OZARK UNDERGROUND LABORATORY

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FINAL PHASE 1 REPORT WITH EMPHASIS ON FITTON CAVE AREA

INVENTORY AND DELINEATION OF KARST HYDROLOGY FEATURES, BUFFALO NATIONAL RIVER, ARKANSAS.

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An investigation and report prepared for the National Park Service, Buffalo National River, Harrison, Arkansas under Contract 1443RQ715096001.

EXECUTIVE SUMMARY

This report deals with the first phase of a two phase study to inventory karst hydrology features and to delineate groundwater recharge areas for important features and areas. Two study areas were involved in these investigations. The Regional Study Area is the larger area, and includes within it the Fitton Cave Study Area. During the Phase 1 work all groundwater tracing was limited to locations within the Fitton Cave Study Area. During the Phase 2 work the groundwater tracing work focused on the Regional Study Area. A subsequent report will deal with the findings from the Phase 2 work.

Section 1 of this report summarizes previous work in the regional study area with special attention to the Fitton Cave Study Area. Several previous groundwater traces (including two by the National Park Service) provided both credible and valuable data.

Section 2 of this report involved mapping of karst features in the Regional Study Area and identification of areas where land use activities might present hazards to groundwater quality. One of the important conclusions from this work was that essentially all of the streams in the areas underlain by the Boone Formation are losing streams, even when the streams have perennial flow. Losing streams are very important groundwater recharge areas.

Land uses which can adversely impact groundwater quality can be divided into point sources and non-point sources. While there are some point source groundwater quality hazard areas which we located and assessed, most of the land uses which impact or could impact groundwater quality are non-point sources.

Section 3 of the report dealt with groundwater tracing investigations to delineate the recharge area for Fitton Spring (which is analogous to the recharge area for Fitton Cave). A total of 13 sampling stations were established for this groundwater tracing work, and 11 separate dye introductions were made during the study. There were five successful traces to Fitton Spring (two of these also yielded dye to Van Dyke Spring). There were six successful groundwater traces to Van Dyke Spring, and two groundwater traces which yielded dye to neither Van Dyke Spring nor Fitton Spring.

The delineated recharge area for Fitton Spring is shown in Figure 3 and consists of two areas (Areas A and B on Figure 3). The total area which contributes recharge water to Fitton Spring is 5.40 square miles (3,460 acres). Approximately 92% of this area also contributes recharge water to Van Dyke Spring. The total area which contributes recharge water to Van Dyke Spring is also shown on Figure 3 and encompasses 12.59 square miles (8,050 acres).

To avoid misunderstandings, the areas which share recharge waters with Fitton and Van Dyke Springs do so in the following manner. During storm events some runoff water sinks from the surface into the groundwater system which feeds Fitton Spring. However, especially during larger runoff events, not all of the runoff water sinks; some remains on the surface until it has left the area which contributes water to Fitton Spring and then some of this surface runoff water enters the groundwater system where it contributes to the flow of Van Dyke Spring. We found no evidence in this study of any areas where the associated groundwater discharges from both of these springs.

It is our conclusion that the most significant present adverse hydrologic impact on Fitton Cave and Fitton Spring is probably sediments derived from the steep NPS service road which leads from the Erbie Road to the old cabin near Chestnut Spring. This road provides valuable access to the cave so that NPS personnel can routinely change the lock combination and check for forced entry into the cave. If this road is to remain open actions are needed to reduce erosion of the road and sediment input into the karst groundwater system.

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BIOGRAPHICAL SKETCH OF THE AUTHORS

Tom and Cathy Aley jointly direct the operations of the Ozark Underground Laboratory (OUL). The OUL is a privately owned contract research facility and hydrobiological field station located near Protem, Missouri. The Laboratory has been in full time operation since 1973 and provides nation-wide services.

Tom Aley holds B.S. and M.S. degrees in forestry, with emphasis in watershed management, from the University of California at Berkeley. He holds national certification as a Professional Hydrogeologist from the American Institute of Hydrology; is a Certified Forester, certified by the Society of American Foresters; is registered as a Professional Geologist in the states of Arkansas and Kentucky; and is a Registered Geologist in the state of Missouri. He has 34 years of professional experience in groundwater hydrology, hydrobiology, and land and water management issues in karst regions.

Cathy Aley holds B.A. and M.S degrees in biology and zoology, with emphasis in aquatic systems, from Wichita State University. She has 23 years of professional experience in groundwater hydrology, hydrobiology, and cave fauna management.

INTRODUCTION

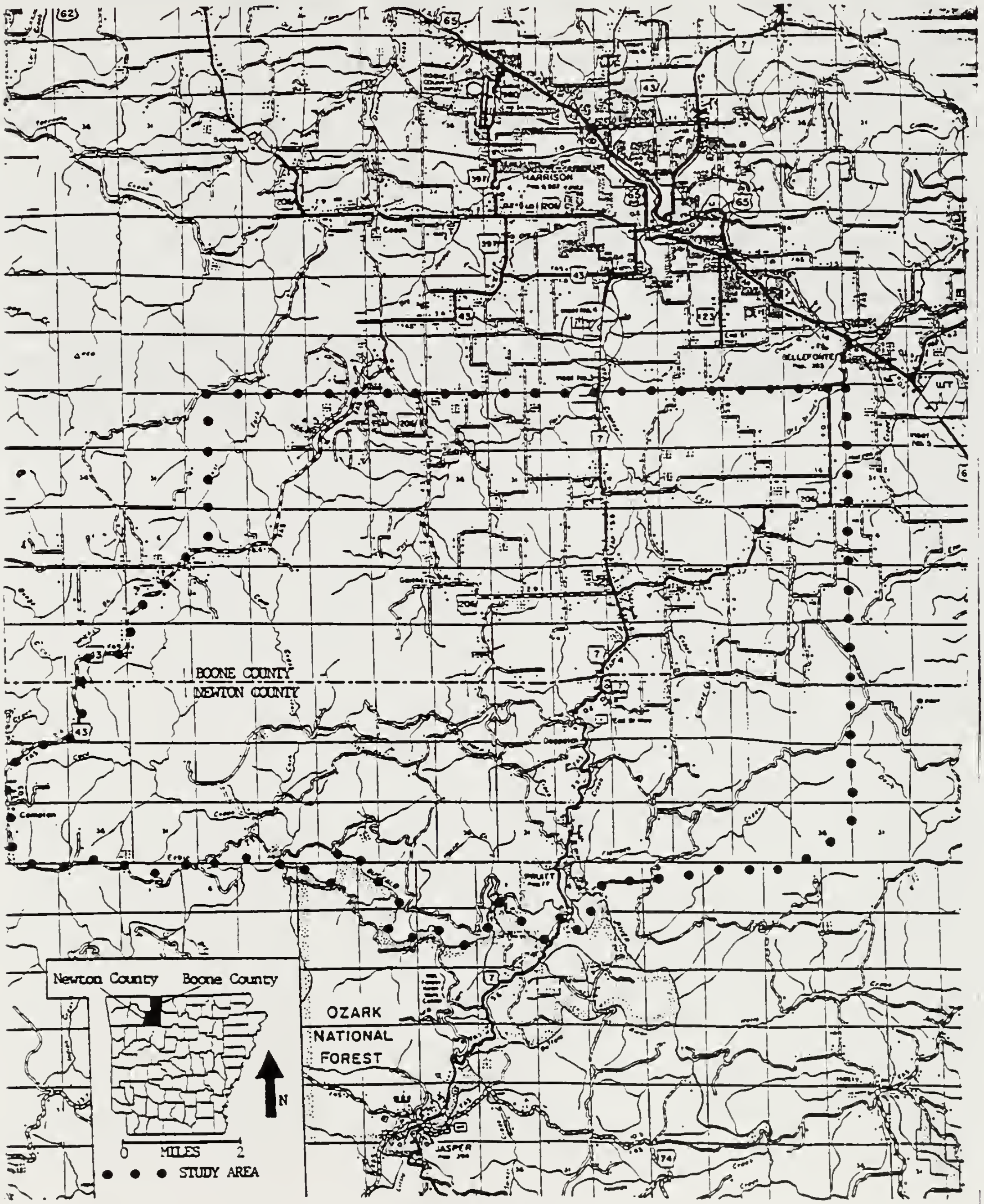
Purpose of the Study and Organization

This report deals with the first phase of a two phase study to inventory karst hydrology features and to delineate groundwater recharge areas for important features and areas. There are actually two study areas involved in this two phase study; we will call them the Regional Study Area and the Fitton Cave Study Area. The Fitton Cave Study Area is located within the south-western corner of the Regional Study Area. The Regional Study Area for the project was outlined by the National Park Service in their request for proposal for the study. Figure 1 is a reproduction of Figure 4 from that request for proposal. The Regional Study Area includes some of the lands located on the Ponca, Jasper, Harrison, Gaither, Osage NE, and Hasty 7.5 minute quadrangle maps. The Fitton Cave Study Area was not defined in any proposal documents; it is simply all lands which were studied to determine if they might contribute waters to Fitton Cave (and the associated Fitton Spring). The Fitton Cave Study Area includes the Cecil Creek topographic basin upstream of the mouth of Cove Creek plus a small portion of the Cove Creek topographic basin located generally south of Tom Thumb Spring and within about a mile and a half of Fitton Spring.

Phase 1 work consisted of three primary tasks. First, relevant work previously conducted in the project area was reviewed. Results of this review work are found in Section 1 of this report. Secondly, a karst inventory relevant to hydrological considerations was conducted for the project area. Results of this inventory work are found in Section 2 of this report. Thirdly, a groundwater tracing study was conducted to delineate the recharge area for Fitton Cave and Fitton Spring. Results of this groundwater work are found in Section 3 of this report.

Two definitions may help the reader. The <u>recharge area</u> for a cave or spring is that land which contributes water to the cave or spring. There are many losing streams in the Ozarks; a <u>losing stream</u> is a surface stream which loses appreciable portions of its flow in localized areas into the groundwater system.

Figure 1. Regional Study Area. Map source: National Park Service request for proposal.



LOCATION OF THE STUDY AREA AND APPROXIMATE BOUNDARY

Acknowledgements

We greatly appreciate the help and encouragement received from David Mott and Chuck Bitting of the National Park Service (NPS), Harrison, Arkansas. Among many things, they accompanied us on a trip into Fitton Cave, provided NPS file information for the region, and provided valuable insight into the hydrology of the Regional Study Area. Pete Lindsley, Project Manager of the Fitton Cave Survey for the Cave Research Foundation, also accompanied us on a trip into Fitton Cave and provided a highly useful set of the maps of the cave. These maps, when overlaid on the topographic map of the area, were of great value in designing our groundwater tracing program. Mark Hudson, U.S. Geological Survey, is involved in a current detailed geologic mapping of the Regional Study Area; he has been very helpful by sharing his preliminary data with us. His data have helped us select dye introduction locations for groundwater traces; the time he has spent with us in the field and in reviewing our preliminary work has been very beneficial to our investigations. Finally, we greatly appreciate the kindness and helpfulness of the many residents of the area who have given us access to their lands.

SECTION 1. PREVIOUS WORK IN THE REGIONAL STUDY AREA

Geology

The generalized geology of the Regional Study Area is depicted on the geologic map of Arkansas (Haley et al., 1976). Mark Hudson, U.S. Geological Survey, has conducted a detailed geologic mapping of the Regional Study Area and has prepared a preliminary map of the area and draft summary report (Hudson, 1998). This current mapping has identified a number of previously unmapped structural features which could have hydrogeological implications. Readers interested in detailed information on the geology of the Regional Study Area should consult Hudson (1998). The following summary is intended to provide a hydrogeologic summary of the geologic setting; thicknesses and areal extents of geologic units are based upon Hudson (1998).

The principal geologic unit in which cave and karst features are developed is the Boone Formation of Mississippian age. It is the geologic unit which underlies approximately 50% of the Regional Study Area, and has a typical thickness of 380 to 405 feet. This thickness includes a 30 to 50 foot thick basal St. Joe member (often called the St. Joe Limestone) and an overlying unnamed unit which comprises the remainder of the Boone Formation. The largest springs in the northern part of the Regional Study Area are Morris, Jenkins, and Milium Springs. All of these discharge from the unnamed upper member of the Boone Formation. The largest springs in the southern part of the Regional Study Area are Upper Dogpatch and Lower Dogpatch Spring; both of these springs discharge from the St. Joe member of the Boone Formation. All of the above springs have highly variable flow rates which routinely exceed one cubic foot per second (cfs). Van Dyke Spring and Fitton Spring also have highly variable flow rates which sometimes (but less often) exceed one cfs. Flow rate measurements and estimates will be summarized later in Table 1.

Overlying the Boone Formation are Mississippian and Pennsylvanian age rock units. In the Regional Study Area these units are comprised mostly of the Batesville Sandstone (40 to 70 feet thick) which immediately overlies the Boone Formation and the Fayetteville Shale (350 to 420 feet) which overlies the Batesville Sandstone. The Mississippian and Pennsylvanian age rocks overlying the Boone Formation underlie approximately 40% of the Regional Study Area. This area is predominantly along the western and southeastern margins of the Regional Study Area. In most cases, areas underlain by the Batesville Sandstone and Fayetteville Shale (and any other overlying rock units) yield overland runoff to areas underlain by the Boone Formation. Much of the runoff water which reaches the Boone Formation enters the karst groundwater system. Hudson (1998) comments that where the Batesville Sandstone has been stripped of the overlying Fayetteville Shale, the top of the Batesville Sandstone typically forms

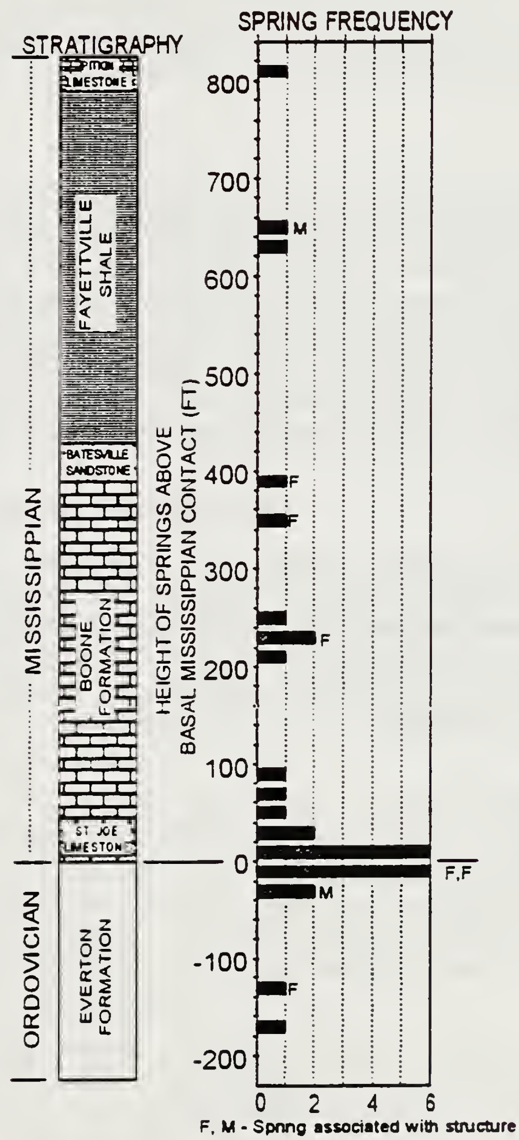
a topographic flat that is the common host of sinkholes formed by collapse into dissolutional cavities in the underlying Boone Formation. Especially in this type of setting it is clear that there is more or less vertical water movement downward through the Batesville Sandstone into the Boone Formation. Whether or not this is restricted to sinkhole collapse zones is unclear since the Batesville Sandstone is cemented with calcium carbonate and dissolution of the cement could result in the transport of sand grains into underlying karst conduits without appreciable structural collapse within the Batesville Sandstone. If this is the typical case, or the case in some settings, then recharge of the karst aquifer in the Boone Formation could occur in areas underlain by the Batesville Sandstone even if there is no evidence of sinkhole collapse. Finally, Bitting (pers. comm., 1999) has found that some sinkholes in the Batesville can form by dissolution of limestone beds found within the Batesville. Some caves are found in these Batesville limestone which transport water horizontally to springs discharging from the Batesville. Therefore, most (but not all) sinkholes in the Batesville directly transport groundwater to the Boone Formation.

Approximately 10% of the Regional Study Area is underlain by Ordovician age rocks which consist predominantly of the Everton Formation and a small amount of the Powell Dolomite. Areas underlain by these rocks are mostly near the Buffalo River and near Mill Creek, Harp Creek, and Flatrock Creek. There are some karst and paleokarst features found within these units. A number of springs discharge from the Ordovician age rock units.

Hudson (1998) developed a histogram relating spring frequencies to stratigraphy within the Regional Study Area. We have reproduced this histogram as Figure 2.

Hudson (1998) provides a structural contour map on the base of the Boone Formation. This map indicates (among other things) a trough near Van Dyke and Fitton Springs, and a bedrock low more or less along the Elmwood Fault Zone in areas northeast of Upper and Lower Dogpatch Springs. The map also indicates that the dip of the base of the Boone Formation in the Crooked Creek topographic basin portion of the Regional Study Area is generally toward the southwest. In contrast, surface water flow in this basin is generally toward the north. If regional groundwater flow were to parallel the general regional dip of the Boone Formation these data would suggest that much of the northern portion of the Regional Study Area might contribute groundwater to the Buffalo River topographic basin. However, the control over groundwater flow in karst aquifers is commonly hydraulic gradient rather than geologic structure. Phase 2 of this investigation is specifically concerned with directions of groundwater flow in the northern portions of the Regional Study Area. Results from the Phase 2 study will be reported upon in a subsequent document.

Figure 2. Histogram of springs frequency versus stratigraphic height above the basal contact of the Boone Formation within the Regional Study Area. F and M represent springs spacially associated with faults and monoclines, respectively. This illustration is a reproduction of Hudson (1998, Figure 5).



Speleology

Cave Research Foundation (1991) has conducted extensive mapping of cave passages in Fitton Cave and kindly provided copies of the map for our use in this study. The mapping is continuing. The mapping basically indicates that the northern limit of cave passages is beneath a small surface valley at a point about 500 feet north of the channel of the Chestnut Spring Branch. The eastern extent of mapped cave passages (CRF, 1991) is about 1,700 feet northwest of Fitton Spring. Mapping of the cave accessible from Fitton Spring shows that it extends westward to a point within about 500 feet of mapped portions of Fitton Cave.

Hydrology

There have been five groundwater traces conducted in the Regional Study Area prior to our work. One trace was associated with Fitton Cave and Fitton Spring (Lindsley, pers. comm.; 1965); two were conducted by the NPS and are associated with lands in the Crooked Creek topographic basin which discharge from Upper Dogpatch Spring and Lower Dogpatch Spring, and the other two traces (Terry, pers. comm. 1986) were from locations in the Mill Creek topographic basin which discharge from Upper Dogpatch Spring and Lower Dogpatch Spring. Each of these traces is discussed in the following sub-sections of this report.

Fitton Cave to Fitton Spring Trace

Pete Lindsley provided us with personal notes on a dye trace which he conducted in 1965 from the stream in Beauty (Fitton) Cave at the 47 foot waterfall to Fitton Spring (known at that time as Huchinson Spring). That trace was conducted with about 0.3 pounds of fluorescein dye mixture and yielded visible color in the spring. The travel time for the first detected arrival of the dye was 27.75 hours; the straight-line travel distance was about 1.25 miles (Lindsley, pers. comm.; 1965).

File data by NPS on Van Dyke Spring shows Hutchinson Spring as an alternate name for this spring. Pete Lindsley told Tom Aley in 1996 that the dye he introduced in Fitton Cave came out of the spring that is now called Fitton Spring; his written notes on the trace called the spring from which the dye was recovered Hutchinson Spring. This is consistent with our dye tracing data. It is our conclusion that Hutchinson Spring is an alternate name for Fitton Spring rather than for Van Dyke Spring.

Two groundwater traces within the Regional Study Area were conducted by the NPS from areas within the Crooked Creek topographic basin to springs in the Mill Creek basin. The tracing work was under the direction of Mr. David Mott, Hydrologist with the NPS. The traces are summarized in the following

paragraphs. It is our conclusion that the results of both tests are credible and that the methods employed were adequate. Furthermore, as will be discussed in the Phase 2 report, the results are consistent with tracing results from our work on the Phase 2 study.

