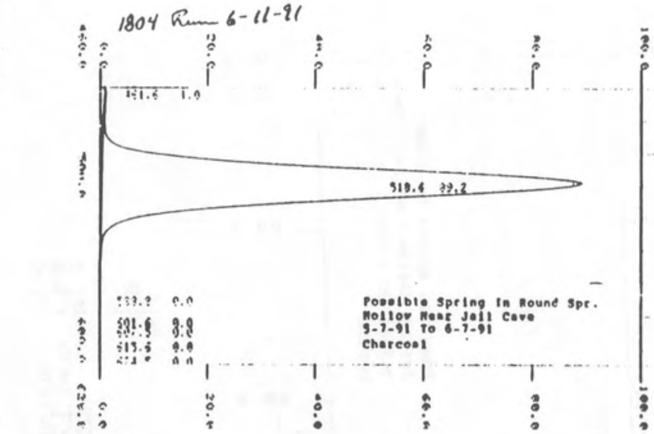
ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	613.0	EMISSION WAVELENGTH	630.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	613.0
EMISSION START WAVELENGTH	469.0	EMISSION END WAVELENGTH	629.0



LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	613.0	EMISSION WAVELENGTH	630.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	613.0
EMISSION START WAVELENGTH	469.0	EMISSION END WAVELENGTH	639.0

1804 Run 6-11-91



LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X1
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	513.0	EMISSION WAVELENGTH	670.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	613.0
EMISSION START WAVELENGTH	460.0	EMISSION END WAVELENGTH	630.0

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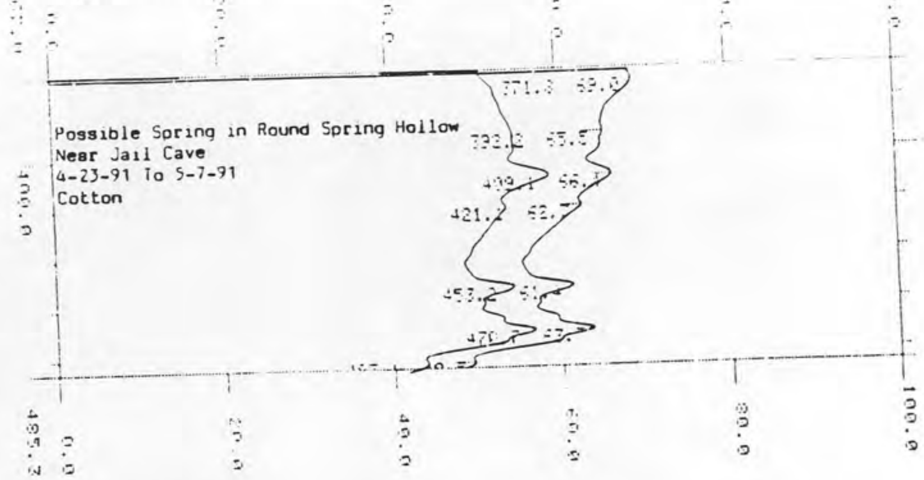
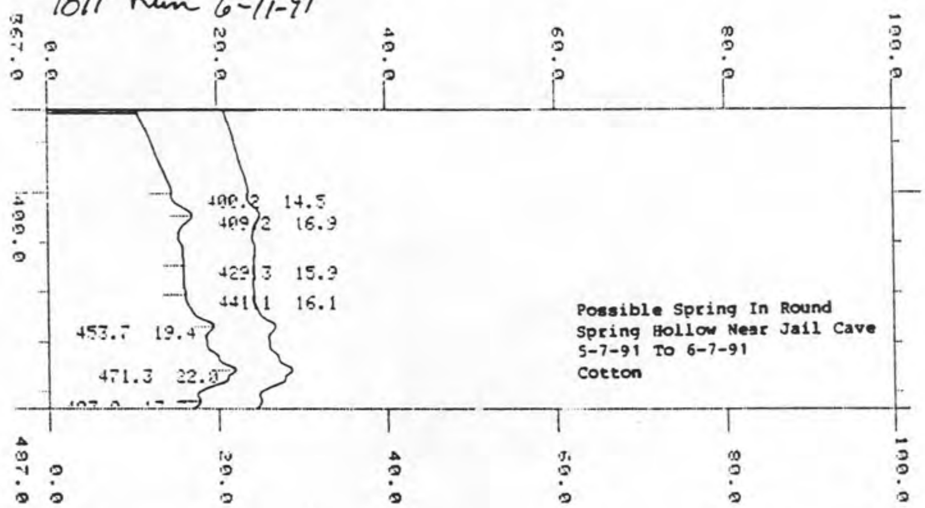
1026 Run 5-8-91



LIST OF PARAMETER

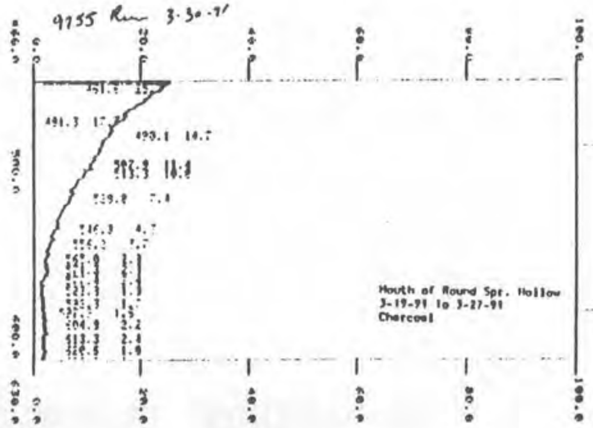
ABSCISSA SCALE	X4	ORDINATE SCALE	X16
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	470.0	EMISSION WAVELENGTH	487.0
EXCITATION START WAVELENGTH	350.0	EXCITATION END WAVELENGTH	470.0
EMISSION START WAVELENGTH	367.0	EMISSION END WAVELENGTH	487.0

1811 Run 6-11-91



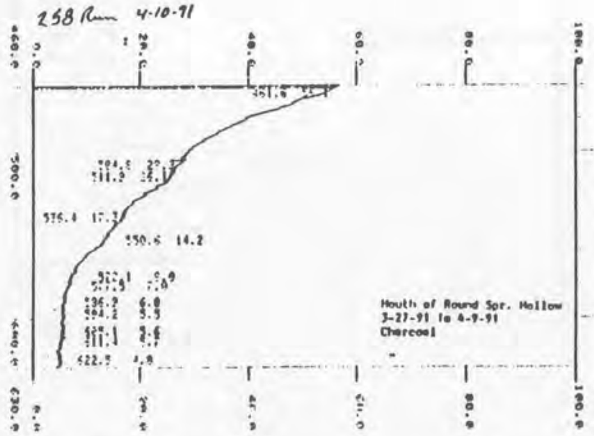
LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X16
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	470.0	EMISSION WAVELENGTH	487.0
EXCITATION START WAVELENGTH	350.0	EXCITATION END WAVELENGTH	470.0
EMISSION START WAVELENGTH	367.0	EMISSION END WAVELENGTH	487.0



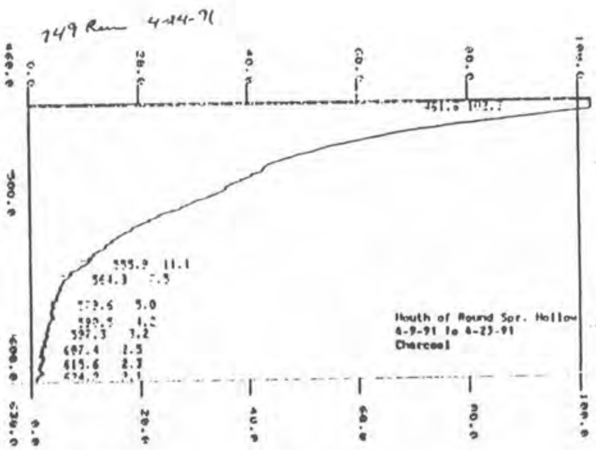
LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	613.0	EMISSION WAVELENGTH	570.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	613.0
EMISSION START WAVELENGTH	460.0	EMISSION END WAVELENGTH	630.0