NPS Trace 1; Mildred Sink Trace

This trace is known as the Mildred Sink Trace. This sinkhole is located in the SW 1/4 SW 1/4 NE 1/4 Section 8, T17N, R20W. The area is shown on the Gaither 7.5 minute quadrangle map, and lies within the Crooked Creek topographic basin. The elevation of the dye introduction point was approximately 1,260 feet.

On May 26, 1992 at 1730 hours 2.2 pounds of fluorescein dye mixture (diluent percentage unknown, but probably 25 to 50%) was introduced with 30 gallons of water into this sinkhole. Sampling stations utilized for this study were as follows:
Lower Dogpatch Spring. NW 1/4 SE 1/4 Section 20, T17N, R20W.
Upper Dogpatch Spring. NE 1/4 SW 1/4 Section 20, T17N, R20W.
Hankins Cave. SW 1/4 SW 1/4 NW 1/4 Section 17, T17N, R20W.
East Fork Crooked Creek upstream of its confluence with the West Fork. SW 1/4 NW 1/4 Section 28, T18N, R20W.
West Fork Crooked Creek at Highway 7 Bridge (which is upstream of the confluence of the East and West Forks of Crooked Creek). SE 1/4 NE 1/4 Section 29, T18N, R20W.
Jenkins Spring. SW 1/4 NW 1/4 Section 28, T18N, R20W.
Milum Spring. SE 1/4 SW 1/4 Section 28, T18N, R20W.
Morris Spring. SE 1/4 SW 1/4 Section 30, T18N, R20W.
Harp Creek at Highway 7 Bridge. SW 1/4 NW 1/4 Section 32, T17N, R20W.

Background sampling was conducted at all sampling stations prior to the dye introduction. After dye introduction, sampling continued at all stations until July 16, 1992.

Lower Dogpatch Spring was the only sampling station at which dye from the Mildred Sink Trace was recovered. An activated carbon sampler in place at this sampling station for the period from May 26 to June 2, 1992 was very strongly positive for fluorescein dye when eluted with a strong base, alcohol, and water solution. An activated carbon sampler in place at this station for the period from June 2 to June 15, 1992, was also very strongly positive for fluorescein dye. An activated carbon sampler in place for the period from June 15 to July 1, 1992 was very weakly positive for fluorescein dye. Fluorescein dye was not detectable in an activated carbon sampler in place for the period from July 1 to 16, 1992.

NPS Trace 2; Trotter Sink Trace

This trace is known as the Trotter Sink Trace. This sinkhole is located in the SE 1/4 SE 1/4 NE 1/4 Section 6, T17N, R20W. The area is shown on the Gaither 7.5 minute quadrangle map, and lies within the Crooked Creek topographic basin. The elevation of the dye introduction point is approximately 1,200 feet.

On June 18, 1993 at 1000 hours 2.2 pounds of fluorescein dye mixture (diluent percentage unknown, but probably 25 to 50%) was introduced with about 2,000 gallons of water into this sinkhole. The water was delivered in seven tanker loads of about 270 gallons each; this water disappeared into the sinkhole at flow rates of up to 100 gallons per minute (which was the maximum discharge rate available for the tank truck). Sampling stations utilized for this study were as follows:
Lower Dogpatch Spring. NW 1/4 SE 1/4 Section 20, T17N, R20W.
Upper Dogpatch Spring. NE 1/4 SW 1/4 Section 20, T17N, R20W.
East Fork Crooked Creek upstream of its confluence with the West Fork. SW 1/4 NW 1/4 Section 28, T18N, R20W.
West Fork Crooked Creek at Highway 7 Bridge (which is upstream of the confluence of the East and West Forks of Crooked Creek). SE 1/4 NE 1/4 Section 29, T18N, R20W.
Jenkins Spring. SW 1/4 NW 1/4 Section 28, T18N, R20W.
Harp Creek at Highway 7 Bridge. SW 1/4 NW 1/4 Section 32, T17N, R20W.

There are no data indicating that background sampling was conducted at any or all of the sampling stations prior to dye introduction. After dye introduction, sampling continued at all stations until July 1, 1993.

Upper Dogpatch Spring was the only sampling station at which dye from the Trotter Sink Trace was recovered. An activated carbon sampler in place at this sampling station for the period from June 18 to June 23, 1993 was strongly positive for fluorescein dye when eluted in a strong base, alcohol, and water solution. Fluorescein dye was not detectable in an activated carbon sampler in place at this station for the period from June 23 to July 1, 1993.

Traces in the Mill Creek Basin.

Jim Terry (1986, pers. comm.) reported on a successful groundwater trace he conducted from the underground stream in Hankins Cave. He introduced fluorescein dye in this stream on September 15, 1986 and recovered it from Upper Dogpatch Spring (but not from Lower Dogpatch Spring) in activated carbon samplers recovered on September 21, 1986. The point of dye introduction in Hankins Cave was apparently in the SW 1/4 SW 1/4 NW 1/4 Section 17, T17N, R20W.

Jim Terry (1986, pers. comm.) also reported that in the 1950's Albert Raney placed dye (probably fluorescein) in the stream of a cave known as the 110 Foot Sinkhole. This feature is located in the SE 1/4 SE 1/4 SE 1/4 Section 17, T17N, R20W. Mr. Terry reports that this dye discharged from Lower Dogpatch Spring within 48 hours, but that there was never any dye detected from Upper Dogpatch Spring.

While data on the Terry Trace of 1986 are limited, Mr. Terry reported his findings to us in substantial detail and we are convinced that the results are credible. The report of the Raney Trace in the 1950's is anecdotal and may not be correct. However, the results of both the Terry and Raney Traces are reasonable in view of the results from the 1992 and 1993 tracing work conducted by the NPS and work conducted by the OUL during Phase 2 of the present study.

Groundwater Tracing Adjacent to the Regional Study Area

Three major groundwater tracing and related groundwater hydrology studies have been conducted by the OUL in areas near the present Regional Study Area. Groundwater tracing associated with Bear Creek Spring and Smokehouse Spring (Aley, 1995) showed that areas within about three miles north of the present Regional Study Area contribute waters to these springs. Groundwater tracing studies in the Green Forest area (Aley, unpublished data, 1985 to 1987) involved areas within about seven miles northwest of the present Regional Study Area. Groundwater tracing in the Pindall and Mitch Hill Springs area (Aley, 1988; Aley and Aley, 1989) involved lands within about twelve miles southeast of the present Regional Study Area. Hydrogeologic conditions in all three of these areas share many features in common with the conditions found in the present Regional Study Area.

The groundwater tracing work in the Green Forest area demonstrated that some of the waters sinking in the channel of Dry Creek downstream of Green Forest move beneath the topographic boundary of this basin and discharge from springs in the adjacent Long Creek basin. Dyes introduced in Dry Creek immediately downstream of the sewage treatment plant serving Green Forest and its industries were recovered from a number of springs and wells in an area encompassing about 60 square miles. This tracing work also demonstrated that the karst groundwater system did not provide effective natural cleansing, and that travel rates through the groundwater system were typically on the order of several miles per week. Similar findings were made in both of the other two nearby study areas. The Green Forest study demonstrated that potentiometric maps of the area were poorly suited to predicting groundwater flow directions as demonstrated by dye tracing investigations. This was due to several factors,

including highly variable depths of the wells used for the mapping and the fact that groundwater movement in karst conduits can be nearly parallel to equipotential lines.

Major groundwater tracing studies were conducted at Bear Creek Spring and the associated Smokehouse Spring for the Arkansas Highway and Transportation Department by the OUL in 1994 and 1995 (Aley, 1995). These studies demonstrated that the recharge area for Bear Creek Spring and Smokehouse Spring extend to a point within about 3 miles of the northern border of the present Regional Study Area. The Aley (1995) studies were focused on potential new highway corridors north of Harrison for US Highway 65 and for a proposed new interchange area for US Highways 65 and 412. As a result, field work in areas nearest to the present Regional Study Area was limited. However, the Aley (1995) investigations do not indicate that any portions of the present Regional Study Area contribute waters to Bear Creek Spring or Smokehouse Spring.

The groundwater tracing studies in the Pindall and Mitch Hill Spring area showed that groundwater flow routes can change dramatically from one season to another. Under wet weather conditions in the Pindall area lands north of the Mill Creek Graben contribute water to Keith Spring; this spring is located about 9,500 feet north of the graben and is a surface tributary to Clear Creek. Under dry weather conditions, groundwater gradients are reversed and flow is toward the southwest with discharge from Mitch Hill Spring, a tributary to the Buffalo River. One trace, conducted just prior to the time when Keith Spring ceased flowing due to dry weather, showed that dye introduced immediately downstream of Keith Spring subsequently discharged from Mitch Hill Spring.

Groundwater tracing studies in the Pindall and Mitch Hill Spring area also demonstrated that springs often share their recharge areas with other springs. This often results in complex groundwater flow systems (Aley, 1988). Structural features such as faults and grabens may enhance dissolution of the rock, yet groundwater flow does not necessarily follow these features. Major groundwater flow routes to Mitch Hill Spring are almost at a right angle to the orientation of the Mill Creek Graben. To avoid confusion, the Mill Creek in the Pindall area is a different Mill Creek from the one in the current Regional Study Area.

Potentiometric Mapping

Pugh (1998) provided a map of the potentiometric surface of the Ozark Aquifer in northern Arkansas. The contour interval on the map was 100 feet, and the map included an area which encompassed portions of 16 counties. The map depicted potentiometric surface elevations of the aquifer in the range of about 1,000 to 1,200 feet for those portions of the Crooked Creek topographic

basin which are within our Regional Study Area. Within the Mill Creek topographic basin, the elevations shown range from about 900 to 1,100 feet. This map suggests that, within the Regional Study Area, the groundwater gradient is steeper near the Buffalo River and that the groundwater divide between the Crooked Creek and Mill Creek topographic basins is located near the Newton and Boone County border. In this area the map is based upon a very limited number of relevant data points, and as a result is highly subjective and it seems likely that the groundwater divide was drawn so as to approximately coincide with the topographic divide. As a result, the map is not particularly useful in identifying spring recharge area boundaries.

Spring Inventories

The NPS has inventoried many of the perennial springs in the Regional Study Area. The data are most extensive for those springs within the Buffalo River topographic basin. The springs inventoried by the NPS have been entered into an NPS data base. Springs inventoried by the NPS in the Regional Study Area include the following; alternate names are those the OUL has encountered during this study:

Upper Dogpatch Spring.
Lower Dogpatch Spring (alternate names Marble Falls Spring; Bluff Spring).
James Spring (Unknown Spring by U.S. Geological Survey).
Jenkins Spring.
Morris Spring.
Milum Spring (alternate names Caravan Spring, Double Spring).
Spring on Harp Creek in Section 30, T17N, R20W.
Walled Spring.
Unnamed Spring on Cecil Creek upstream of Broadwater Hollow.
Willis Spring.
Compton Road Spring.
Unnamed Spring; on surface tributary to Cecil Creek.
Chestnut Spring.
Van Dyke Spring (apparently incorrect alternate name is Hutchinson Spring).
Mill Creek Boil (Boiling Spring; Unknown Spring by U.S. Geological Survey).
Fitton Spring (alternate name Hutchinson Spring).
East Fork Braden Mountain Hollow Spring.
West Fork Braden Mountain Hollow Spring.

Flow Rates of Springs

There have been a limited number of flow rate estimates and measurements made of springs in and near the Regional Study Area. We have summarized the available data in the following paragraphs. Table 1 summarizes this information.

Table 1. Spring flow measurements and estimates. E = Estimate

Spring	Date	Flow Rate (cfs)	Reference
Boiling	5/2/68	1.27	Lamonds (1972)
Dogpatch, Lower	5/2/68	8.42	Lamonds (1972)
	8/19/91	1.9	Maner and Mott (1991)
	3/19/92	6.3	NPS file data
	5/26/92	3.4	NPS file data
	3/2/98	37.5	NPS file data
	5/5/98	5.9	NPS file data
Dogpatch, Upper	8/19/91	0.9	Maner and Mott (1991)
	3/19/92	3.6	NPS file data
	5/26/92	1.6	NPS file data
	3/2/98	12.6	NPS file data
	5/5/98	2.8	NPS file data
Fitton	7/15/92	0.18	NPS file data
	8/30/96	0.1E	OUL
	11/8/96	5.0E	OUL
James	5/2/68	2.61	Lamonds (1972)
	7/5/92	0.24	NPS file data
	3/2/98	2.7	NPS file data
	5/5/98	0.9	NPS file data
Jenkins	1963	0.7	Estimated July-Aug. flow rate. MME (1963)
	3/2/98	6.7	NPS file data
	5/5/98	3.1	NPS file data

Table 1 (continued). Spring flow measurements and estimates. E = Estimate

Spring	Date	Flow Rate (cfs)	Reference
Milum	12/27/44	1.13	MME (1963)
	1963	0.9 to 1.1	Estimated July-Aug. flow rate. MME (1963)
	5/15/63	1.7 E	MME (1963)
	3/2/98	2.5	NPS file data
	5/5/98	3.5	NPS file data
Morris	1963	0.56	Estimated July-Aug. flow rate. MME (1963)
	5/15/63	0.7 to 0.9 E	MME (1963)
Van Dyke	7/15/92	0.62	NPS file data
Wilson *	1963	0.8 to 0.9	Estimated July-Aug. flow rate. MME (1963)
	6/3/97	1.0E	OUL
	3/2/98	5.3	NPS file data
	5/5/98	2.3	NPS file data

* Outside Regional Study Area.
MME (1963 = Max Mehlburger Engineers, 1963).

Max Mehlburger Engineers (1963) did a water supply assessment of the City of Harrison water supply for the Harrison Chamber of Commerce. In 1963, the population of Harrison was 6,600 and the entire water supply for the city was provided by Jenkins Spring and Mitchell Spring. Jenkins Spring is within the Regional Study Area; Mitchell Spring (currently known as Wilson Spring) is about three miles north of the Regional Study Area although it was routinely monitored for the presence of tracer dyes during Phase 2 of this investigation. Max Mehlburger Engineers (1963) included a statement about Wilson Spring in the cover letter to their report; they apparently did not realize that Wilson Spring was an alternate name for Mitchell Spring. The location indicated on a map with their report verify that Mitchell and Wilson Spring are alternate names for the same spring.

Max Mehlburger Engineers (1963) reported that Mitchell (Wilson) Spring was developed as a city water supply in 1916, and that its flow rate was as small as 350 to 400 gallons per minute (gpm) during July and August. Jenkins Spring was developed as a city water supply in 1952, and had a low flow rate during July and August estimated at about 315 gpm. Milum Spring was estimated to have flow rates of about 400 to 500 gpm during summer conditions. The flow of this spring was measured on December 27, 1944 at 510 gallons per minute, and was estimated to be 750 gpm on May 15, 1963. Milum Spring is within the Regional Study Area; it is also known as Caravan Spring and Double Spring. The name "Caravan Spring" undoubtedly derives from the fact that the Fancher wagon train gathered at this spring prior to leaving for California. This wagon train was the victim of the Mountain Meadows Massacre, which occurred in what is now southern Utah; a monument on the Harrison square provides information on the massacre.

Max Mehlburger Engineers (1963) estimated that the flow of Morris Spring (also in the Regional Study Area and monitored during the dye tracing studies) was 300 to 400 gpm on May 15, 1963. They further estimated that dependable summer flow rates of this spring would be about 250 gpm.

Lamonds (1972) presents water resources data for the Ozark Plateaus Province of Northern Arkansas; this includes our Regional Study Area. This report has only limited utility to our investigation. However, it does include a table summarizing measured flow rates from 27 selected springs in the large study area used by Lamonds (1972). Three springs in our Regional Study Area were included in this table. Marble Falls Spring (called Dogpatch Spring in our study) had a measured flow rate on May 2, 1968 of 8.42 cfs (Lamonds, 1972). A spring which Lamonds (1972) labelled as having an unknown name; known in this study as James Spring, had a measured flow rate on May 2, 1968 of 2.61

cfs. Another spring which Lamonds (1972) labelled as having an unknown name; known in this study as Boiling Spring, had a measured flow rate on May 2, 1968 of 1.27 cfs.

Water Quality Investigations

Two University of Arkansas reports have dealt with general groundwater conditions typical of the Boone Formation in Northwest Arkansas (Ogden, 1980; MacDonald et al., 1975). Both of these reports demonstrate that the Boone Formation, in areas near our Regional Study Area, is vulnerable to groundwater pollution. As noted earlier, most of our Regional Study Area is underlain by the Boone Formation or by areas which yield runoff water to the Boone Formation. A report by the Northwest Arkansas Economic Development District (1973) also recognizes the vulnerability of the groundwater system in our Regional Study Area.

Mott (1997) summarized ten years of water quality monitoring for the Buffalo National River. This is an excellent summary report for the region in general, yet it does not provide much information specific to the Regional Study Area since such data do not exist.

Maner and Mott (1991) conducted a water quality survey of Mill Creek and collected a number of water quality samples on August 19, 1991. This study indicated that Mill Creek was a major source of nitrogen for waters in the Buffalo River. The NPS has subsequently done additional water quality monitoring of springs in the Regional Study Area. Table 2 summarizes existing water quality data for springs in and near the Regional Study Area; the parameters summarized in the table are specific conductance, nitrate nitrogen, fecal coliform, and chloride. Other parameters were also measured, but are not included in this discussion.

Table 2. Water quality measurements at selected springs in and near the Regional Study Area. SC = Specific Conductance

Spring	Date	SC micromhos per cm	Nitrate (N) mg/l	Fecal coliform colonies/ 100 ml	Chloride mg/l	Data Source
Chestnut	8/30/96	249	--	--	--	OUL
Dogpatch, Upper	8/4/91	323	1.00	44	--	Maner & Mott 1991
	3/2/98	285	1.19	18	5.1	NPS
	5/5/98	407	1.14	12	4.5	NPS
Dogpatch, Lower	8/4/91	319	1.46	--	--	Maner & Mott 1991
	3/2/98	225	1.05	112	4.8	NPS
	5/5/98	375	1.56	18	5.8	NPS
Fitton	6/3/97	133	--	--	--	OUL
	8/30/96	220	--	--	--	OUL
James	3/2/98	225	0.325	32	2.3	NPS
	5/5/98	379	0.294	12	2.6	NPS
Jenkins	3/2/98	270	1.59	18	4.0	NPS
	5/5/98	356	1.32	28	3.7	NPS
Milum	3/2/98	280	1.73	14	4.2	NPS
	5/5/98	371	1.49	14	4.1	NPS
Van Dyke	6/3/97	211	--	--	--	OUL
Wilson	6/3/97	320	--	--	--	OUL
	3/2/98	300	2.94	6	6.0	NPS
	5/5/98	400	3.04	4	5.8	NPS

We can draw some water quality generalizations from the data presented in Table 2. The reader should recognize that the data are limited, and as a result may change as more data become available.

Lower Dogpatch Spring has a greater flow rate than does Upper Dogpatch Spring. Comparing Lower Dogpatch Spring with Upper Dogpatch Spring:
1) Specific conductance is typically lower at Lower Dogpatch Spring.
2) Nitrate nitrogen concentrations are lower at Upper Dogpatch Spring.
3) Fecal coliform concentrations are somewhat lower at Lower Dogpatch Spring.
4) Chloride concentrations are not consistently different between the two springs.

James Spring has lower flow rates than either of the Dogpatch Springs. If we compare the two Dogpatch Springs with James Spring:
1) Specific conductance and fecal coliform concentrations are similar.
2) Nitrate nitrogen concentrations are much lower at James Spring.
3) Chloride concentrations are lower at James Spring.

The flow rates of Milum Spring appear to be slightly greater than flow rates of Jenkins Spring, although this may not be a consistent difference. However, there is a water supply pipe which connects Milum and Jenkins Springs, and as of August 18, 1998, the Harrison Water Department reported that the pipe was still conveying water from Milum to Jenkins Spring. Comparing data attributed to these two springs (the data ignore the pipe connection):
1) Specific conductance is slightly lower at Jenkins Spring.
2) Nitrate nitrogen concentrations are lower at Jenkins Spring.
3) Fecal coliform concentrations are lower at Milum Spring.
4) Chloride concentrations are slightly lower at Jenkins Spring.