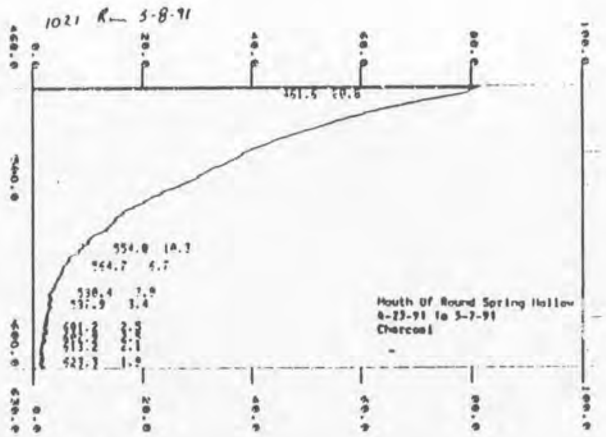
LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	613.0	EMISSION WAVELENGTH	570.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	613.0
EMISSION START WAVELENGTH	460.0	EMISSION END WAVELENGTH	630.0



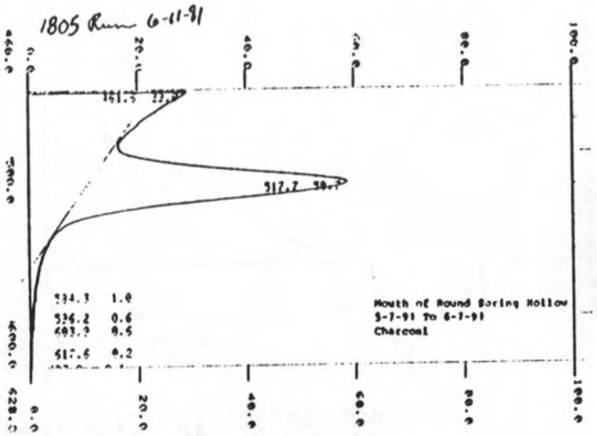
LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	613.0	EMISSION WAVELENGTH	570.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	613.0
EMISSION START WAVELENGTH	460.0	EMISSION END WAVELENGTH	630.0



LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	1
EXCITATION WAVELENGTH	613.0	EMISSION WAVELENGTH	570.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	613.0
EMISSION START WAVELENGTH	460.0	EMISSION END WAVELENGTH	630.0



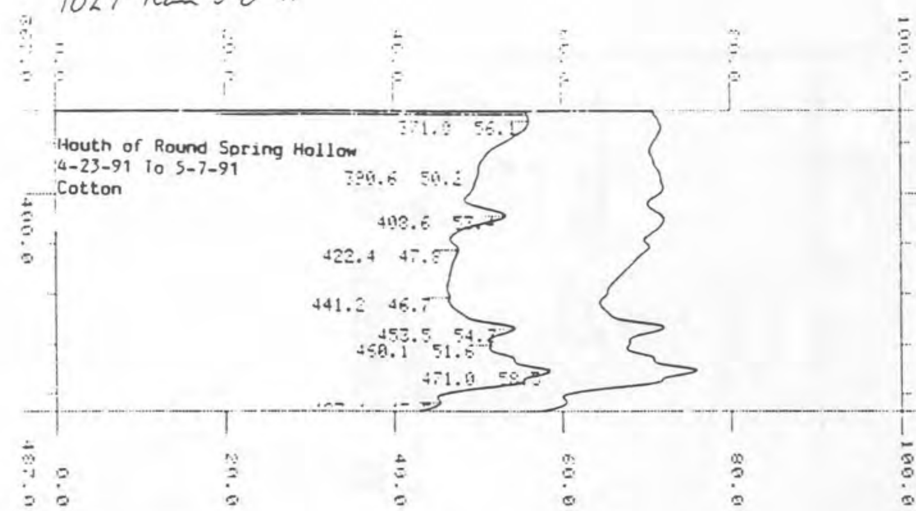
LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X128
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	513.0	EMISSION WAVELENGTH	530.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	513.0
EMISSION START WAVELENGTH	460.0	EMISSION END WAVELENGTH	620.0

ADZU CORPORATION CHART 200-91527

SHIMADZU CORPORATION CHART 200-91527

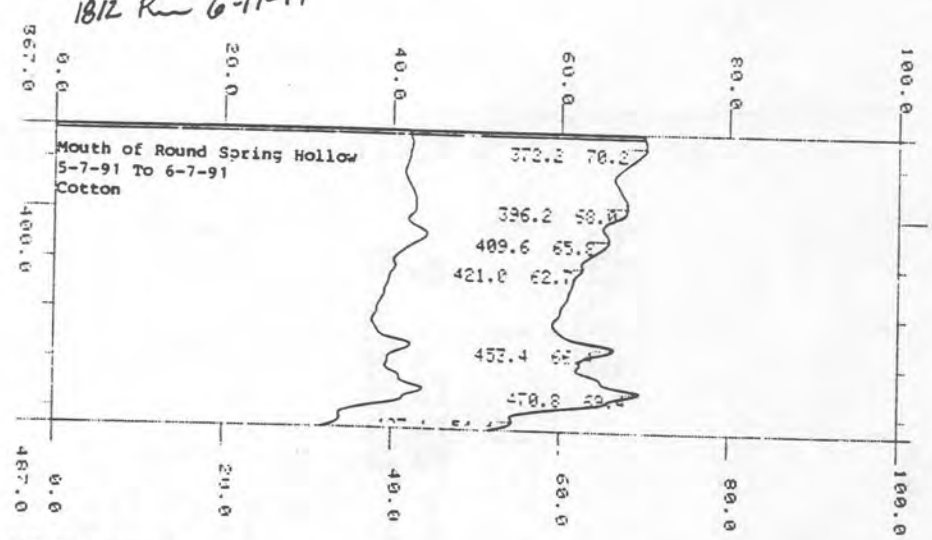
1027 Run 5-8-91



LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X16
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	470.0	EMISSION WAVELENGTH	487.0
EXCITATION START WAVELENGTH	350.0	EXCITATION END WAVELENGTH	470.0
EMISSION START WAVELENGTH	367.0	EMISSION END WAVELENGTH	487.0

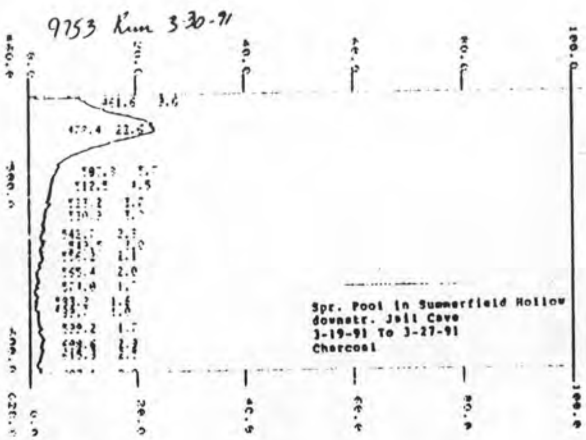
1812 Run 6-11-91



SHIMADZU CORPORATION CHA

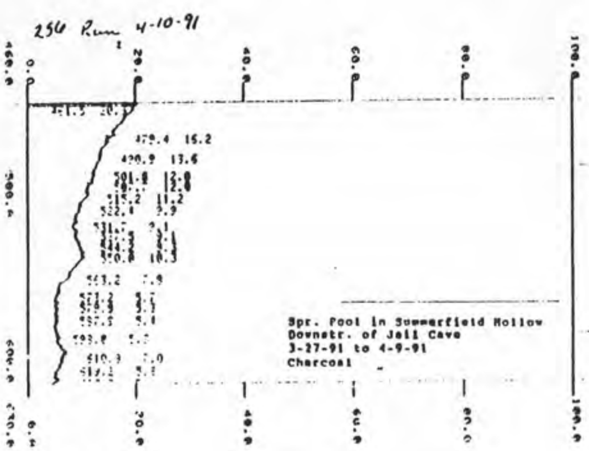
LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X16
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	470.0	EMISSION WAVELENGTH	487.0
EXCITATION START WAVELENGTH	350.0	EXCITATION END WAVELENGTH	470.0
EMISSION START WAVELENGTH	367.0	EMISSION END WAVELENGTH	487.0