The combined flow of the two Dogpatch Springs appear to vary in flow rate more than does the combined flow of Milum and Jenkins Springs. The combined mean flow rate of the two Dogpatch Springs is probably greater than the combined mean flow rates of Milum and Jenkins Springs. Comparing the Lower Dogpatch Spring with Milum and Jenkins Springs:
1) Specific conductance is more variable at Lower Dogpatch Spring; this is consistent with the more variable flow rate at this spring.
2) Mean nitrate nitrogen concentrations are lower at Lower Dogpatch Spring although some measurements may be higher.
3) Fecal coliform concentrations are generally similar, although appreciable concentrations are associated with high flow discharges from Lower Dogpatch Spring.
4) Chloride concentrations are lower at Milum and Jenkins Springs.

Wilson Spring has flow rates slightly smaller than those of Jenkins Spring and Milum Spring. Comparing Wilson Spring with Jenkins and Milum Springs:
1) Specific conductance, nitrate nitrogen, and chloride concentrations are typically lower at Milum and Jenkins Springs.
2) Fecal coliform concentrations are lower at Wilson Spring.

Leidy (1989) conducted nine rounds of water quality sampling at Bear Creek Spring for a masters thesis. Interpretations in her study were flawed by her incorrect assumption that most of the recharge area for this spring was located north of the spring. Work by Aley (1995) demonstrated that most of the recharge area for this spring lies to the south and southwest of the mouth of the spring. The recharge area for Bear Creek Spring lies generally north of the current Regional Study Area, so the water quality measurements made by Leidy (1989) are of some interest.

Flow rates were measured or estimated for all nine water samples from Bear Creek Spring. They ranged from a minimum of 1,300 gallons per minute (gpm) to a maximum of 7,000 gpm; the mean value was 3,850 gpm (which equals 8.6 cfs). These values show that the storm event through which Leidy (1989) sampled was relatively small; during the Aley (1995) work we estimated peak discharge from Bear Creek Spring at 125 cfs.

Chloride concentrations from Bear Creek Spring (Leidy, 1989) for the nine measurements ranged from 3.1 to 5.6 mg/l; the mean was 4.6 mg/l. The total of nitrate and nitrite concentrations (expressed as nitrogen) for the nine measurements ranged from 0.51 to 1.44 mg/l; the mean was 1.09 mg/l.

Fecal coliform values for the nine measurements (Leidy, 1989) ranged from 7 to 1,200 colonies per 100 ml. Median values are a better reflection of average bacterial conditions than are mean values. The median fecal coliform concentration was 420 colonies per 100 ml.

The generalizations about water quality in the Regional Study Area are intended to provide the reader with a general picture of water quality conditions within the study area. The water quality of the springs is generally good, although it is clearly not pristine. Parameters such as nitrates and fecal coliform are often derived from animal wastes; concentrations of these parameters generally increase as animal populations increase in the recharge area for the spring. Chloride concentrations in spring water in the Ozarks are routinely small; elevated concentrations often (but not always) indicate sewage contamination.

The water quality of springs and surface streams in the Crooked Creek and Mill Creek portions of the Regional Study Area is typically poorer than general water quality within the Buffalo River basin. Mill Creek derives much of its water from the two Dogpatch Springs, and these springs (as will be shown

in results from the Phase 2 work) derive much of their water from lands within the Crooked Creek topographic basin. Based upon present data, Mill Creek contributes over 90% of the nitrate load in the Buffalo River basin below the mouth of Mill Creek. Protection of the quality of spring water discharging to the Mill Creek basin is clearly crucial to the protection of water quality in the Buffalo River.

SECTION 2. KARST FEATURE MAPPING AND ASSESSMENT

Methods

This phase of the work was designed to identify karst features of hydrological significance and to identify and assess land use activities likely to create significant adverse groundwater quality impacts. The objective of this work was to develop information adequate to characterize the extent and functioning of the karst aquifer systems within the Regional Study Area. This characterization will be presented in the Phase 2 report since groundwater tracing results from that work will be a crucial facet of the characterization.

The location of significant springs was a component of the karst inventory. In addition to locating and describing the springs we made at least one measurement of specific conductance at each spring. These measurements were designed to provide possible insight into recharge areas for the springs. As a generalization (and depending upon weather and flow rate conditions), springs with lower specific conductance values often receive appreciable recharge from losing stream segments. In contrast, springs with higher specific conductance values commonly receive lesser amounts of recharge from losing stream segments and more recharge from upland areas. Unfortunately, in this study we found that this generalization did not work well in this region and that the specific conductance values were of limited value in understanding recharge areas. The reason or reasons for the poor applicability of this generalization are unclear.

We placed major emphasis on identifying and locating losing stream segments. Based upon OUL data for the Ozarks, valleys encompass about 10% of the land area, yet losing stream portions of these valleys introduce about 40% of the total annual groundwater recharge. Contaminants derived from points upstream of a losing stream segment can be introduced into the karst groundwater system through the losing stream segment. Losing stream segments routinely provide very ineffective natural cleansing for the recharge waters passing through them. Many of the losing stream segments in the Ozarks are clusters of sinkholes that have been filled with coarse stream gravels.

One technique used for identifying and locating losing stream segments was to make estimates of flow rates of streams at road crossings throughout the Regional Study Area. Such reconnaissance estimates were made during periods of low to moderately low flow conditions to help ensure data comparability. We often found that the flow of an upstream point on a stream is greater than the flow at a downstream point; there are clearly intervening losing stream segments between the two observation points. In other cases we found that streams segments with topographic basins of several square miles lacked perennial flow. For this portion of the Ozarks, stream segments with topographic

basins of 1,000 acres or more routinely have perennial flow unless there is appreciable water movement from the topographic basin into the underlying karst aquifer.

Our reconnaissance and mapping work involved a stereoscopic study of aerial photos for the entire Regional Study Area. The photos used were flown on March 15, 1994 for the U.S. Department of Agriculture. In addition, we drove all public roads within the Regional Study Area and recorded information on relevant features. We also covered some areas on foot, and interviewed a number of residents of the area.

One situation encountered during the field work was strong public concern (and often anger) by area residents over what is perceived as an attack on private property rights by governmental agencies. One issue often mentioned was possible regulations or other actions by the State of Arkansas relative to gravel mining in streams and cattle access to streams where these streams are located on private lands. These concerns clearly diminished the willingness of some residents to provide information or to permit access to their property. Some people were willing to provide us with information, but requested that we not identify the source of the information; we have honored that request. We very much appreciate the assistance and kindness given us by residents of the area. We also recognize and appreciate that most of the land in the Regional Study Area is in private ownership, and that a long history of good land stewardship on most of the lands has resulted in generally good groundwater quality in the area.

One objective of our studies was to identify and assess land use activities likely to create significant adverse groundwater quality impacts. There are a few confined animal operations (such as poultry and dairy operations) which we have shown on the map with this report as point source areas. These features are visible from roads in the area and/or on aerial photos. Additionally, there are a few service stations in the area which could be sources of petroleum spills. However, most of the activities which could impact groundwater quality are better assessed as non-point source land use activities. These include the numerous small roadside and gully dumps which are found scattered throughout the area; roads and highways which yield sediment or contaminants from leaks or spills on or along the roads; livestock grazing; and sewage disposal facilities serving homes scattered throughout the area.

Results

Mapping of Karst Features and Flow Rates of Streams

Important karst features of the Regional Study Area include springs, caves, sinkholes, and losing streams. The large map which accompanies this report shows the larger springs in the area in addition to some smaller perennial springs which were encountered during field work. The map also shows the larger or more obvious sinkholes or sinkhole areas. The marked areas are based on field observations since some dry ponds in the area cannot be distinguished from sinkholes on the topographic maps.

The National Park Service had previously identified most of the springs (and certainly all of the more significant springs) in the Regional Study Area. During the course of our work we found a few additional springs which we have shown on the map discussed above. The following brief comments focus on information we developed during the study on previously unidentified springs.

Spout Spring is located in the SW 1/4 NW 1/4 NE 1/4 of Section 36, T18N, R21W, Boone County, Arkansas. The area is shown on the Gaither 7.5 minute quadrangle map. The spring discharges from a bedding plane opening about ten feet above the channel of the West Fork of Crooked Creek at an elevation of about 1160 feet. Based upon discussions with Ms. Helen Bill (Hall) Hunsaker, the spring routinely flows at a rate of about 10 gallons per minute, and the flow persisted even during the drought years of the 1930's. The estimated flow rate of the spring on June 9, 1998 was about 20 gallons per minute.

Our recharge area map shows two additional unnamed springs in Section 36. The spring on the west side of Hall Road and north of the Hall (Hunsaker) residence (which we will call Hall Spring West) is located about 75 feet from the road and rises from a tile that extends about two feet above ground level. This spring is located in the SE 1/4 NW 1/4 NW 1/4 Section 36, T18N, R21W at an elevation of about 1150 feet. The estimated flow rate on March 26, 1998 was 100 gallons per minute. Water is always present at the spring, but may not always discharge from the top of the tile.

Hall Spring East is located on the east side of Hall Road and about 50 feet from the road. It rises from a rocked-in pool next to a small stream channel. This spring is located in the SW 1/4 SE 1/4 NW 1/4 Section 36, T18N, R21W at an elevation of about 1150 feet. The estimated flow rate on March 26, 1998 was 50 gallons per minute. In dry weather water from the spring sinks again a few feet downstream.

In 1996 a new sinkhole collapse occurred south-southeast of the two above-described Hall Springs. The sinkhole was located in a field near a small tributary stream channel in the SW 1/4 SE 1/4 NW 1/4 Section 36, T18N, R21W. Previous sinkholes have occurred in this area, but all of them are now obscured. At least one of the sinkholes occurred during plowing.

Trace 98-04 involved dye introduction into a cave stream which was accessible through an abandoned dug well in the back room of a house located immediately east of Long Cemetery in the NW 1/4 NE 1/4 NW 1/4 Section 36, T18N, R21W. The water level elevation in the cave stream on March 26, 1998 was about 1120 feet; the flow rate was very small, but there was some current visible when the stream was viewed with a flashlight from the top of the dug well.

Two springs are shown on our recharge area delineation map in the NE 1/4 NE 1/4 Section 14, T17N, R21W, Boone County. These are located on the Robert Massengale property at the southern end of Massengale Road. On March 26, 1998 each of the spring was discharging about 20 gallons per minute from the sandstone. These springs plus surface flow in the adjacent stream totalled about 100 gallons per minute on March 26, 1998. On this date all of this water was entering the groundwater system between the downstream spring and the dye introduction point used for Trace 98-06.

Many of the caves in the area are on private land and contain sensitive speleothems, cave fauna, or sometimes archeological materials. To ensure the protection of these caves and their features we have not shown the locations of any of the caves in the Regional Study Area on the maps included in this report.

The most wide-spread karst features in the Regional Study Area are losing streams. In fact, most of the stream channels immediately underlain by the Boone Formation in the area are losing streams. The presence of perennial flow in a stream segment underlain by the Boone Formation does not necessarily demonstrate that the stream segment is not losing water to the groundwater system. This is nicely demonstrated by Trace 98-12, the Union Church Trace. This trace was conducted during Phase 2 of our studies and will be reported upon in detail in the report on that phase of the work. Briefly, for Trace 98-12, dye was introduced into the East Fork of Crooked Creek near Union Church. It is our conclusion that there is continuous perennial flow in the East Fork from Union Church downstream to (and beyond) the confluence of Crooked Creek with West Fork Dry Creek. This is based upon aerial photographs and direct observations of the creek at all public road crossings in this stream segment. However, dye introduced in the East Fork a short distance downstream of Union Church was recovered from both Milum and Jenkins Springs; this demonstrated that at least some portions of this stream segment recharge

groundwater supplies and are thus losing stream segments. There is a pipe which conveys some of the flow of Milum Spring to Jenkins Spring; this pipe was still connecting the two springs throughout the duration of our work in the area based upon information from the Harrison Water Department. As a result, sampling at Jenkins Spring actually represents a composite sample from both Milum and Jenkins Spring.

Another illustration that even streams with perennial flow may contain losing stream segments is provided by Maner and Mott (1991). These authors measured flow rates at multiple points on Mill Creek during low flow conditions on August 19, 1991. These measurements demonstrated that Mill Creek lost about half of its flow to the groundwater system between the furthest downstream Dogpatch dam on Mill Creek and the Spring Valley Road. The flow rate increased to about the same amount as noted at the downstream Dogpatch dam by the confluence of Harp Creek with Mill Creek.

Based upon field observations and dye tracing results, apparent exceptions to the generalization that most of the streams are losing streams are the following stream segments:

1) West Fork of Crooked Creek downstream of Morris Spring.
2) Crooked Creek downstream of Milum Spring.
3) Mill Creek downstream of mouth of Harp Creek.
4) Cecil Creek downstream of Van Dyke Spring.
5) Cove Creek from about the Boone and Newton County line downstream to the mouth.
6) The downstream 1.5 miles of Harp Creek.

While some portions of Flatrock Creek have perennial flow, under moderately low flow conditions the entire flow of this creek sinks in the downstream 2,500 feet of this stream. Dye tracing conducted during Phase 2 of this study demonstrated that some of this water discharges from Boiling Spring and that some of the water also discharges to the channel of Mill Creek upstream of Boiling Spring.

The large map which accompanies this report shows flow rate estimates made at a number of locations throughout the study area. Each estimate indicates the date of the observation. Most of these estimates were made during the following time periods:

August 30, 1996
June 2 and 3, 1997
June 26 and 27, 1997
September 13 and 14, 1997

A few observations, or repeated observations, were made on other dates

The flow rate observations were made under low to relatively low flow conditions. Based upon general hydrologic conditions, it is our opinion that streams with topographic basins of approximately 1,000 acres or more (approximately 1.5 square miles) should yield perennial flow if these basins provided little or no recharge to the karst groundwater system. For streams in areas underlain by the Boone Formation, the map indicates that most streams with topographic basins of this size or larger had no flow under low to relatively low flow conditions. Based upon this observation, most of the streams in the Regional Study Area are draining topographic basins which lose an appreciable amount of their runoff waters to the karst groundwater system. The extent to which this groundwater recharge is localized along losing streams rather than through sinkholes and other features is unknown. However, dye tracing studies conducted during the Phase 2 investigations relied primarily on dye introductions into losing streams, and these dye introductions routinely yielded positive groundwater traces. It is our opinion that the data indicate that an appreciable portion of the groundwater recharge occurs through losing streams.

Many losing streams in karst areas of the Ozarks have surface flow which persists for only a few hours to a few days after appreciable precipitation. While similar conditions are found on some of the surface streams of the Regional Study Area, most of the surface streams in this area continue to have surface water flow for periods of a week to a few weeks after a period of appreciable precipitation. This longer persistence of surface flow could be caused by several factors including less permeable soils, less intensive karst groundwater system development and hydrologic integration, or the presence of seasonal or periodic perched water tables.

Most of the losing stream segments in the Regional Study Area lack readily obvious sinking points except under ideal and infrequent hydrologic conditions. Shortly after an appreciable rainfall one can find locations along many of the streams in the area where flow rates ranging from a few gallons per minute to a few tens of gallons per minute sink into the karst groundwater system. Under most other conditions there is little obvious evidence of losing stream segments. It is our conclusion that, for land management purposes, all surface stream channels crossing the Boone Formation in the Regional Study Area should be viewed as losing streams.

Specific Conductance Measurements

In the proposal for Phases 1 and 2 we stated that during our karst inventory work we would make at least one measurement of specific conductance at each significant spring. During our field work we made the required measurements plus specific conductance measurements at most of the stream stations where we monitored for tracer dyes. While we had hoped that specific conductance

measurements would provide insight into recharge areas for springs, that did not prove to be the case. Specific conductance measurements which we made as a part of delineating the recharge area for Fitton Cave and Fitton Spring are included with the data in Table 2. Specific conductance measurements made elsewhere in the Regional Study Area will be presented with the Phase 2 report.

Specific conductance measurements made on June 3, 1997 were interesting. The value at Fitton Spring was 133 micromhos/cm, whereas at Van Dyke Spring the value was 211 micromhos/cm. The difference in values is likely a reflection of the findings in our dye tracing studies that Van Dyke Spring gets much of its recharge water from Cecil Creek and its tributaries whereas Fitton Spring gets much less of its flow from major surface streams. Furthermore, the mean travel distance for water discharging from Fitton Spring is less than that for water discharging from Van Dyke Spring. Increases in travel distance and travel time tend to increase the amount of rock dissolved by the water and the resulting specific conductance value.

Assessment of Point Source Land Use Activities

Most people living in the study area are served by on-site sewage systems, most of which are septic systems. One exception is the Dogpatch development which is served by a sewage collection and treatment system. Studies of the extent of groundwater contamination associated with septic systems in Greene County, Missouri (Aley and Thomson, 1984) concluded that 60% of on-site systems yielded some contaminants to groundwater, and that 15% of the systems were major sources of groundwater contamination. Most of the springs included in the Greene County study were located in geologic units which are mapped as the Boone Formation in the Regional Study Area.

The Aley and Thomson (1984) study also found that the frequency and extent of groundwater contamination from septic systems is not a function of lot size, but instead is related to characteristics of the site selected for the septic system. The risk that septic systems would contaminate groundwater supplies was five times greater for systems located in soils derived from very cherty rock units than for systems in soils derived from rock units with little chert. Because of the finding that septic system density is not a controlling factor, we have not shown any of the crossroad communities in the study area as point sources of groundwater contamination.

One should not conclude that a community sewage collection and treatment system will necessarily preclude groundwater contamination by sewage. Exfiltration from sewage conveyance lines can create problems which equal or exceed those associated with on-site sewage systems.

There are some moderate sized dairies in the Regional Study Area. Studies in southern California in the early 1960's found that approximately six acre feet of water per year was required to wash 100 milking cows and the milking barn at Grade A dairies. The resulting waste water is high in fecal material and nitrogen compounds and presents disposal difficulties. In the hydrogeologic setting found in most of the Regional Study Area waste lagoons are undesirable because of leakage into the groundwater system. Spray irrigation of wastewater onto well established and maintained vegetation is often a desirable strategy, yet it works poorly during periods of runoff and when plants are not actively growing and taking up nutrients. Dairy operations are likely to be significant sources of nitrates and fecal material to karst groundwater supplies. The current prices paid to farmers for milk are low and make it difficult (or almost impossible) for most dairy farmers to construct, operate, and maintain waste disposal facilities needed to provide good groundwater quality protection in karst areas. The current trend for dairies in the Ozarks is for the number of dairies to diminish and for their size to increase. Water considerations (including both supply and waste disposal) do not appear to be conducive to the development of large dairies in the Regional Study Area.

Confined animal operations (both chickens and hogs) are continuing to expand in northwest Arkansas. While there are some broiler houses in the Regional Study Area (and some within areas which contribute waters to springs in the Mill Creek topographic basin), the density of these operations is much less than in areas further to the west. This may or may not change with time.

The confined animal operations produce large quantities of waste, most of which is land applied. The wastes are high in bacteria concentrations and in phosphates and nitrogen compounds. Land application rates have historically been regulated based upon the ability of the soils to accept additional nitrogen. Nitrogen, in the form of nitrates, is highly mobile in water and an appreciable portion of the applied nitrogen can move downward into the groundwater system from land application sites or it can move off-site via overland runoff and enter the groundwater system through losing stream segments. There are currently substantial efforts being made to modify the regulatory strategy for land application of animal wastes so that the regulating parameter will be phosphates rather than nitrates. Phosphates are less mobile in soils and in karst groundwater than are nitrates. The net effect of regulations focused on phosphate additions would be a dramatic reduction of the per acre amount and frequency of land application of animal wastes. Should this occur, it will probably require that the large poultry and hog rearing operations become more widely spaced so as to have sufficient land available for waste disposal. It would

seem that relatively flat lands such as found in the Crooked Creek topographic basin portion of the Regional Study Area would be perceived as desirable lands for future land application of confined animal wastes.

The map which accompanies this report locates point-source water quality hazard areas with the letter "H" followed by a number. A description of each of these point source areas follows.

H-1 is a poultry operation with two broiler houses. It is located in Section 13, T17N, R20W on the Hasty 7.5 minute quadrangle map.

H-2 is a large poultry operation with six large broiler houses. It is located in Section 22, T17N, R20W on the Hasty 7.5 minute quadrangle map.

H-3 is a poultry farm of unknown size; it is not visible from a public road. It is located in Section 4, T16N, R20W on the Hasty 7.5 minute quadrangle map.

H-4 is an old feed lot which is now out of operation. It is located in Section 8, T17N, R20W on the Gaither 7.5 minute quadrangle map.

H-5 is a poultry operation with six broiler houses. It is located in Section 31, T18N, R20W on the Gaither 7.5 minute quadrangle map.

H-6 is a moderate sized dairy. It is located in Section 36, T18N, R21W on the Gaither 7.5 minute quadrangle map.