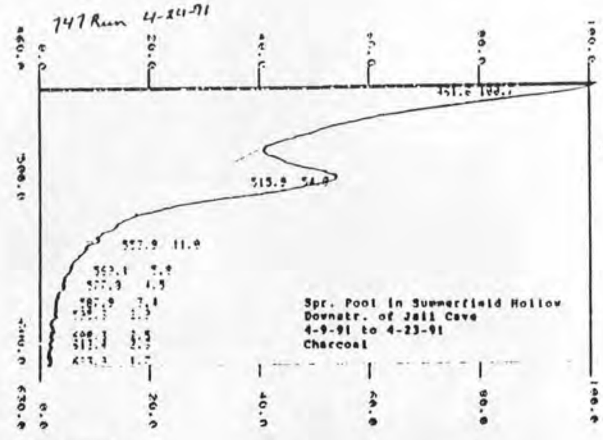
LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	613.0	EMISSION WAVELENGTH	670.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	613.0
EMISSION START WAVELENGTH	460.0	EMISSION END WAVELENGTH	632.0



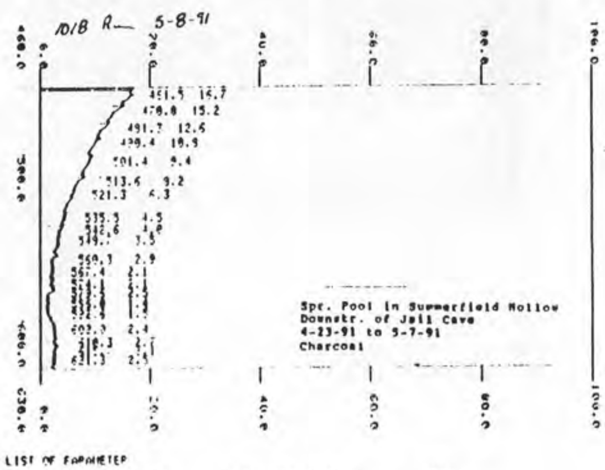
LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	613.0	EMISSION WAVELENGTH	670.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	613.0
EMISSION START WAVELENGTH	460.0	EMISSION END WAVELENGTH	630.0



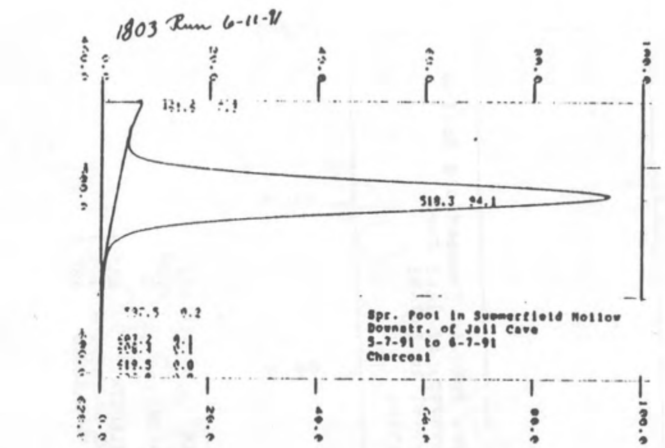
LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	613.0	EMISSION WAVELENGTH	670.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	613.0
EMISSION START WAVELENGTH	460.0	EMISSION END WAVELENGTH	630.0



LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	613.0	EMISSION WAVELENGTH	670.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	613.0
EMISSION START WAVELENGTH	460.0	EMISSION END WAVELENGTH	630.0

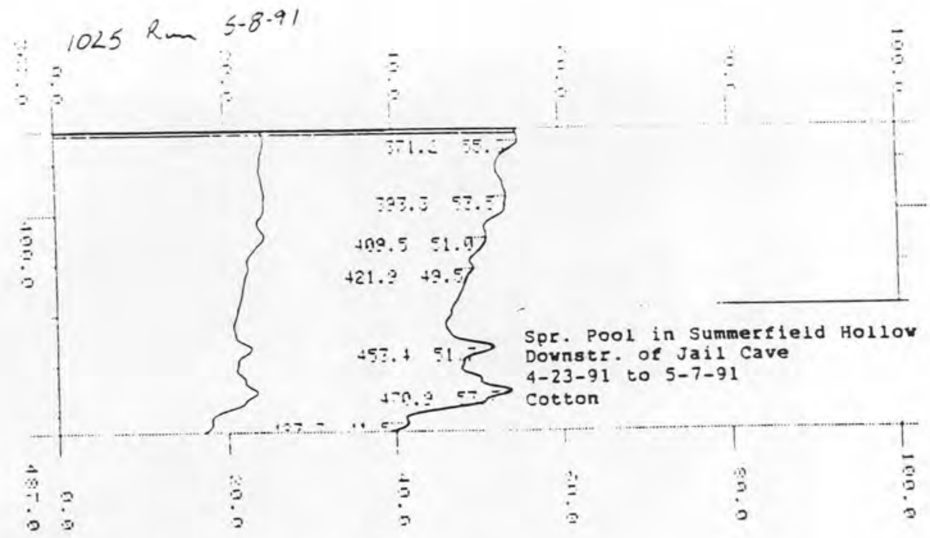


LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X72
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	613.0	EMISSION WAVELENGTH	670.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	613.0
EMISSION START WAVELENGTH	460.0	EMISSION END WAVELENGTH	630.0

● SHIMADZU CORPORATION CHART 200-91527

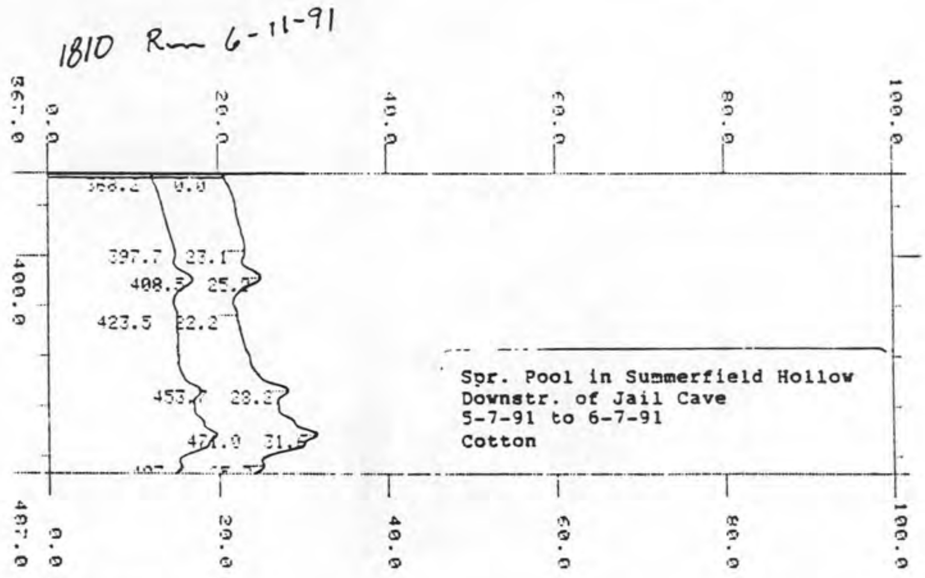
SHIMADZU CORPORATION CHART 200-91527



LIST OF PARAMETER

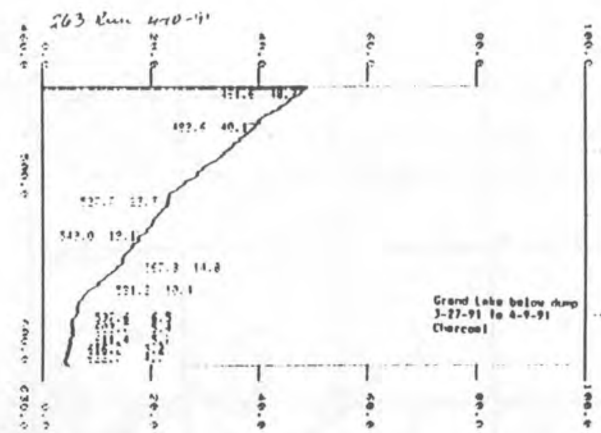
ABSCISSA SCALE	X4	ORDINATE SCALE	X16
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	470.0	EMISSION WAVELENGTH	487.0
EXCITATION START WAVELENGTH	350.0	EXCITATION END WAVELENGTH	470.0
EMISSION START WAVELENGTH	367.0	EMISSION END WAVELENGTH	487.0