H-7 is a poultry operation with two broiler houses; it is located about 3/4 mile east of the study area boundary, and is in Section 31, T18N, R19W on the Harrison 7.5 minute quadrangle map.

H-8 is a service station with underground tanks located at Compton. It is located in Section 27, T17N, R22W on the Ponca 7.5 minute quadrangle map.

H-9 is a service station at the intersection of Highways 7 and 206. It is located in Section 9, T17N, R20W on the Harrison 7.5 minute quadrangle map.

Assessment of Non-Point Source Land Use Activities.

We have divided this assessment into four categories, each of which will be discussed in the following sub-sections.

Agricultural and Forestry Activities. The most areally extensive agricultural activity in the area is the production of beef cattle. There are no feedlots in the area at present. Instead, cattle are grazed on permanent pasture and are typically fed locally produced hay during the winter and during summer droughts.

While there are exceptions, most pasturelands are not grazed so heavily that they yield appreciable sediment loads to overland runoff and subsequently (through losing streams) to the karst groundwater system. Extreme drought periods, such as the summer of 1998, are an exception to this generalization.

Storm runoff from pastureland can yield appreciable bacteria from fecal material into losing streams and ultimately into the karst groundwater system. In addition, runoff from pasturelands will routinely contain elevated concentrations of nutrients (and especially nitrates) which are ultimately transported into the karst groundwater system.

Land management activities related to beef cattle production which can reduce sediment, bacterial contamination and elevated nutrient additions to the groundwater system include the following:
1) Pasture rotation and stocking which ensures maintenance of a good ground cover.
2) Exclusion of livestock from both intermittent and perennial stream channels and establishment and protection from grazing of well vegetated riparian zones along the margins of all streams. Due to ownership patterns and the local topography it will often be expensive to exclude cattle from stream courses, and especially from the smaller intermittent streams.
3) Use of concentrated feeding areas which are separated from stream channels by well vegetated riparian zones from which cattle are excluded.
4) Programs which assist landowners in understanding, financing, and accomplishing activities 1, 2, and 3.

There are some forestry activities in the study area, but they generally do not appear to present any appreciable problems. One exception to this generalization is sediment production from skid trails and haul roads; it is recognized that most sediment production associated with forestry activities is derived from such features.

Sewage Disposal Facilities. The only community sewage collection and disposal facility in the study area is the one serving Dogpatch. Appreciable sewer line exfiltration from this system is likely due to the rugged topography, the age of the system, and the limited maintenance which it has probably received. We made no site-specific investigations of this system since this was outside of the purview of this study.

Landfills, Dumps, and Salvage Yards. We did not find any sizeable landfills or salvage yards in the Regional Study Area. However, there are numerous small dumps in the Regional Study Area, and some of these are currently receiving trash and garbage. Many of these are not visible from public roads. Two of the groundwater traces conducted during Phase 2 work were in drainageways which are currently receiving trash and which were posted against

trash disposal by the Boone County Health Department. While contaminants of concern have probably already been mostly flushed out of the older wastes and into surface and groundwater supplies, some undesirable and/or harmful compounds undoubtedly remain. Newer wastes may also contain contaminants of concern. Dead animals are sometimes disposed of in stream channels and in sinkholes.

Transportation Routes. The most heavily travelled highway in the Regional Study Area is Arkansas Highway 7 which runs generally north-south through the center of the area. Less heavily travelled state highways within the Regional Study Area are Arkansas Highways 43 and 206. Spills and leaks of materials harmful to groundwater quality will occur occasionally along these highways. Liquid spills of harmful materials resulting from accidents present the greatest risk to groundwater quality. Prompt cleanup and remediation of spill sites is extremely important, yet liquids can often enter the groundwater system so rapidly that much of the spilled material cannot be recovered or treated.

Stormwater runoff from highways is also detrimental to groundwater quality. However, traffic volumes in the study area are not so great that this represents a major problem to groundwater quality at receiving springs.

There are many miles of unpaved public and private roads in the Regional Study Area. Many of these roads yield large volumes of sediment to streams which recharge the karst aquifer. Kattelmann (1997) notes that roads are considered the principal cause of accelerated erosion in forests throughout the western United States. He notes that: "Roads destroy all vegetation and surface organic matter, minimize infiltration and maximize overland flow, over-steepen adjacent cut-and-fill slopes to compensate for the flat roadbed, and intercept subsurface flow, directing more water across the compacted surface".

In the Fitton Cave area, the rugged and steep road which leads from the Erbie Road to Chestnut Spring is an appreciable source of sediment for the karst groundwater system drained by Fitton Spring. Under present and typical conditions this road is probably the single most important adverse water quality impact within the Fitton Spring recharge area.

SECTION 3. GROUNDWATER TRACING STUDY FOR DELINEATION OF THE RECHARGE AREA FOR FITTON CAVE AND FITTON SPRING

Introduction

Fitton Cave is an extremely important natural feature within the Buffalo National River. Portions of the cave are traversed by an underground stream. A previous groundwater trace in the region (Lindsley, 1965) involved the introduction of fluorescein dye in Fitton Cave (also known as Beauty Cave) and its reported visible detection at Fitton Spring. No other previous groundwater tracing work had been conducted associated with Fitton Cave or Fitton Spring, and no previous efforts had been made to delineate the recharge area for Fitton Cave and Fitton Spring.

Some portions of a recharge area may contribute part of their flow to a cave or spring and part of their flow to surface runoff and/or to other springs. This is a common occurrence in the Ozarks where much of the water which enters groundwater systems is derived from losing streams. Very few of the losing stream segments in the Ozarks lose all of their flow to the groundwater system under moderate to high flow conditions. Under these conditions there is typically continuous surface flow down the channels of the losing streams. The flows occurring during moderate to high flow conditions result in stream channel morphology similar to what one might see in a non-karst landscape. The most readily obvious visible difference between most losing streams in the Ozark karstlands and streams which are not losing streams is that there is little or no water in the losing streams during most of the year.

Groundwater Tracing Methods

Groundwater tracing using fluorescent dyes is the most appropriate method for delineating cave and spring recharge areas (Aley and Aley, 1991). Field work is conducted to identify locations where waters sink from the surface into the karst groundwater system. Next, a selected tracer dye can be introduced into the sinking water, and springs, cave streams, surface streams, and other potentially relevant locations can be sampled for the subsequent presence of the dye. By careful selection of dye introduction points, and by conducting multiple traces, one can delineate the area which contributes waters to a particular feature (such as a cave or spring).

Three different dyes were used during the recharge area delineation work. These were fluorescein, eosine, and rhodamine WT. Figure 3 shows the chemical structure of each of these dyes and summarizes some of their more important properties. All three of these dyes are environmentally safe (Smart, 1984; Field et al., 1995) and pose no risk to humans or to aquatic life in the concentrations used in professionally directed groundwater tracing work.

Activated Carbon Samplers

The detection of the tracer dyes placed primary reliance on activated carbon samplers. The limited use of water samples will be discussed later. All three of the dyes used (fluorescein, eosine, and rhodamine WT) can be adsorbed onto laboratory grade coconut shell charcoal samplers. The samplers are placed in the water to be sampled and are left for periods which may range from a few hours to a couple of weeks or sometimes more. The most common duration for leaving activated carbon samplers in place is about a week.

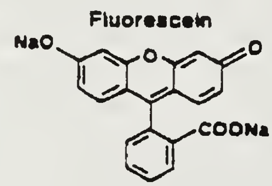
The activated carbon samplers used during this study were manufactured by the OUL. They were packets of fiberglass screening partially filled with approximately 4.25 grams of activated coconut charcoal. The charcoal used by the OUL was Barnebey and Sutcliffe coconut shell carbon, 6 to 12 mesh, catalog type AC. The samplers are about four inches long by two inches wide; the samplers are closed by heat sealing.

The activated carbon samplers (simply called "samplers" in the following discussions) are used as the primary sampling approach because they sample continuously and accumulate dyes. These samplers are ideal for determining whether or not a tracer dye has reached a sampling station. A few water samples were analyzed during the study for background samples or in cases where the associated activated carbon samplers had been lost to flood flows and the collection of a water sample seemed useful.

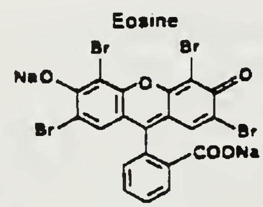
Samplers placed at springs and surface streams were placed in flowing water and firmly anchored with wire and weighted in place. Cords were sometimes run from the packets to trees along the banks so that samplers could be recovered even during relatively high flow events. Samplers were concealed to minimize disturbance or loss by people who might otherwise see them.

Figure 3. Properties of tracer dyes used in the study.

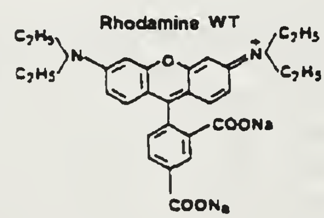
Fluorescein dye (Acid Yellow 73; Color Index Constitution Number 45350) is a brilliant fluorescent yellow-green dye which has been used in groundwater tracing work since near the turn of the century. This dye has a long history of successful use in groundwater tracing in karst and fractured rock aquifers. Fluorescein is the most detectable of the commonly used fluorescent dyes. Fluorescein can be adsorbed onto activated carbon samplers for cumulative sampling. It can also be analyzed for in water samples.



Eosine dye (Acid Red 87; Color Index Constitution Number 45380) is a greenish to peach-colored dye (the color is a function of concentration). This dye is very successful when used in groundwater tracing in karst and fractured rock aquifers; it has good resistance to adsorption onto soil and rock materials. Eosine is one of the most detectable of the fluorescent dyes. Eosine can be adsorbed onto activated carbon samplers for cumulative sampling. It can also be analyzed for in water samples.



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 somewhat less resistant to adsorption onto soil and rock than eosine or fluorescein, yet all of these dyes routinely work well in karst areas. Rhodamine WT is also less detectable than either of the other two dyes considered. Rhodamine WT can be adsorbed onto activated carbon samplers for cumulative sampling. It can also be analyzed for in water samples.



At all stream and spring sampling stations at least two independently anchored samplers were placed to minimize the risk of sampler loss. To the extent reasonable both samplers were placed in similar settings so that they would be likely to produce similar analytical results.

When carbon samplers were collected, new samplers were placed. Collected samplers were placed in sterile plastic bags ("Whirl-Paks"). The bags were labelled on the outside with the station name and the date and time of collection. At stream and spring stations where two samplers were collected both samplers were placed in the same sample bag. Sometimes one of the samplers might be out of the water at the time of collection because of flooding or because of a drop in water level. If this were the case, or if for some other reason one sampler appeared to have been appreciably better positioned to sample the water, the better positioned packet was folded prior to insertion into the sample bag to identify it. This better positioned sampler was then the sampler selected in the laboratory for analysis.

Upon arrival at the OUL samplers were immediately refrigerated at 4 degrees C. until analysis. All sampler placement and collection work was conducted by personnel of the OUL.

Carbon samplers arriving at the OUL were washed under relatively strong jets of water to remove sediment and organic material. For stations where two samplers were collected for the same sampling period one of the samplers was placed in frozen storage. One sampler from each sampling station was then eluted with 15 ml of a standard eluting solution for a period of one hour. The standard eluting solution was prepared as follows. First, a solution was prepared which consisted of 5% aqua ammonia solution and 95% isopropyl alcohol solution. The aqua ammonia solution contained 29% ammonia and 71% reagent water. The isopropyl alcohol solution was 70% isopropyl alcohol and 30% reagent water. Next, pellets of potassium hydroxide were added to the solution until saturation occurred; this was evidenced by the development of a super-saturated solution in the bottom of the container. The supernatant (i.e., the liquid above the super-saturated layer) was then poured off and was used as the eluting solution.

After the one hour elution period the eluting liquid was gently poured off the activated carbon from a sampler and the carbon was discarded. All containers used for elution or sample transfer were disposable and were kept covered with disposable covers. Approximately 2.5 ml of the elutant was withdrawn with a disposable pipette and placed in a disposable cuvette. This sample was then subjected to analysis in a Shimadzu RF-5000U Spectrofluorophotometer using a synchronous scan of excitation and emission wavelengths with a 17 nm wavelength separation. Elutant samples were analyzed using a 5

nm excitation slit and a 3 nm emission slit to insure adequate discrimination between tracer dyes and other fluorescent materials which might be present. A Shimadzu RF-540 Spectrofluorophotometer was available as a back-up instrument, but was not used during this study. All disposable materials are used only once and are then discarded.

Fluorescence peaks in the emission fluorescence profile were picked to the nearest 0.1 nm. The OUL has a large data base of results from actual groundwater traces. Using this data base, the OUL has calculated an acceptable wavelength range for each of the tracer dyes in each matrix tested (the matrixes are the standard eluting solution and water). Acceptable wavelength ranges are specific to the instrument being used. The acceptable wavelength range is the mean emission fluorescence peak plus and minus two standard deviations. The acceptable wavelength ranges for the three dyes used in this study are identified in the following paragraphs; the detection limit for each of the dyes (based upon the as-sold weight of the dye) is also indicated.

The acceptable wavelength range for fluorescein dye in the standard elutant is from 510.7 to 515.0 nm. The detection limit is 0.010 micrograms per liter (parts per billion).

The acceptable wavelength range for eosine dye in the standard elutant is from 533.0 to 539.6 nm. The detection limit is 0.020 micrograms per liter (parts per billion).

The acceptable wavelength range for rhodamine WT dye in the standard elutant is from 561.7 to 568.9 nm. The detection limit is 0.155 micrograms per liter (parts per billion).

Criteria for Positive Fluorescein Dye Recoveries in Elutant

There are often some fluorescence background peaks in the range of fluorescein dye present at some of the stations used in groundwater tracing studies. We routinely conduct background sampling prior to the introduction of any tracer dyes to characterize this background fluorescence and to identify the existence of any tracer dyes which may be present in the area. For activated carbon packet elutant samples subjected to analysis on the RF-5000U we routinely identify all fluorescence peaks with wavelengths between 503.9 and 520.9 nm. The fact that a fluorescence peak is identified in our analytical results is <u>not</u> proof that it is fluorescein dye or that it is fluorescein dye from the trace of concern. The following 4 criteria are used to identify wavelength peaks which are deemed to be fluorescein dye recoveries from our tracing work.

Criterion 1. There must be at least one fluorescence peak at the station in question in the range of 510.7 to 515.0 nm for samples analyzed by the RF-5000U.

Criterion 2. The dye concentration associated with the fluorescence peak must be at least 3 times the detection limit. For the RF-5000U the fluorescein detection limit in elutant samples is 0.010 ppb, thus this reporting concentration limit equals 0.030 ppb.

Criterion 3. The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

Criterion 4. The shape of the fluorescence peak must be typical of fluorescein. Much background fluorescence yields low, broad, and asymmetrical fluorescence peaks rather than the more narrow and symmetrical fluorescence peaks typical of fluorescein. In addition, there must be no other factors which suggest that the fluorescence peak may not be fluorescein dye from our groundwater tracing work.

Criteria for Positive Eosine Dye Recoveries in Elutant

There are usually no detectable fluorescence background peaks in the general range of eosine dye encountered in most groundwater tracing studies. The following four criteria are used to identify wavelength peaks which are deemed to be eosine dye.

Criterion 1. There must be at least one fluorescence peak at the station in question in the range of 533.0 to 539.6 nm for samples analyzed by the RF-5000U.

Criterion 2. The dye concentration associated with the fluorescence peak must be at least 3 times the detection limit. For the RF-5000U the eosine detection limit in elutant samples is 0.020 ppb, thus this reporting concentration limit equals 0.060 ppb.

Criterion 3. The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

Criterion 4. The shape of the fluorescence peak must be typical of eosine. Much background fluorescence yields low, broad, and asymmetrical fluorescence peaks rather than the more narrow and symmetrical fluorescence peaks typical of eosine. In addition, there must be no other factors which suggest that the fluorescence peak may not be eosine dye from our groundwater tracing work.

Criteria for Positive Rhodamine WT Dye Recoveries in Elutant

There are generally no detectable fluorescence background peaks in the general range of rhodamine WT dye encountered in most groundwater tracing studies. The following four criteria are used to identify wavelength peaks which are deemed to be rhodamine WT.

Criterion 1. For samples analyzed on the RF-5000U, there must be at least one fluorescence peak at the station in question in the range of 561.7 to 568.9 nm.

Criterion 2. The dye concentration associated with the rhodamine WT peak must be at least 3 times the detection limit. For the RF-5000U, the detection limit in elutant samples is 0.155 ppb, thus this reporting concentration limit equals 0.465 ppb.

Criterion 3. The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

Criterion 4. The shape of the fluorescence peak must be typical of rhodamine WT. In addition, there must be no other factors which suggest that the fluorescence peak may not be dye from the groundwater tracing work under investigation.

Water Samples

Water collections were made in disposable 50 ml. capped vials and were kept refrigerated until analysis. Approximately 2.5 ml of the water sample was withdrawn with a disposable pipette and placed in a disposable cuvette. This sample was then subjected to analysis in a Shimadzu RF-5000U Spectrofluorophotometer using a synchronous scan of excitation and emission wavelengths with a 17 nm wavelength separation. Water samples were analyzed using a 5 nm excitation slit and a 10 nm emission slit to insure adequate discrimination between tracer dyes and other fluorescent materials which might be present.

Fluorescence peaks in the emission fluorescence profile were picked to the nearest 0.1 nm. The OUL has a large data base of results from actual groundwater traces. Using this data base, the OUL has calculated an acceptable wavelength range for each of the tracer dyes in each matrix tested (the matrixes are the standard eluting solution and water). Acceptable wavelength ranges are specific to the instrument being used. The acceptable wavelength range is the mean emission fluorescence peak plus and minus two standard deviations. The acceptable wavelength ranges for the three dyes relevant to the water

samples collected (fluorescein, eosine, and rhodamine WT) are identified in the following paragraphs; the detection limit for each of the dyes (based upon the as-sold weight of the dye) is also indicated.

The acceptable wavelength range for fluorescein dye in water is from 505.6 to 510.5 nm. The detection limit is 0.0005 micrograms per liter (parts per billion).

The acceptable wavelength range for eosine dye in water is from 529.6 to 538.4 nm. The detection limit is 0.001 micrograms per liter (parts per billion).

The acceptable wavelength range for rhodamine WT dye in water is from 569.4 to 574.8 nm. The detection limit is 0.007 micrograms per liter (parts per billion).

Criteria for Positive Fluorescein Dye Recoveries in Water

The following three criteria are used to identify emission fluorescence peaks which are fluorescein dye in water samples.

Criterion 1. The associated activated carbon sampler for the station should also contain fluorescein dye in accordance with the criteria listed earlier. This criterion may be waived if no activated carbon sampler exists.

Criterion 2. There must be no fact or factors which suggest that the fluorescence peak may not be fluorescein dye from the tracing work under investigation. The fluorescence peak should generally be in the range of 505.6 to 510.5 nm.

Criterion 3. The dye concentration associated with the fluorescein peak must be at least 3 times the detection limit. For the RF-5000U, the detection limit in water samples is 0.0005 ppb, thus this reporting concentration limit equals 0.0015 ppb.

Criteria for Positive Eosine Dye Recoveries in Water

The following three criteria are used to identify emission fluorescence peaks which are eosine dye in water samples.

Criterion 1. The associated activated carbon sampler for the station should also contain eosine dye in accordance with the criteria listed earlier. This criterion may be waived if no activated carbon sampler exists.

Criterion 2. There must be no fact or factors which suggest that the fluorescence peak may not be eosine dye from the tracing work under investigation. The fluorescence peak should generally be in the range of 529.6 to 538.4 nm.

Criterion 3. The dye concentration associated with the eosine peak must be at least 3 times the detection limit. For the RF-5000U, the detection limit in water samples is 0.001 ppb, thus this reporting concentration limit equals 0.003 ppb.

Criteria for Positive Rhodamine WT Dye Recoveries in Water

The following three criteria are used to identify emission fluorescence peaks which are rhodamine WT dye in water samples.

Criterion 1. The associated activated carbon sampler for the station should also contain rhodamine WT dye in accordance with the criteria listed earlier. This criterion may be waived if no activated carbon sampler exists.

Criterion 2. There must be no fact or factors which suggest that the fluorescence peak may not be rhodamine WT dye from the tracing work under investigation. The fluorescence peak should generally be in the range of 569.4 574.8 nm.