⊕ SHIMADZU CORPORATION CHART 200-91527



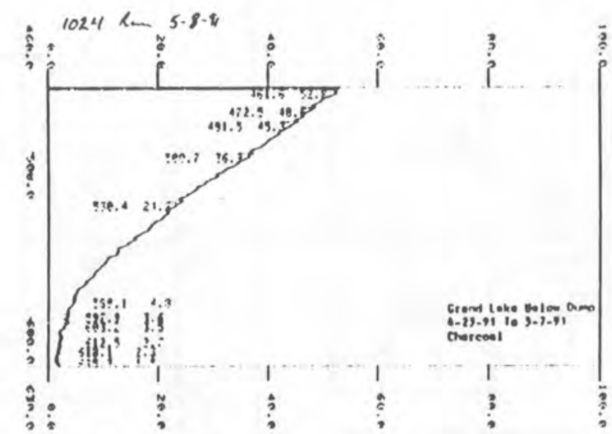
LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X16
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	470.0	EMISSION WAVELENGTH	487.0
EXCITATION START WAVELENGTH	350.0	EXCITATION END WAVELENGTH	470.0
EMISSION START WAVELENGTH	367.0	EMISSION END WAVELENGTH	487.0



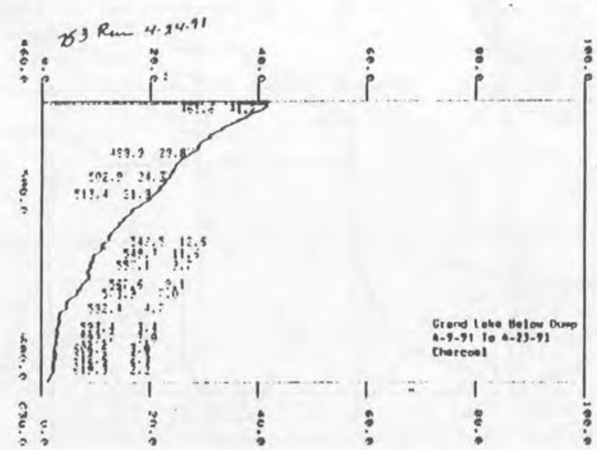
LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	613.0	EMISSION WAVELENGTH	670.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	613.0
EMISSION START WAVELENGTH	450.0	EMISSION END WAVELENGTH	630.0



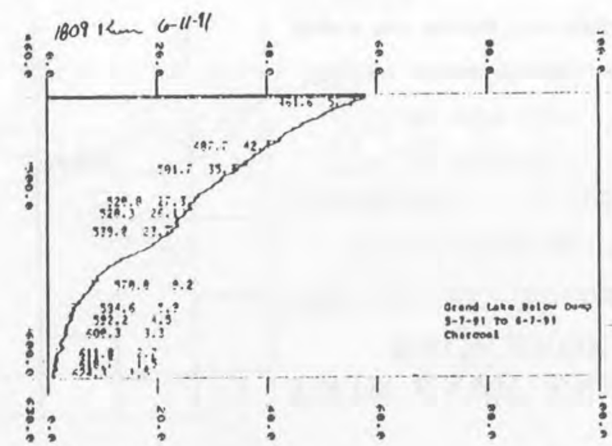
LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	613.0	EMISSION WAVELENGTH	670.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	613.0
EMISSION START WAVELENGTH	450.0	EMISSION END WAVELENGTH	630.0