Criterion 3. The dye concentration associated with the rhodamine WT peak must be at least 3 times the detection limit. For the RF-5000U, the detection limit in water samples is 0.007 ppb, thus this reporting concentration limit equals 0.021 ppb.

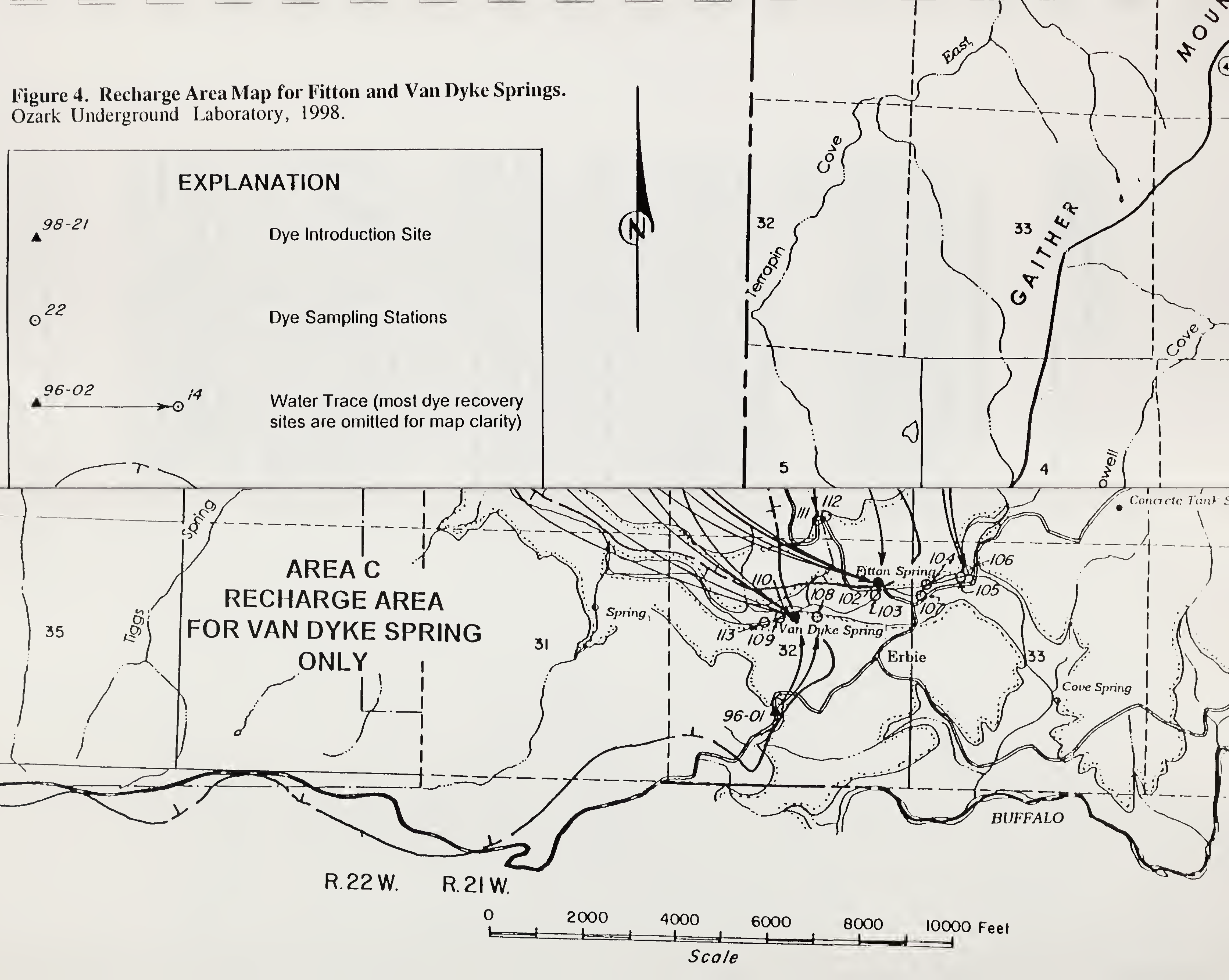
Sampling Stations

A total of 13 sampling stations (assigned numbers 101 through 113) were established during the course of this study. During field work we commonly establish some sampling stations prior to making final decisions about the exact locations of dye introduction points. As a result, samples may never be collected from some sampling stations. In addition, some sampling stations may be relevant only for a few of the dye traces and thus may be sampled for only part of the study period. The station numbers, names, and locations are shown in Table 3. The station numbers are also shown on the recharge area delineation map (Figure 4). Station numbers used in this study are assigned numbers 101 through 113.

Table 3. Sampling station locations

Station Number and Name	Elevation (feet)	Location
101. Chestnut Spring near Caver Cabin	1445	NW1/4 SE1/4 NE1/4 Section 30, T17N, R21W
102. Fitton Spring	920	SW1/4 NE1/4 /NE1/4 Section 32, T17N, R21W
103. Cecil Creek Upstream of Fitton Spring	890	SW1/4 NE1/4 NE1/4 Section 32, T17N, R21W
104. Cecil Creek 1/4 Mile Downstream of Fitton Spring	880	SW1/4 NW1/4 NW1/4 Section 33, T17N, R21W
105. Cecil Creek Upstream of Cove Creek	870	SE1/4 NW1/4 NW1/4 Section 33, T17N, R21W
106. Cove Creek at Mouth	870	NE1/4 NW1/4 NW1/4 Section 33, T17N, R21W
107. Rippled Slab	890	SW1/4 NW1/4 NW1/4 Section 33, T17N, R21W
108. First Tributary Downstream of Van Dyke Spring	940	NW1/4 SW1/4 NE1/4 Section 32, T17N, R21W
109. Cecil Creek Overflow near Van Dyke Spring	980	NE1/4 SE1/4 NW1/4 Section 32, T17N, R21W
110. Van Dyke Spring	980	NE1/4 SE1/4 NW1/4 Section 32, T17N, R21W
111. Tributary to Cecil Creek at Road Crossing in SE 1/4 Section 29.	1180	SE1/4 SW1/4 SE1/4 Section 29, T17N, R21W
112. Little Spring Branch	1210	SE1/4 SW1/4 SE1/4 Section 29, T17N, R21W
113. Main Stem of Cecil Creek Upstream Van Dyke Spring	970	NE1/4 SE1/4 NW1/4 Section 32, T17N, R21W

Figure 4. Recharge Area Map for Fitton and Van Dyke Springs.
Ozark Underground Laboratory, 1998.



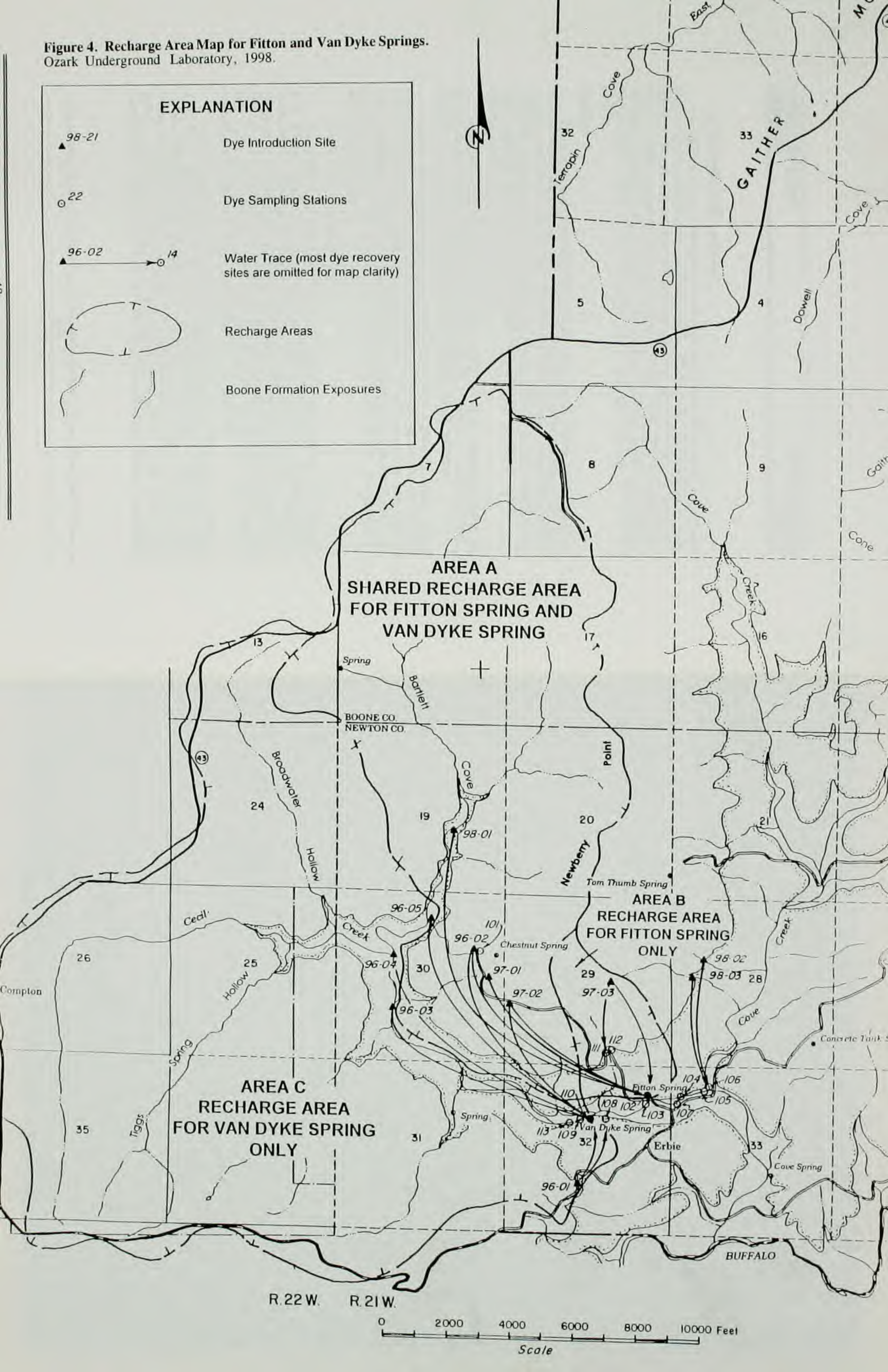


Figure 4. Recharge Area Map for Fitton and Van Dyke Springs. Ozark Underground Laboratory, 1998.

Dye Introduction Locations

A total of 11 dye introductions were made by the OUL in the Fitton Cave Study Area in conjunction with this study. Each trace was assigned a trace number; the first two digits indicate the year during which the dye was introduced. Traces conducted for a particular project are assigned a consecutive number; this number is indicated by the second two digits in the trace number. For example, Trace 97-03 is the third trace conducted during 1997 for this project.

Results

Tables included within the text include dye analysis results for all sampling stations where tracer dyes were detected. Sampling results at stations that were sampled, but where dye was not detected, are not included within these tables. Appendix A presents all dye analysis results for activated carbon samplers and water samples for all sampling stations; this appendix includes results from stations where dyes were not detected.

Appendix B presents four-to-a-page copies of all dye analysis graphs for all activated carbon samples and water samples. Figure 4 shows sampling stations, dye introduction locations, and recharge area boundaries.

Eleven dye introductions were made by the OUL during the study. These traces resulted in five traces to Fitton Spring. The tracing results are summarized in the following subsections of this report. All dye sampling and analysis work conducted by the OUL was conducted in accordance with established and published protocols (these have been summarized in this report), and all analysis work was quantitative.

Trace 96-01. Sinkhole Trace.

One pound of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into an intermittent unnamed tributary stream immediately adjacent to a county road. This unnamed tributary stream is a tributary to Cecil Creek. The dye introduction point was located in the SE 1/4 NE 1/4 SW 1/4 Section 32, T17N, R21W at an elevation of approximately 1,240 feet. The area is shown on the Jasper 7.5 minute quadrangle map; the dye introduction point is located in Newton County, Arkansas.

The dye introduction for Trace 96-01 was made on November 8, 1996 at 1305 hours. Appreciable precipitation occurred in the area on November 6 and 7; this created conditions suitable for the dye introductions. The flow of the stream at the time of dye introduction was estimated at about 15 gallons per minute. The peak flow of the storm runoff had passed by the time of dye introduction. Much (but not all) of the flow in this tributary stream was sinking

just downstream of the contact between the Batesville Sandstone and the Boone Formation. There is a large sinkhole, and a smaller sinkhole, located a short distance south of the dye introduction point; these sinkholes are on the opposite side of the road from the dye introduction point we used. We had hoped to be able to introduce a tracer dye into the larger of these sinkholes, but there was no surface flow available during the early afternoon of November 8. In fact, there was no evidence of any surface runoff into the larger sinkhole during that storm period. Runoff into this sinkhole is a relatively rare event.

Trace 96-01 was designed to determine if the area of the dye introduction contributes any groundwater recharge to Fitton Spring. If dye from Trace 96-01 had been recovered at Fitton Spring it could have reached the spring either through conduits which pass beneath Cecil Creek or else from waters that sink in Cecil Creek. Prior to the dye introduction it was our expectation that dye from Trace 96-01 would not be recovered from Fitton Spring. However, the trace was conducted to verify or refute this expectation.

No dye from Trace 96-01 was recovered from Fitton Spring even though sampling which could have detected dye from this trace continued at Fitton Spring until March 26, 1997. Dye from Trace 96-01 was recovered from Station 110 (Van Dyke Spring) and from Station 108 (First Tributary Downstream of Van Dyke Spring). Both Station 108 and 110 are located on the opposite site of Cecil Creek from Fitton Spring.

The dye recovered at Station 108 was detected in an activated carbon sampler in place at this location for the period from November 8 at 1700 hours to November 14, 1996 at 1140 hours. The dye concentration in this sampler was 670 parts per billion (ppb). This result indicates that a substantial amount of the dye introduced followed the general course of this tributary hollow from the dye introduction point to the sampling station. The rest of the dye from this dye introduction was recovered at Van Dyke Spring.

The dye recovered at Station 110 (Van Dyke Spring) was detected during two sampling periods. The first recovery was in an activated carbon sampler in place at this spring for the period from November 8, 1996 at 1630 hours to November 14, 1996 at 1130 hours. The eosine dye concentration was approximately 46.7 ppb, but it was difficult to measure accurately because of a large fluorescence peak in this sampler from fluorescein. A duplicate sampler from this station contained an even larger fluorescence peak due to fluorescein, and as a result we made no attempt to estimate the eosine concentration in that sample. Eosine dye from Trace 96-01 was also detected in two activated carbon samplers in place at Van Dyke Spring for the period from November 14 at 1130

hours to December 6, 1996 at 1010 hours. The dye concentration was 25.1 ppb in the first sampler and 21.1 ppb in the second. Such concentration differences are common with duplicate activated carbon samplers.

Trace 96-02. Chestnut Spring Trace.

One pound of rhodamine WT dye solution containing approximately 20% dye and 80% diluting agent was introduced into an intermittent stream fed in part by discharge from Chestnut Spring. This stream is a tributary to Cecil Creek. The dye introduction point was located about 50 feet downstream of the road crossing below Chestnut Spring; this is the road that leads to the old log house near Fitton Cave. The dye introduction point is located in the NW 1/4 SE 1/4 NE 1/4 Section 30, T17N, R21W at an elevation of approximately 1,440 feet. The area is shown on the Ponca 7.5 minute quadrangle map; the dye introduction point is in Newton County, Arkansas.

The dye introduction for Trace 96-02 was made on November 8, 1996 at 1410 hours under moderately high flow conditions. The flow of the Chestnut Spring Branch at the time of dye introduction was estimated at between 5 and 6 cubic feet per second (cfs); the peak flow of the storm runoff had passed by the time of dye introduction.

Trace 96-02 was designed to confirm that water from the Chestnut Spring Branch entered the groundwater system and subsequently discharged from Fitton Spring.

Rhodamine WT from Trace 96-02 was recovered from Station 102 (Fitton Spring). The first dye recovery at this station was in an activated carbon sampler in place for the period from November 8 at 1350 hours to November 14, 1996 at 1030 hours. The dye concentration in this sampler was 44.1 ppb. Activated carbon samplers in place at this station from November 14 to December 6, 1996 did not contain any detectable rhodamine WT dye. In addition, rhodamine WT from this dye introduction was not recovered in any subsequent activated carbon samplers from Fitton Spring.

Rhodamine WT from Trace 96-02 was also recovered at Station 109 (Cecil Creek Overflow near Van Dyke Spring). This station monitors water flowing in Cecil Creek a short distance upstream of Van Dyke Spring. The first dye recovery at Station 109 was in an activated carbon sampler in place for the period from November 8 at 1640 hours to November 14, 1996 at 1120 hours; the dye concentration was 106 ppb. Essentially all of the rhodamine WT dye passed this sampling station by November 14; a sampler in place for the period from November 14 to December 6, 1996 had a "shoulder" in the acceptable

wavelength range of rhodamine WT dye. A shoulder indicates that some dye may be present in the sample, but that the concentration is less than the detection limit.

Rhodamine WT dye from Trace 96-02 was also detected at Van Dyke Spring in an activated carbon sampler in place for the period from November 8, 1996 at 1630 hours to November 14, 1996 at 1130 hours. The dye concentration was 27.5 ppb. In addition, results from Trace 96-03 (to be discussed next) demonstrate that Van Dyke Spring receives recharge waters from portions of Cecil Creek through which rhodamine WT from Trace 96-02 passed.

The concentration of rhodamine WT dye in the activated carbon sampler from Fitton Spring was about 40% of that in the sampler from the Cecil Creek Overflow near Van Dyke Spring. Cecil Creek provided at least a five-fold dilution of dyed water derived from the Chestnut Spring tributary. The differences in dye concentrations between the two sampling stations and the magnitude of surface water dilution indicate that only a relatively small portion (probably on the order of 5 to 15%) of the dyed water in the Chestnut Spring tributary entered the groundwater system and ultimately discharged from Fitton Spring. It should be remembered that this trace was conducted under moderately high flow conditions; the percent of water flowing to Fitton Spring would undoubtedly be smaller under higher flow and is almost certainly 100% under low flow conditions.

Trace 96-03. Main Cecil Creek Trace.

One pound of fluorescein dye mixture containing approximately 25% diluent and 75% dye was introduced into the flow in the channel of Cecil Creek at a point about 100 feet downstream of the mouth of the unnamed tributary valley in which the Fitton Cave entrance is located. The dye introduction point is located in the SW 1/4 NE 1/4 SW 1/4 Section 30, T17N, R21W at an elevation of approximately 1,015 feet. The area is shown on the Ponca 7.5 minute quadrangle map, and is in Newton County, Arkansas.

The dye introduction for Trace 96-03 was made on November 8, 1996 at 1500 hours. The flow of the stream at the time of dye introduction was estimated at between 30 and 50 cfs; the peak flow of the storm runoff had passed by the time of dye introduction. At the time of the dye introduction all of the flow in the tributary valley in which the main Fitton Cave entrance is located was sinking at, or upstream of, a point about 300 feet downstream of the entrance.

Trace 96-03 was designed to determine if Cecil Creek downstream of the dye introduction point contributed any water to Fitton Spring and/or Van Dyke Spring. No dye from this trace was recovered at Fitton Spring even though sampling which could have detected dye from this trace continued at Fitton

Spring until March 26, 1997. Dye from Trace 96-03 was recovered from Station 109(Cecil Creek Overflow near Van Dyke Spring) and Station 110 (Van Dyke Spring). The first recovery of dye from this trace at Van Dyke Spring was in an activated carbon sampler in place for the period from November 8 at 1630 hours to November 14, 1996 at 1130 hours. Two samplers from this station were in place for the same sampling period and both were subjected to analysis. The fluorescein dye concentration in one was 202 ppb and in the other was 300 ppb. These concentration differences are common with activated carbon samplers.

Trace 96-04. Cecil Creek Upstream Bartlett Cove Trace.

Two pounds of rhodamine WT dye solution containing approximately 20% dye and 80% diluting agent was introduced into the flow in the channel of Cecil Creek at a point about 50 feet upstream of its confluence with Bartlett Cove. Water was not visibly sinking at the time of dye introduction, however, water from the dye introduction point was observed sinking in a pool in Cecil Creek during portions of the summer of 1996. The dye introduction point is located in the SE 1/4 NW 1/4 Section 30, T17N, R21W at an elevation of approximately 1,062 feet. The area is shown on the Ponca 7.5 minute quadrangle map, and is in Newton County, Arkansas.

The dye introduction for Trace 96-04 was made on December 6, 1996 at 1145 hours. The flow of the stream at the time of dye introduction was estimated at 5 cfs.

Trace 96-04 was designed to determine if Cecil Creek downstream of the dye introduction point contributed any water to Fitton Spring. No dye from this trace was recovered at Fitton Spring even though sampling which could have detected dye from this trace continued at Fitton Spring until March 23, 1997. Dye from Trace 96-04 was recovered from Station 109 (Cecil Creek Overflow near Van Dyke Spring) and Station 110 (Van Dyke Spring). The first recovery of dye from this trace at Van Dyke Spring was in activated carbon samplers in place for the period from December 6 at 1010 hours to December 16, 1996 at 1255 hours. The rhodamine WT dye concentration in one was 146 ppb and in the other was 139 ppb. These concentration differences are common with activated carbon samplers. Activated carbon samplers in place at Van Dyke Spring for the period from December 16, 1996 at 1255 hours to March 20, 1997 at 1325 hours also contained rhodamine WT dye from Trace 96-04. The concentration of dye in these samplers was an order of magnitude smaller than the concentrations at this spring during the previous sampling period. This indicates that there is relatively little storage in the karst aquifer between the dye introduction point and Van Dyke Spring.

Trace 96-05. Bartlett Cove 150 Feet Upstream of Chestnut Spring Branch Trace.

Two pounds of fluorescein dye mixture containing approximately 25% diluent and 75% dye was introduced into the flow in the channel of Bartlett Cove at a point about 150 feet upstream of the mouth of the Chestnut Spring Branch. The dye introduction point is located in the SW 1/4 NW 1/4 NE 1/4 Section 30, T17N, R21W at an elevation of approximately 1,120 feet. The area is shown on the Ponca 7.5 minute quadrangle map, and is in Newton County, Arkansas.

The dye introduction for Trace 96-05 was made on December 6, 1996 at 1245 hours. The flow of the stream at the time of dye introduction was estimated at 1 cfs. At the time of the dye introduction all of the flow in Bartlett Cove was sinking at a gravel bar just a few feet upstream of the mouth of Chestnut Spring Branch.

Trace 96-05 was designed to determine if Cecil Creek downstream of the dye introduction point contributed any water to Fitton Spring. Trace 96-02 had shown that some dye introduced into Chestnut Spring Branch did enter the groundwater system and discharge from Fitton Spring.

No dye from Trace 96-05 was recovered at Fitton Spring even though sampling which could have detected dye from this trace continued at Fitton Spring until March 23, 1997. Dye from Trace 96-05 was recovered from Station 109 (Cecil Creek Overflow near Van Dyke Spring) and Station 110 (Van Dyke Spring). The first recovery of dye from this trace at Van Dyke Spring was in activated carbon samplers in place for the period from December 6, 1996 at 1010 hours to December 16, 1996 at 1225 hours. The fluorescein dye concentration in one was 513 ppb and in the other was 504 ppb. These concentration differences are common with activated carbon samplers. Activated carbon samplers in place at Van Dyke Spring for the period from December 16, 1996 at 1255 hours to March 20, 1997 at 1325 hours also contained fluorescein dye from Trace 96-05. The concentration of dye in these samplers was more than an order of magnitude smaller than the concentrations at this spring during the previous sampling period. This result is compatible with that found at this spring for Trace 96-04 and further indicates that there is relatively little storage in the karst aquifer between the dye introduction points for Traces 96-04 and 96-05 and the groundwater discharge point at Van Dyke Spring.

Trace 97-01. Tributary 1 Trace.

One pound of rhodamine WT dye solution containing approximately 20% dye and 80% diluting solution was introduced into the flow of this small intermittent stream. The dye was introduced immediately downstream of a

road crossing. The dye introduction point is located in the SE 1/4 SE 1/4 NE 1/4 Section 30, T17N, R21W at an elevation of approximately 1,465 feet. The area is shown on the Jasper 7.5 minute quadrangle map, and is in Newton County, Arkansas.

The dye introduction for Trace 97-01 was made on March 26, 1997 at 1145 hours. The flow of the stream at the time of dye introduction was estimated at 10 to 15 gallons per minute. Trace 97-01 was designed to determine if this small tributary stream contributed any flow to Fitton Spring.

Dye from Trace 97-01 was recovered at Fitton Spring. The first dye recovery was in an activated carbon sampler in place for the period from March 26 at 1120 hours to April 3, 1997 at 1105 hours. The rhodamine WT concentration in this sampler was 172 ppb. Rhodamine WT dye was also recovered at this spring during the next sampling period (from April 3 to April 11, 1997. No dye from this trace was recovered from either Station 109 (Cecil Creek Overflow near Van Dyke Spring) or from Station 110 (Van Dyke Spring).

Dye from Trace 97-01 was also recovered from Station 105 (Cecil Creek Upstream of Cove Creek) for the sampling period from March 26, 1997 at 1430 hours to April 3, 1997 at 1045 hours. The concentration of dye in this activated carbon sampler was 29.2 ppb. It is our interpretation that this dye was derived from dye which discharged from Fitton Spring.

Trace 97-02. Tributary 2 Trace.

One pound of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into the flow of this small intermittent stream. The dye was introduced immediately downstream of a road crossing. The dye introduction point is located in the SW 1/4 NW 1/4 SW 1/4 Section 29, T17N, R21W at an elevation of approximately 1,465 feet. The area is shown on the Jasper 7.5 minute quadrangle map, and is in Newton County, Arkansas.

The dye introduction for Trace 97-02 was made on March 26, 1997 at noon. The flow of the stream at the time of dye introduction was estimated at 5 to 10 gallons per minute.

Trace 97-02 was designed to determine if this small tributary stream contributed any flow to Fitton Spring. Dye from Trace 97-02 was recovered at Fitton Spring. The first dye recovery was in an activated carbon sampler in place for the period from March 26 at 1120 hours to April 3, 1997 at 1105 hours. The eosine concentration in this sampler was 151 ppb. Eosine dye persisted in samplers at this sampling station for five additional sampling periods (see data in Appendix A).

Dye from Trace 97-02 was also recovered from Station 105 (Cecil Creek Upstream of Cove Creek) for the sampling period from March 26, 1997 at 1430 hours to April 3, 1997 at 1045 hours. The concentration of dye in this activated carbon sampler was 22.8 ppb. Eosine dye was also found in a concentration of 1.67 ppb in the activated carbon sampler in place at this station for the sampling period from April 3, 1997 at 1045 hours to April 11, 1997 at 1225 hours. It is our interpretation that this dye was derived from dye which discharged from Fitton Spring. Finally, eosine dye from this dye introduction was recovered at concentrations of less than one part per billion from Van Dyke Spring in samplers in place for the period from April 3, 1997 at 1235 hours to April 11, 1997 at 1325 hours, and for the period from April 11, 1997 at 1325 hours to June 3, 1997 at 1400 hours. It is our interpretation that there was some surface flow from the point of dye introduction all the way to Cecil Creek. Trace 96-03 has shown that the recharge area for Van Dyke Spring includes nearby sinking segments of Cecil Creek.

Trace 97-03. Tributary 3 Trace.

One pound of fluorescein dye mixture containing approximately 75% dye and 25% diluent was introduced into the flow of this small intermittent stream. The dye was introduced immediately downstream of the crossing of a closed road. The dye introduction point is located in the SW 1/4 SW 1/4 NE 1/4 Section 29, T17N, R21W at an elevation of approximately 1,465 feet. The area is shown on the Jasper 7.5 minute quadrangle map, and is in Newton County, Arkansas.

The dye introduction for Trace 97-03 was made on March 26, 1997 at 1330. The flow of the stream at the time of dye introduction was estimated at 10 gallons per minute. Trace 97-03 was designed to determine if this small tributary stream contributed any flow to Fitton Spring.

Dye from Trace 97-03 was recovered at Fitton Spring. The first dye recovery was in an activated carbon sampler in place for the period from March 26 at 1120 hours to April 3, 1997 at 1105 hours. The fluorescein concentration in this sampler was 181 ppb. Fluorescein dye persisted in samplers at this sampling station for three additional sampling periods (see data in Appendix A). No dye from this trace was recovered from either Station 109 (Cecil Creek Overflow near Van Dyke Spring) or from Station 110 (Van Dyke Spring).

Dye from Trace 97-03 was also recovered from Station 111 (Tributary to Cecil Creek at Road Crossing in SE 1/4 Section 29). An activated carbon sampler in place at this station for the period from March 26 at 1400 hours to April 3, 1997 at 1120 hours contained fluorescein dye at a concentration of 4,740

ppb. Based upon this large concentration, it is likely that much or all of the dye from Trace 97-03 which ultimately reached Fitton Spring entered the groundwater system downstream of Station 111.

Dye from Trace 97-03 was also recovered from Station 105 (Cecil Creek Upstream of Cove Creek) for the sampling period from March 26, 1997 at 1430 hours to April 3, 1997 at 1045 hours. The concentration of dye in this activated carbon sampler was 23.3 ppb. Fluorescein dye was also found in a concentration of 5.76 ppb in the activated carbon sampler in place at this station for the sampling period from April 3, 1997 at 1045 hours to April 11, 1997 at 1225 hours. It is our interpretation that this dye was derived from dye which discharged from Fitton Spring.

Trace 98-01. Upper Bartlett Cove Trace

One pound of fluorescein dye mixture containing approximately 75% dye and 25% diluent was introduced into a small sinking stream which entered the groundwater system approximately 50 feet downstream of the dye introduction point and about 50 feet upstream of the confluence of this stream with the channel of Bartlett Cove. The dye introduction point was located in the NE 1/4 NW 1/4 SE 1/4 Section 19, T17N, R21W at an elevation of approximately 1,260 feet. The area is shown on the Ponca 7.5 minute quadrangle map; the dye introduction point is located in Newton County, Arkansas.

The dye introduction for Trace 98-01 was made on February 25, 1998 at 1400 hours. The flow of the stream at the time of dye introduction was approximately 20 gallons per minute; all of this flow entered the groundwater system within 50 feet of the dye introduction point. At the time of dye introduction there was no flow in Bartlett Cove from the mouth of the unnamed hollow in which the dye was introduced downstream to a point about 300 feet upstream of the mouth of Chestnut Spring Branch.

Trace 96-05 involved a dye introduction at a point about 150 feet upstream of the mouth of Chestnut Spring Branch. Dye from Trace 96-05 was recovered from Van Dyke Spring, but was not recovered from Fitton Spring. Trace 96-04 involved dye introduction at a point on Cecil Creek about 50 feet upstream of its confluence with Bartlett Cove. Dye from Trace 96-04 was recovered from Van Dyke Spring, but was not recovered from Fitton Spring.

Trace 98-01 was designed to determine if any portions of Bartlett Cove upstream of the site used for Trace 96-05 might contribute waters to Fitton Spring. Fluorescein dye from Trace 98-01 <u>was</u> recovered from Fitton Spring. No fluorescein dye was detectable in an activated carbon sampler in place at this spring for the background sampling period (February 12 at 1700 hours to February 25, 1998 at 0940 hours). The activated carbon sampler in place at

Fitton Spring for the period from February 25 at 0940 to March 3, 1998 at 1300 hours contained 3,460 parts per billion (ppb) fluorescein dye. A subsequent sampler at this spring for the period from March 3 to March 23, 1998 contained 19.9 ppb fluorescein. A grab sample of water from the spring collected on March 3, 1998 at 1300 hours contained 0.057 ppb fluorescein.

The recovered dye concentrations suggest that most (and probably all) of the dye from Trace 98-01 discharged from Fitton Spring. Based upon these results, it is our conclusion that the entire topographic basin of Bartlett Cove upstream of a point approximately 300 feet north of the mouth of Chestnut Spring Branch is within the recharge area for Fitton Cave and the associated Fitton Spring. However, other traces have shown that this area also contributes water to Van Dyke Spring via downstream sinking points in Cecil Creek and Bartlett Cove.

Trace 98-02. Quinn Trace

One pound of rhodamine WT dye mixture containing approximately 20% dye and 80% diluting agent was introduced into a small intermittent sinking stream on the Gerald Quinn property located within the Cove Creek topographic basin. The dye introduction point is in the area between Fitton Spring and Tom Thumb Cemetery. Based upon geologic mapping by Hudson (1998) and our field observations, the dye was introduced at the approximate contact between the Batesville Sandstone and the underlying Boone Formation. The dye introduction point was located in the NE 1/4 SW 1/4 NW 1/4 Section 28, T17N, R21W at an elevation of approximately 1,250 feet. The area is shown on the Jasper 7.5 minute quadrangle map; the dye introduction point is located in Newton County, Arkansas.

The dye introduction for Trace 98-02 was made on February 29, 1998 at 1220 hours. The flow of the stream at the time of dye introduction was approximately 20 gallons per minute; all of this flow entered the groundwater system within 10 feet of the dye introduction point. The flow of the stream 300 feet upstream of the dye introduction point was about 50 gallons per minute. Water is withdrawn from the intermittent stream a short distance upstream of the dye introduction point as raw water for the Quinn residence. The intermittent stream is a topographic tributary to Cove Creek.

Trace 98-02 was designed to determine if lands in this region contributed any waters to Fitton Spring. Much of the land in this area has been divided into small acreage tracts, and there are a number of residences in the area which are served by on-site sewage systems. Most of the tracts in this area are steep, very rocky, and do not appear to be well suited for septic systems capable of providing good waste water treatment.

Rhodamine WT dye from Trace 98-02 was recovered from Station 106 (Cove Creek at Mouth). The first dye recovery at this sampling station was in an activated carbon sampler in place at this station for the period from February 27 at 1355 hours to March 3, 1998 at 1225 hours. The concentration of dye in this sampler was 261 ppb. An activated carbon sampler in place at this station for the period from March 3, 1998 at 1225 hours to March 23, 1998 at 1145 hours did not contain any detectable rhodamine WT dye. No dye from Trace 98-02 was recovered from Fitton Spring. It is our conclusion that this dye introduction point lies outside of the recharge area for Fitton Spring (and Fitton Cave).

Trace 98-03. Steep Canyon Trace

0.75 pounds of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into a small intermittent stream tributary to Cove Creek. The dye introduction point is in the area between Fitton Spring and Tom Thumb Cemetery, and is south of the dye introduction point for Trace 98-02. Based upon geologic mapping by Hudson (1998) and our field observations, the dye was introduced at a point about 30 feet in elevation below the top of the Boone Formation. The dye introduction point is located in the SE 1/4 SW 1/4 NW 1/4 Section 28, T17N, R21W at an elevation of approximately 1,200 feet. The area is shown on the Jasper 7.5 minute quadrangle map; the dye introduction point is located in Newton County, Arkansas.

The dye introduction for Trace 98-03 was made on February 29, 1998 at 1245 hours. The flow of the stream at the time of dye introduction was approximately 75 gallons per minute. The stream was not followed all the way to Cove Creek to determine if some of the flow persisted on the surface to that point.

Trace 98-03 was designed to determine if lands in this region contributed any waters to Fitton Spring. Much of the land in this area has been divided into small acreage tracts, and there are a number of residences in the area which are served by on-site sewage systems. Most of the tracts in this area are steep, very rocky, and are probably not well suited for septic systems capable of providing good waste water treatment. Essentially all of these small tracts of land are located north of this dye introduction point, and the absence of any dye at Fitton Spring from this introduction would indicate that these tracts of land do not cause hydrologic impacts on Fitton Cave and Fitton Spring.

Eosine dye from Trace 98-03 was recovered from a Station 106 (Cove Creek at Mouth). The first dye recovery at this sampling station was in an activated carbon sampler in place at this station for the period from February 27 at 1355 hours to March 3, 1998 at 1225 hours. The concentration of dye in

this sampler was 264 ppb. No dye from Trace 98-03 was recovered from Fitton Spring. It is our conclusion that this dye introduction point lies outside of the recharge area for Fitton Spring (and Fitton Cave).

Delineation of Recharge Areas

Introduction

Eleven successful groundwater traces have been conducted by the OUL to aid in the delineation of the Fitton Spring Recharge Area. Five of the dye introductions resulted in dye recoveries at Fitton Spring. Six of the dye introductions resulted in dye recoveries at Van Dyke Spring. Two of the dye introductions were outside of the recharge areas for both Fitton Spring and Van Dyke Spring. There were no dye introductions where dye was not recovered at one or more sampling stations. The locations of all dye introduction points and dye sampling stations are shown on Figure 4; diagrammatic lines are drawn from the dye introduction points to dye recovery sites. Some dye recoveries at surface stream stations are omitted for map clarity purposes. Figure 4 also shows the delineated recharge areas for Fitton Spring and for Van Dyke Spring. Delineation of the recharge area for Van Dyke Spring was not required under this contract, but sufficient information was developed to make the delineation technically feasible.

Fitton Spring Recharge Area

There have been five successful groundwater traces to Fitton Spring made by the OUL and one successful trace by Lindsley (1965). Fitton Spring is the discharge point for water in Fitton Cave. The successful traces by the OUL were as follows:

Trace 96-02. Chestnut Spring Trace.
Trace 97-01. Tributary 1 Trace.
Trace 97-02. Tributary 2 Trace.
Trace 97-03. Tributary 3 Trace.
Trace 98-01. Upper Bartlett Cove Trace.

Dye from Traces 96-02 and 97-02 was also recovered from Van Dyke Spring. The successful trace to Fitton Spring by Lindsley (1965) was from the stream in Fitton Cave.

Mapped portions of Fitton Cave extend to locations very near Fitton Spring; the spring is a component of the Fitton Cave system. For management purposes, the delineated recharge area for Fitton Spring is identical to the recharge area for Fitton Cave.

Four of the OUL dye introductions which yielded dye to Fitton Spring were made in the upland area lying generally north and east of Cecil Creek. This is the area traversed by the road leading from a locked NPS gate up to the old log house located near the cave entrances. This road is subject to appreciable erosion, and is likely to yield sediments into Fitton Cave. Keeping the road open is beneficial to frequent inspection of the gate on the cave and to periodic changing of the combination on the lock. We recommend that the Buffalo National River improve erosion control on this road if it is to remain open to official vehicle travel.

During the study we made four dye introductions into Cecil Creek or in Bartlett Cove upstream of its confluence with Cecil Creek. These were Traces 96-03,96-04,96-05,and 98-01. No dye from the first three of these traces (Traces 96-03, 96-04, and 96-05) was recovered in Fitton Spring. However, dye from Trace 98-01 (the Upper Bartlett Cove Trace) was recovered at Fitton Spring and demonstrates that the entire topographic basin of Bartlett Cove upstream of this dye introduction point contributes water (at least under some conditions) to Fitton Cave and subsequently to Fitton Spring. The point at which dye was introduced for Trace 98-01 was on the opposite side of Bartlett Cove from any of the known passages in Fitton Cave.

There are no data to indicate that Cecil Creek upstream of the mouth of Bartlett Cove and upstream of the dye introduction point for Trace 96-04 contributes any waters to Fitton Cave or Fitton Spring, yet this is a possibility that has not been tested by groundwater tracing. However, based upon the locations of dye introduction points 96-04, 96-05, and 98-01 plus the relatively small flow rates characteristic of Fitton Spring, it is our opinion that this portion of the Cecil Creek topographic basin does not contribute any waters to Fitton Cave or subsequently to Fitton Spring.

The recharge area for Fitton Spring is shown in Figure 4 and is divided into two component areas. Area A of the Fitton Spring Recharge Area encompasses a total area of 4.96 square miles (3,170 acres). Area B of the Fitton Spring Recharge Area encompasses a total of 0.44 square miles (280 acres). The total area which contributes water to Fitton Spring is the sum of Areas A and B, which is 5.40 square miles (3,460 acres). Essentially none of this area yields all of its runoff water to Fitton Spring.

Area A contributes surface runoff water to Cecil Creek plus some recharge water to Fitton Spring and to Van Dyke Spring. Under low to moderate flow conditions most of the water yielded from Area A south of the Chestnut Spring Branch discharges from Fitton Spring. Under moderately high to high flow conditions essentially all of this area contributes some water to surface runoff and some to groundwater which discharges from Fitton Spring. Based upon

the results of our tracing work, it appears that most, and perhaps all, of the recharge water contributed from this area to Van Dyke Spring is derived from waters which sink in or near the channel of Cecil Creek.