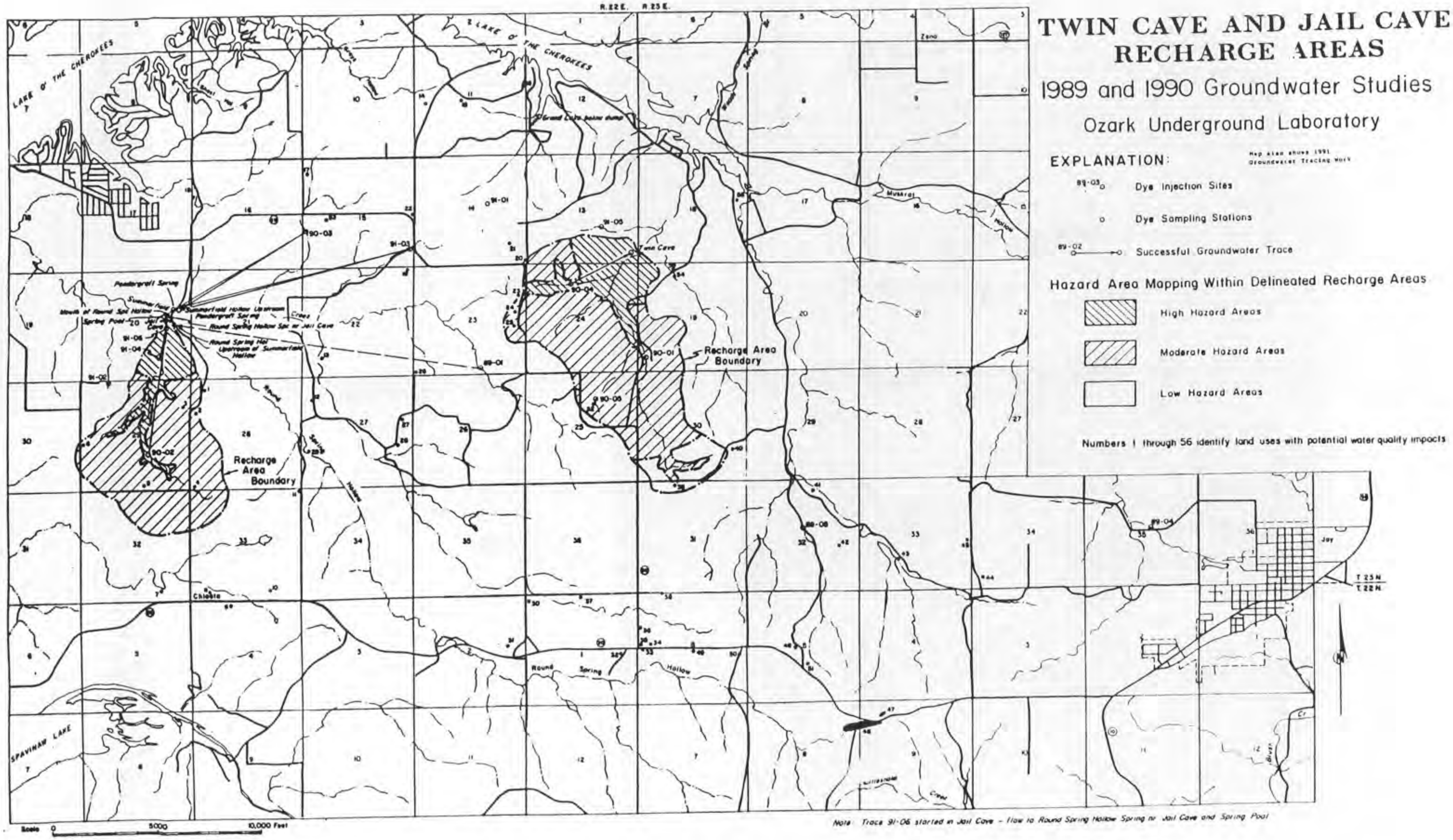
LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	613.0	EMISSION WAVELENGTH	670.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	613.0
EMISSION START WAVELENGTH	450.0	EMISSION END WAVELENGTH	630.0



LIST OF PARAMETER

ABSCISSA SCALE	X4	ORDINATE SCALE	X512
SCAN SPEED	VERY FAST	SENSITIVITY	HIGH
EXCITATION SLIT(NM)	5	EMISSION SLIT(NM)	2
EXCITATION WAVELENGTH	613.0	EMISSION WAVELENGTH	670.0
EXCITATION START WAVELENGTH	443.0	EXCITATION END WAVELENGTH	613.0
EMISSION START WAVELENGTH	450.0	EMISSION END WAVELENGTH	630.0


TWIN CAVE AND JAIL CAVE RECHARGE AREAS
1989 and 1990 Groundwater Studies
Ozark Underground Laboratory
EXPLANATION:
Dye Injection Sites
Dye Sampling Stations
Successful Groundwater Trace
Hazard Area Mapping Within Delineated Recharge Areas
High Hazard Areas
Moderate Hazard Areas
Low Hazard Areas
Numbers 1 through 56 identify land uses with potential water quality impacts
R.22E.
R.23E.
T.23N.
T.22N.
LAKE O' THE CHEROKEES
SPAVINAW LAKE
Recharge Area Boundary
Twin Cave
Pendergraft Spring
Spring Pool
Jail Cave
Round Spring Hollow
Zena
Jay
Chloeta
Scale 0 5000 10,000 Feet
Note: Trace 91-06 started in Jail Cave - flow to Round Spring Hollow Spring nr Jail Cave and Spring Pool