Area B of the Fitton Spring Recharge Area encompasses a total area of 0.44 square miles (280 acres). This area contributes surface runoff water to Cecil Creek plus some recharge water to Fitton Spring. Based upon our groundwater tracing work, this area does not appear to contribute any recharge water to Van Dyke Spring. It appears that all losing stream segments of Cecil Creek which contribute waters to Van Dyke Spring are located upstream of Area B. Under low to moderate flow conditions almost all of the water yielded from Area B enters the groundwater system and discharges from Fitton Spring. Under moderately high to high flow conditions there is appreciable surface runoff from this area into Cecil Creek.

The exact location of the southern and western Fitton Spring recharge area boundaries for Areas A and B in Sections 30, 31, and 32 is unknown. Fitton Cave passages are known to lie relatively close to Cecil Creek, and we have observed waters sinking in the channels of several of the tributary streams at points relatively near their confluences with Cecil Creek. It is our conclusion that the actual boundary of the Fitton Spring Recharge Area in this area lies very close to (but does not include) the channel of Cecil Creek; this is the way we have drawn the recharge area boundary.

Van Dyke Spring Recharge Area

There were six successful groundwater traces to Van Dyke Spring. These were:

Trace 96-01. Sinkhole Trace.
Trace 96-02. Chestnut Spring Trace.
Trace 96-03. Main Cecil Creek Trace.
Trace 96-04. Cecil Creek Upstream of Bartlett Cove Trace.
Trace 96-05. Bartlett Cove 150 Feet Upstream of Chestnut Spring Branch Trace.
Trace 97-02. Tributary 2 Trace.

Dye from Traces 96-02 and 97-02 was also recovered from Fitton Spring. In addition, while Van Dyke Spring was not sampled during Trace 98-01, results from previous traces demonstrate that some waters from the vicinity of the dye introduction point for Trace 98-01 also discharge from Van Dyke Spring.

The recharge area for Van Dyke Spring includes 92% of the recharge area for Fitton Spring. This is Area A as shown on Figure 4. In addition, Van Dyke Spring receives recharge water from Area C (see Figure 4); this area comprises 7.63 square miles (4,880 acres). The total size of the recharge area for Van

Dyke Spring is the total of Areas A and C, which comprises 12.59 square miles (8,050 acres). Much of the water contributed from this area sinks in the channel of Cecil Creek or some of the surface tributaries to this stream.

Other Recharge Areas

Two dye introductions (Traces 98-02 and 98-03) were made in the Cove Creek topographic basin south of Tom Thumb Spring. Dye from both of these traces was recovered at a sampling station at the mouth of Cove Creek. No dye from either of these traces was recovered at either Fitton Spring or Van Dyke Spring.

Lands in the vicinity of these two traces have been subdivided into small acreage tracts. Homes have been constructed on some of the tracts, and future home construction on other tracts is expected to occur. The homes in the area are served by on-site sewage systems, even though such systems typically do not perform well on the steep sites with shallow and/or rocky soils which characterize the area. However, based upon the results of our groundwater tracing studies, none of the subdivided area lies within the recharge area for either Fitton Spring or Van Dyke Spring.

A Conceptual Hydrologic Model for Fitton Cave and Nearby Major Springs.

The purpose of this section is to briefly place Fitton Cave and Van Dyke Spring (the only nearby major spring) into a generalized conceptual hydrologic model. We seek to provide a general answer to the question of: "how does water move into and through Fitton Cave, and how does this cave and its spring relate to nearby Van Dyke Spring?

Fitton Spring is the sole known groundwater discharge point for waters which have entered Fitton Cave. The spring discharges from near the base of the St. Joe Limestone Member of the Boone Formation. The stratigraphic positions of Fitton Spring and Van Dyke Spring are similar. Furthermore, this stratigraphic position is common to many of the larger springs in the Regional Study Area (including the two Dogpatch Springs). The reasons that many of the larger springs in the region occur at this stratigraphic position include the fact that the St. Joe Limestone is readily soluble and a common cave-forming unit, plus the fact that the underlying Everton Formation is a sandstone which is less subject to dissolution by groundwater than is the St. Joe Limestone.

Fitton Cave is located within the Cecil Creek topographic basin. In most of this basin the St. Joe Limestone and the rest of the Boone Formation are overlain by younger geologic units of Mississippian and Pennsylvania age. These include, in ascending order, the Batesville Sandstone, Fayetteville Shale, Pitkin

Limestone, the Hale Formation, and the Boyd Formation. Depending upon the local topography, many of these units have been eroded away by canyon cutting and at any given location are no longer present.

Within the study area the only rock types which are subject to appreciable dissolution are limestone and dolomite. The Pitkin Limestone is a relatively thin unit located stratigraphically above the Fayetteville Shale. Small caves and springs are sometimes found in this formation, but these features are hydrologically and structurally isolated from caves and springs in the Boone Formation by the existence of the Fayetteville Shale and to a lesser extent by the presence of the Batesville Sandstone. Precipitation which falls on lands underlain by the Fayetteville Shale or any of the overlying units is subject to evaporation, transpiration by plants, or ultimately surface runoff which passes down-slope and ultimately onto lands underlain by the Batesville Sandstone.

Most of the water which falls on the Batesville Sandstone or is yielded to this geologic unit by overland runoff from higher stratigraphic units flows off the Batesville Sandstone as surface flow. However, there are some limestone members within the Batesville Sandstone which are subject to dissolution and to the development of small caves and dissolutionally modified groundwater flowpaths. In addition, fracture flow of water downward through the Batesville Sandstone is common. The fractures followed by the descending water have commonly been induced by dissolutional subsidence in the underlying Boone Formation. The extent of this fracture flow is greatest where the Batesville Sandstone is exposed to the surface and sinkholes have formed. Less obvious fracture flow through the Batesville Sandstone occurs where the Batesville is crossed by surface stream channels. A good example of such a stream channel is the Chestnut Spring Branch which crosses mapped portions of Fitton Cave.

The recharge area for a spring or cave is that land area which contributes at least some water to the particular spring or cave. Most of the recharge area for Fitton Cave contributes only part of its flow to the cave. This is especially true during periods of storm runoff when the rates at which water can move into the Fitton Cave groundwater system are often exceeded by the available supply of water. When this occurs, some of the runoff water sinks into the ground and ultimately enters the cave. Other runoff water may flow to points outside of the recharge area for Fitton Cave but within the recharge area for Van Dyke Spring where some of this water may sink and ultimately discharge from Van Dyke Spring. Still other water may stay entirely on the surface and never enter the groundwater systems for either Fitton Cave or Van Dyke Spring.

Much of the mapped portions of Fitton Cave roughly parallel the course of Cecil Creek and lie generally to the north and east of the creek. Several dye introductions within Cecil Creek yielded dye recoveries at Van Dyke Spring

but no recoveries at Fitton Spring. An exception was Trace 98-01, where dye was introduced into a segment of Bartlett Cove (a tributary to Cecil Creek) and was recovered from Fitton Spring. While surface flow reaching the proximity of the dye introduction point for Trace 98-01 will contribute to the flow of Fitton Spring, Cecil Creek per se does not contribute waters to Fitton Spring. This is certainly not what we initially anticipated.

Finally, there do not appear to be any underground connections between Fitton Spring and Van Dyke Spring. Additionally, we found no dramatic seasonal changes in groundwater flow directions in the Fitton Spring or Van Dyke Spring area. This is different from the conditions found in the delineation work for Mitch Hill Spring located further down the Buffalo River (Aley, 1988; Aley and Aley, 1989) where complex radial flow was documented.

SUMMARY AND CONCLUSIONS

This report deals with the first phase of a two phase study to inventory karst hydrology features and to delineate groundwater recharge areas for important features and areas. Two study areas were involved in these investigations. The Regional Study Area is the larger area, and includes within it the Fitton Cave Study Area. During the Phase 1 work all groundwater tracing was limited to locations within the Fitton Cave Study Area. During the Phase 2 work the groundwater tracing work focused on the Regional Study Area. A subsequent report will deal with the findings from the Phase 2 work.

Section 1 of this report summarized previous work in the regional study area with special attention to the Fitton Cave Study Area. The mapping of Fitton Cave by Cave Research Foundation and the recent geologic mapping of the Regional Study Area by Hudson (1998) were particularly useful. In addition, several previous groundwater traces provided both credible and valuable data.

Section 2 of this report involved mapping of karst features in the Regional Study Area and identification of areas where land use activities might present hazards to groundwater quality. Essentially all of the streams in the areas underlain by the Boone Formation are losing streams, even when the streams have perennial flow. Losing streams are very important groundwater recharge areas. Most of the groundwater tracing conducted during the Phase 2 studies involved dye introductions in losing streams of the area. Results of this work will be included in the Phase 2 report. While there are some point source groundwater quality hazard areas, most of the land uses which impact or could impact groundwater quality are non-point sources. The impacts of land uses on groundwater quality are assessed in Section 2 of the report.

Section 3 of the report dealt with groundwater tracing investigations to delineate the recharge area for Fitton Spring (which is analogous to the recharge area for Fitton Cave. A total of 13 sampling stations were established for this groundwater tracing work, and 11 separate dye introductions were made during the study. There were five successful traces to Fitton Spring (two of these also yielded dye to Van Dyke Spring). There were six successful groundwater traces to Van Dyke Spring, and two successful groundwater traces which yielded dye to neither Van Dyke Spring nor Fitton Spring.

The delineated recharge area for Fitton Spring is shown in Figure 4 and consists of two areas (Areas A and B on Figure 4). The total area which contributes recharge water to Fitton Spring is 5.40 square miles (3,460 acres). Approximately 92% of this area also contributes recharge water to Van Dyke Spring. The total area which contributes recharge water to Van Dyke Spring is also shown on Figure 4 and encompasses 12.59 square miles (8,050 acres).

Some surface flow in Bartlett Cove enters the groundwater system and discharges from Fitton Spring. As a result, almost all of the Bartlett Cove topographic basin can contribute both water and contaminants to Fitton Spring. The upstream end of this topographic basin is traversed by approximately 1.5 miles of Arkansas Highway 43 in Boone County northeast of Compton. Highway spills in this area could impact Fitton Cave.

It is our conclusion that the most significant present adverse hydrologic impact on Fitton Cave and Fitton Spring is probably sediments derived from the steep NPS service road which leads from the Erbie Road to the old cabin near Chestnut Spring. This road provides valuable access to the cave so that NPS personnel can routinely change the lock combination and check for forced entry into the cave. If this road is to remain open actions are needed to reduce erosion of the road and sediment input into the karst groundwater system.

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APPENDIX A

TABLE OF DYE ANALYSIS RESULTS

Table A-1. Dye analysis results for charcoal and water samples (results for charcoal unless otherwise indicated).

OUL Lab#	Sta #	Station Name	Date/time	Date /time	Fluorescein Results		Eosine Results		Rhodamine WT Results	
			Placed	Recovered	Peak nm	Conc. ppb	Peak nm	Conc. ppb	Peak nm	Conc. ppb
F6838	101	Chestnut Spr near Caver Cabin	8-30-96 1315	9-11-96 1225	ND		ND		ND	
F6839	102	Fitton Spring	8-30-96 1345	9-11-96 1200	ND		ND		ND	
F7584	102	Fitton Spring	9-11-96 1200	11-8-96 1350	ND		ND		ND	
F7624	102	Fitton Spring	11-8-96 1350	11-14-96 1030	ND		ND		563.3	44.1
F7831	102	Fitton Spring	11-14-96 1030	12-6-96 0920	ND		ND		ND	
F7883	102	Fitton Spring	12-6-96 0920	12-16-96 1225	ND		ND		ND	
F9716	102	Fitton Spring	12-16-96 1225	3-20-97 1230	ND		ND		ND	
F9719	102	Fitton Spring	Water	3-20-97 1230	ND		ND		ND	
F9990	102	Fitton Spring	3-20-97 1230	3-26-97 1120	ND		ND		ND	
G0513	102	Fitton Spring	3-26-97 1120	4-3-97 1105	514.6	181	536.4	151	563.2	172
G0588	102	Fitton Spring	4-3-97 1105	4-11-97 1250	513.4	73.3	536.8	36.5	562.8	31.0
G1755	102	Fitton Spring	4-11-97 1250	4-17-97 1710	513.0	22.7	535.2	11.8	ND	
G4047	102	Fitton Spring	4-17-97 1710	6-3-97 1325	512.9	9.86	535.6	9.91	ND	
G8894	102	Fitton Spring	6-3-97 1325	9-13-97 1110	ND		538.0	6.41	ND	
H1130	102	Fitton Spring	9-13-97 1110	2-12-98 1700	ND		536.4	1.79	ND	
H1207	102	Fitton Spring	2-12-98 1700	2-25-98 0940	ND		ND		ND	
H1309	102	Fitton Spring	2-25-98 0940	3-3-98 1300	513.9	3460	ND		ND	
H1396	102	Fitton Spring	Water	3-3-98 1300	507.0	0.057	ND		ND	
H1656	102	Fitton Spring	3-3-98 1300	3-23-98 1200	513.0	19.9	ND		ND	

Table A-1 (cont). Dye analysis results for charcoal and water samples (results for charcoal unless otherwise indicated).

OUL Lab#	Sta #	Station Name	Date/time Placed	Date /time Recovered	Fluorescein Results		Eosine Results		Rhodamine WT Results	
					Peak nm	Conc. ppb	Peak nm	Conc. ppb	Peak nm	Conc. ppb
F6841	103	**Cecil Creek u/s Fitton Spring**	**8-30-96 1520**	**9-11-96 1150**	**ND**		**ND**		**ND**	
	104	**Cecil Cr. 1/4 ml d/s Fitton Spring**	nc							
F6842	105	**Cecil Creek u/s Cove Creek**	**8-30-96 1430**	**9-11-96 1100**	**ND**		**ND**		**ND**	
G0516	105	Cecil Creek u/s Cove Creek	3-26-97 1430	4-3-97 1045	513.7	23.3	535.6	22.8	564.0	29.2
G0587	105	Cecil Creek u/s Cove Creek	4-3-97 1045	4-11-97 1225	512.9	5.76	536.4	1.67	ND	
F6843	106	**Cove Creek @ Mouth**	**8-30-96 1440**	**9-11-96 1110**	**ND**		**ND**		**ND**	
F9715	106	Cove Creek @ Mouth	Water	3-20-97 1211	ND		ND		ND	
F9989	106	Cove Creek @ Mouth	3-20-97 1211	3-26-97 1105	ND		ND		ND	
G0512	106	Cove Creek @ Mouth	3-26-97 1105	4-3-97 1050	ND		ND		ND	
G0586	106	Cove Creek @ Mouth	4-3-97 1050	4-11-97 1230	ND		ND		ND	
G4051	106	Cove Creek @ Mouth	4-11-97 1230	6-3-97 1310	ND		ND		ND	
G8895	106	Cove Creek @ Mouth	6-3-97 1310	9-13-97 1205	ND		ND		ND	
H1326	106	Cove Creek @ Mouth	9-13-97 1205	2-27-98 1355	ND		ND		ND	
H1310	106	Cove Creek @ Mouth	2-27-98 1355	3-3-98 1225	ND		538.8	264	565.2	261
H1397	106	Cove Creek @ Mouth	Water	3-3-98 1225	ND		ND		ND	
H1657	106	Cove Creek @ Mouth	3-3-98 1225	3-23-98 1145	ND		537.2	2.95	SH	
F6844	107	**Rippled Slab**	**8-30-96 1500**	**9-11-96 1120**	**ND**		**ND**		**ND**	

Table A-1 (cont). Dye analysis results for charcoal and water samples (results for charcoal unless otherwise indicated).

OUL Lab#	Sta #	Station Name	Date/time Placed	Date /time Recovered	Fluorescein Results		Eosine Results		Rhodamine WT Results	
					Peak nm	Conc. ppb	Peak nm	Conc. ppb	Peak nm	Conc. ppb
F7622	108	1st Tributary d/s of Van Dyke Spring	11-8-96 1700	11-14-96 1140	ND		538.2	670	ND	
F7623	109	Cecil Creek Overflow near Van Dyke Spring	11-8-96 1640	11-14-96 1120	513.3	392	ND		563.8	106
F7832	109	Cecil Creek Overflow near Van Dyke Spring	11-14-96 1120	12-6-96 1005	ND		ND		561.6a	SH
F7884	109	Cecil Creek Overflow near Van Dyke Spring	12-6-96 1005	12-16-96 1250	513.3	422	ND		564.0	279
F9718	109	Cecil Creek Overflow near Van Dyke Spring	12-16-96 1250	3-20-97 1316	512.4	3.46	ND		559.2a	2.55
F9722	109	Cecil Creek Overflow near Van Dyke Spring	Water	3-20-97 1316	ND		ND		ND	
F9987	109	Cecil Creek Overflow near Van Dyke Spring	3-20-97 1316	3-26-97 1035	ND		ND		ND	
G0510	109	Cecil Creek Overflow near Van Dyke Spring	3-26-97 1035	4-3-97 1230	ND		ND		ND	
G0590	109	Cecil Creek Overflow near Van Dyke Spring	4-3-97 1230	4-11-97 1321	ND		ND		ND	
G4050	109	Cecil Creek Overflow near Van Dyke Spring	4-11-97 1321	6-3-97 1355	ND		ND		ND	
G8896	109	Cecil Creek Overflow near Van Dyke Spring	6-3-97 1355	9-13-97 1030	ND		ND		ND	
F7625	110	Van Dyke Spring	11-8-96 1630	11-14-96 1130	513.4	202	537.6e	46.7	564.8	27.5
F7625D	110	Van Dyke Spring	11-8-96 1630	11-14-96 1130	513.4	300	c		c	
F7830	110	Van Dyke Spring	11-14-96 1130	12-6-96 1010	513.4	3.67	537.4	25.1	ND	
F7830D	110	Van Dyke Spring	11-14-96 1130	12-6-96 1010	512.7	4.32	537.1	21.1	ND	
F7882	110	Van Dyke Spring	12-6-96 1010	12-16-96 1255	513.3	513	ND		562.7	146
F7882D	110	Van Dyke Spring	12-6-96 1010	12-16-96 1255	513.5	504	ND		563.4	139
F9717	110	Van Dyke Spring	12-16-96 1255	3-20-97 1325	513.2	8.84	536.0	4.52	560.8a	11.8
F9717D	110	Van Dyke Spring	12-16-96 1255	3-20-97 1325	513.3	13.5	536.8	5.31	561.6a	15.7
F9721	110	Van Dyke Spring	Water	3-20-97 1325	ND		ND		ND	

Table A-1 (cont). Dye analysis results for charcoal and water samples (results for charcoal unless otherwise indicated).

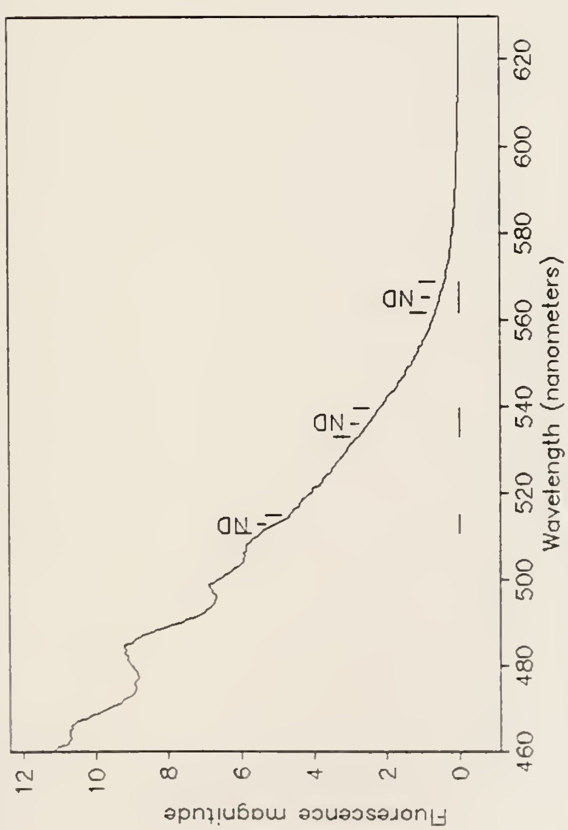
OUL Lab#	Sta #	Station Name	Date/time Placed	Date /time Recovered	Fluorescein Results		Eosine Results		Rhodamine WT Results	
					Peak nm	Conc. ppb	Peak nm	Conc. ppb	Peak nm	Conc. ppb
F9988	110	Van Dyke Spring	3-20-97 1325	3-26-97 1040	ND		ND		ND	
F9988D	110	Van Dyke Spring	3-20-97 1325	3-26-97 1040	ND		ND		ND	
G0511	110	Van Dyke Spring	3-26-97 1040	4-3-97 1235	ND		ND		ND	
G0511D	110	Van Dyke Spring	3-26-97 1040	4-3-97 1235	ND		ND		ND	
G0589	110	Van Dyke Spring	4-3-97 1235	4-11-97 1325	ND		533.2	0.520	ND	
G0589D	110	Van Dyke Spring	4-3-97 1235	4-11-97 1325	ND		535.2	0.470	ND	
G4049	110	Van Dyke Spring	4-11-97 1325	6-3-97 1400	ND		534.4	0.549	ND	
G4049D	110	Van Dyke Spring	4-11-97 1325	6-3-97 1400	ND		534.8	0.714	ND	
G8897	110	Van Dyke Spring	6-3-97 1400	9-13-97 1035	ND		ND		ND	
G8897D	110	Van Dyke Spring	6-3-97 1400	9-13-97 1035	ND		ND		ND	
G0514	**111**	**Trib. to Cecil Cr. at rd xing in SE1/4 of Sec. 29**	**3-26-97 1400**	**4-3-97 1120**	**514.2**	**4740**	**ND**		**ND**	
G0515	**112**	**Little Spring Branch**	**3-26-97 1413**	**4-3-97 1125**	**ND**		**ND**		**ND**	
G0517	**113**	**Main Stem of Cecil Cr u/s Van Dyke Spring**	**Water**	**4-3-97 1240**	**ND**		**ND**		**ND**	
G0591	113	Main Stem of Cecil Cr u/s Van Dyke Spring	4-3-97 1240	4-11-97 1315	ND		ND		ND	
G4048	113	Main Stem Cecil Cr u/s Van Dyke Spring	4-11-97 1315	6-3-97 1405	ND		ND		ND	
G8898	113	Main Stem Cecil Cr u/s Van Dyke Spring	6-3-97 1405	9-13-97 1045	ND		ND		ND	

a = a fluorescense peak is present which is out of the normally acceptable wavelength range for this dye, but it has been calculated as though it were dye.
c = concentrations for this dye were not calculated
c = Due to large concentrations of fluorescein dye in this sample, the amount of eosine dye is difficult to calculate accurately
nc = never collected
ND = none detected   SH = shoulder

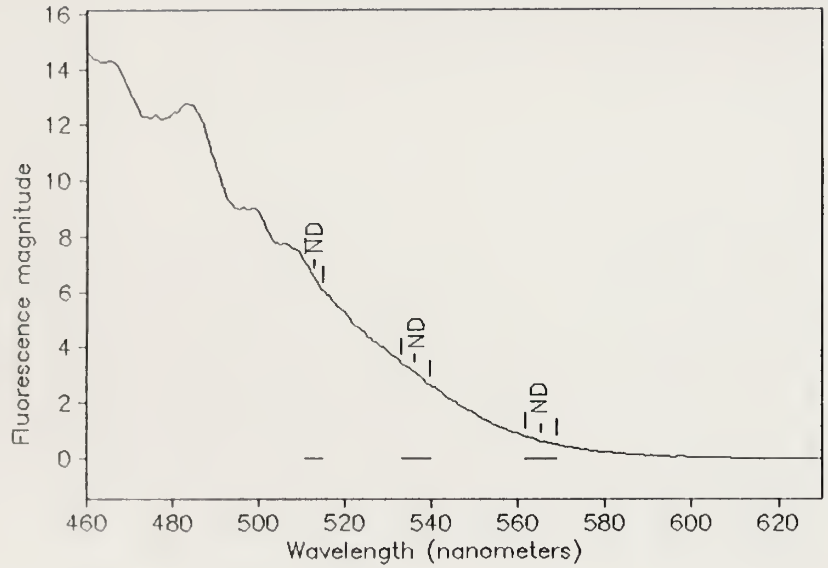
f docs fitton fitton

APPENDIX B

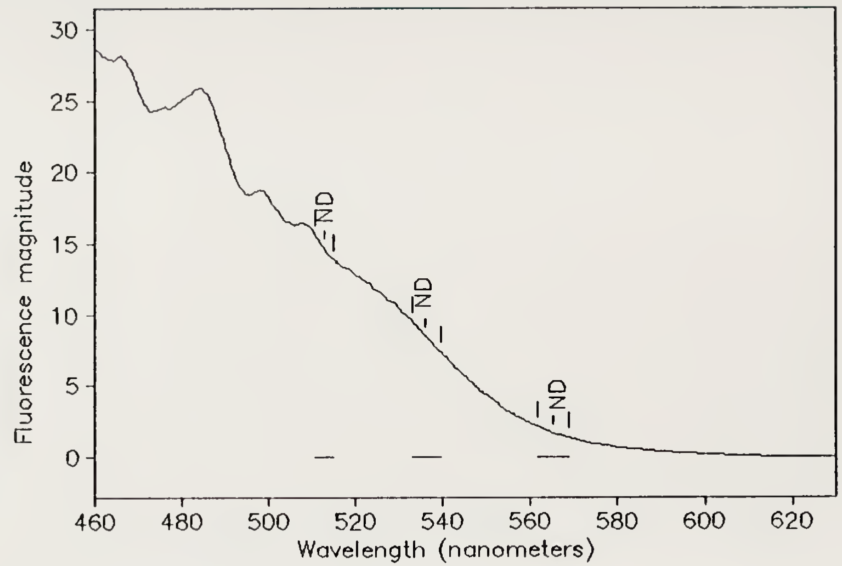
DYE ANALYSIS GRAPHS



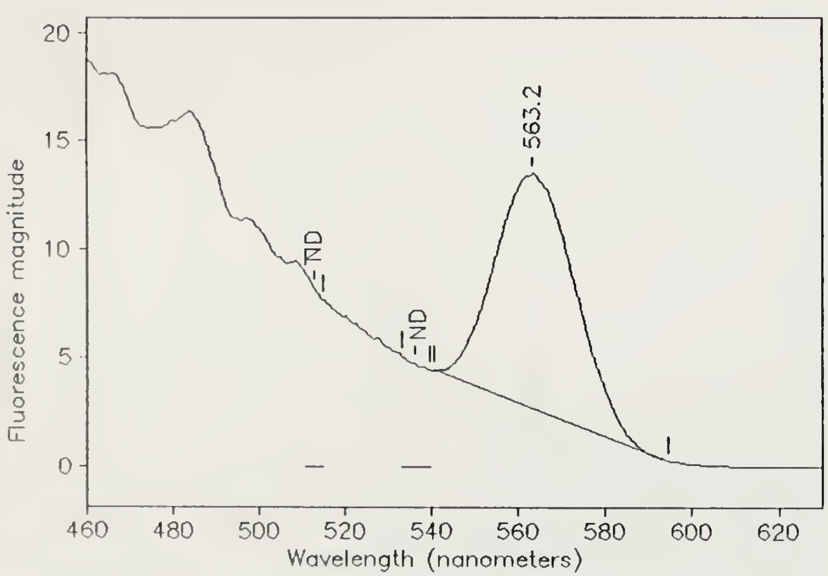
Station 101: Chestnut Spring near Caver Cabin
OUL number: F6838 Type: Charcoal Analyzed: 19960920
Date placed: 08/30/96 Date recovered: 09/11/96
Time placed: 1315 Time recovered: 1225



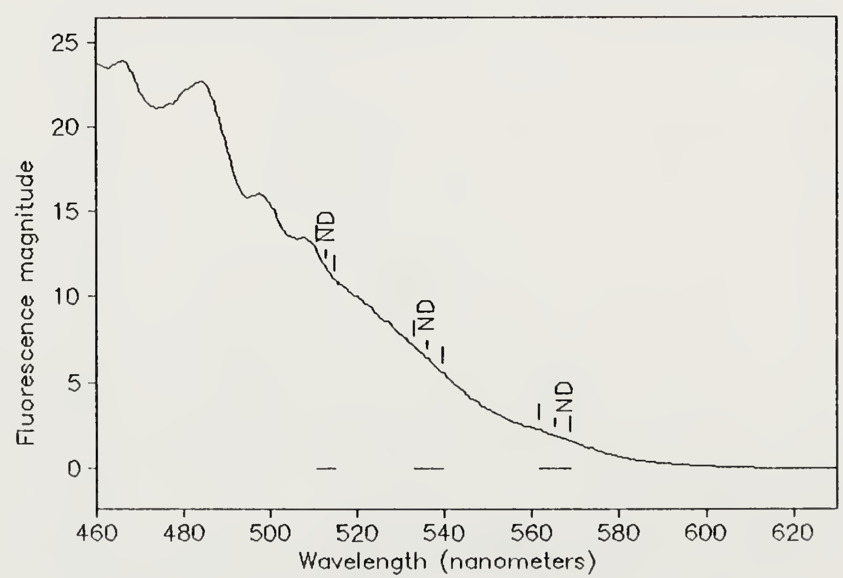
Station 102: Fitton Spring
OUL number: F6839 Type: Charcoal Analyzed: 19960920
Date placed: 08/30/96 Date recovered: 09/11/96
Time placed: 1345 Time recovered: 1200



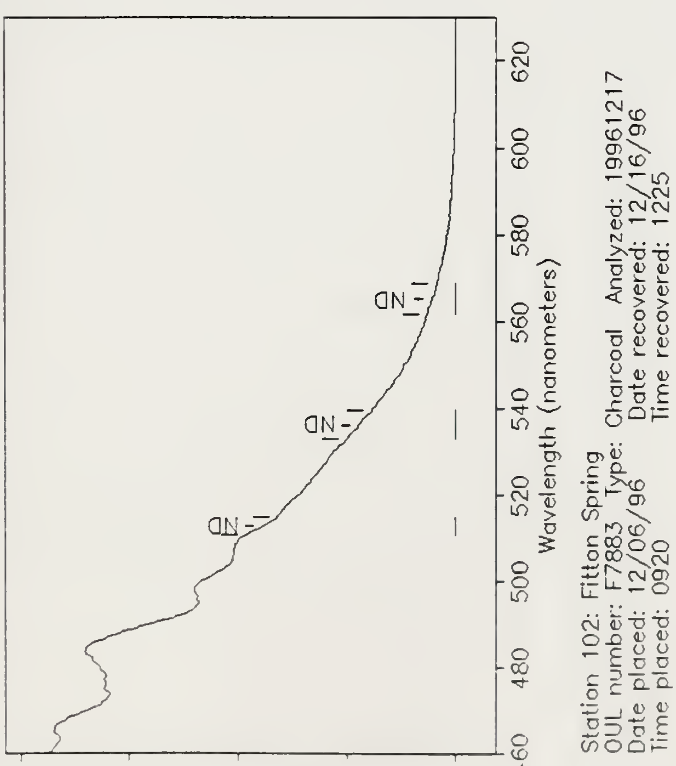
Station 102: Fitton Spring
OUL number: F7584 Type: Charcoal Analyzed: 19961111
Date placed: 09/11/96 Date recovered: 11/08/96
Time placed: 1200 Time recovered: 1350

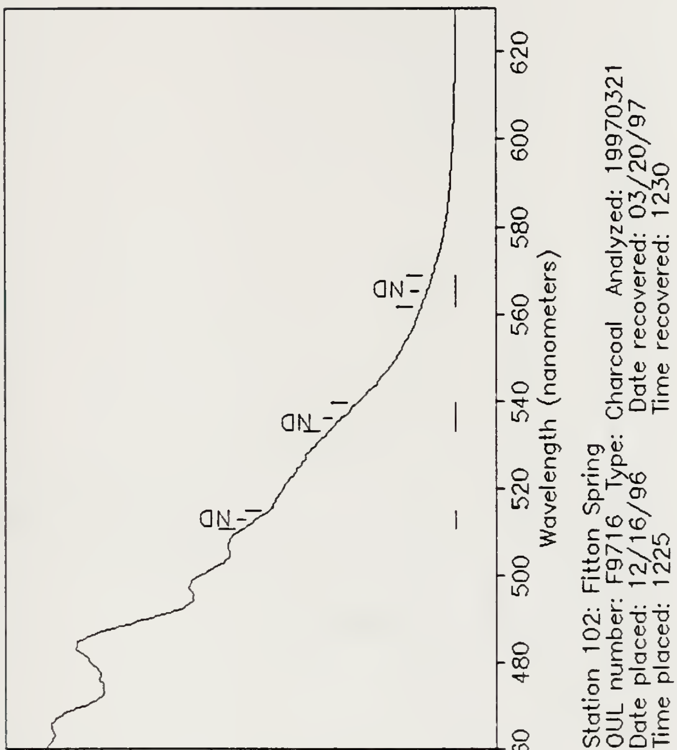


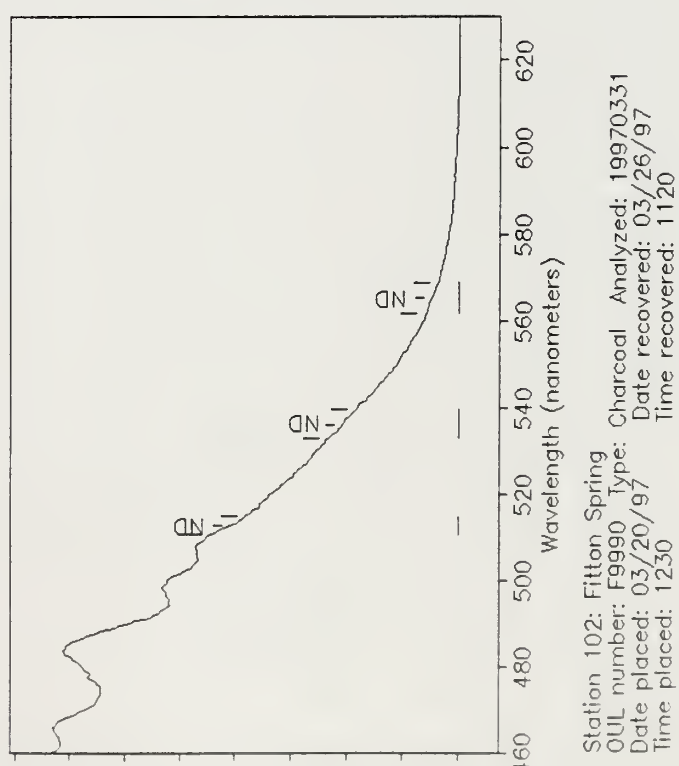
Station 102: Fitton Spring
OUL number: F7624 Type: Charcoal Analyzed: 19961115
Date placed: 11/08/96 Date recovered: 11/14/96
Time placed: 1350 Time recovered: 1030

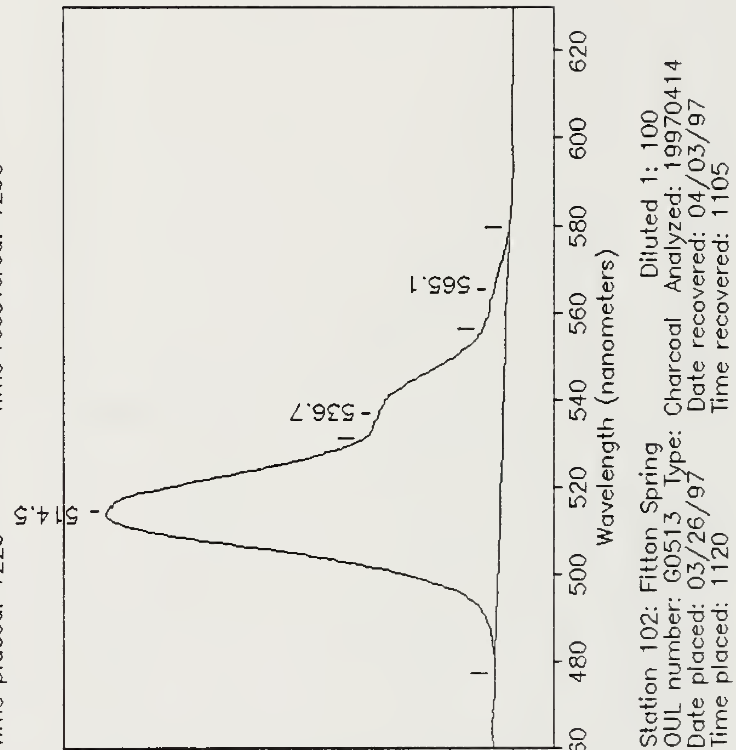


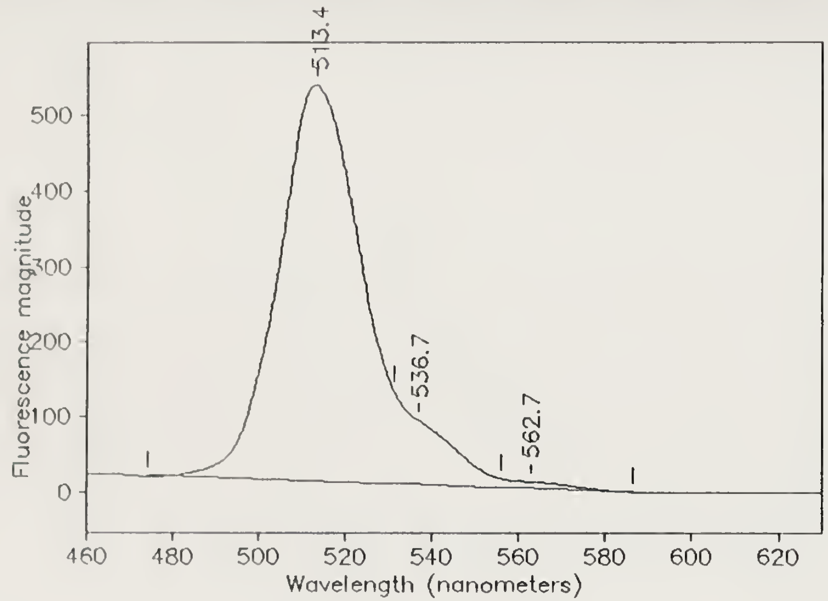
Station 102: Fitton Spring
OUL number: F7831 Type: Charcoal Analyzed: 19961211
Date placed: 11/14/96 Date recovered: 12/06/96
Time placed: 1030 Time recovered: 0920


Fluorescence magnitude
Wavelength (nanometers)
ND
ND
ND
Station 102: Fitton Spring
OUL number: F7883 Type: Charcoal Analyzed: 19961217
Date placed: 12/06/96 Date recovered: 12/16/96
Time placed: 0920 Time recovered: 1225

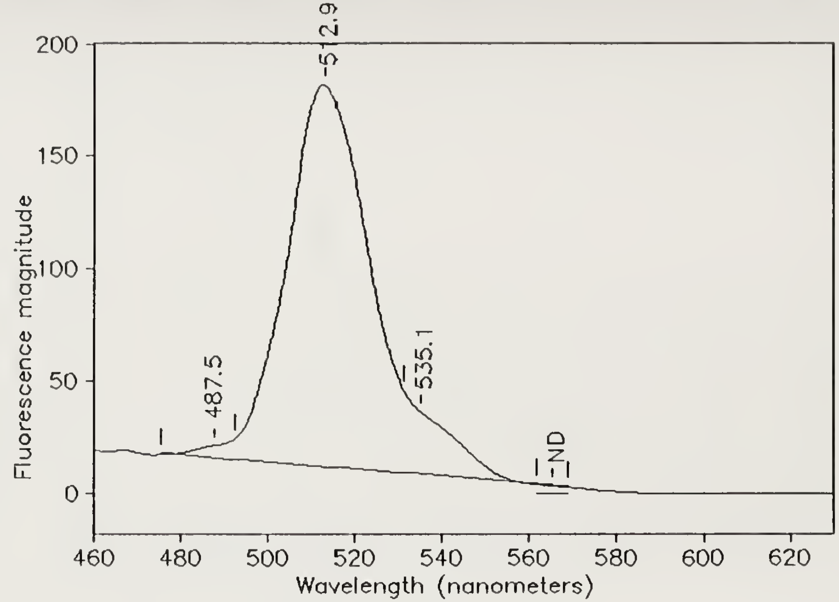

Fluorescence magnitude
Wavelength (nanometers)
ND
ND
ND
Station 102: Fitton Spring
OUL number: F9716 Type: Charcoal Analyzed: 19970321
Date placed: 12/16/96 Date recovered: 03/20/97
Time placed: 1225 Time recovered: 1230


Fluorescence magnitude
Wavelength (nanometers)
ND
ND
ND
Station 102: Fitton Spring
OUL number: F9990 Type: Charcoal Analyzed: 19970331
Date placed: 03/20/97 Date recovered: 03/26/97
Time placed: 1230 Time recovered: 1120

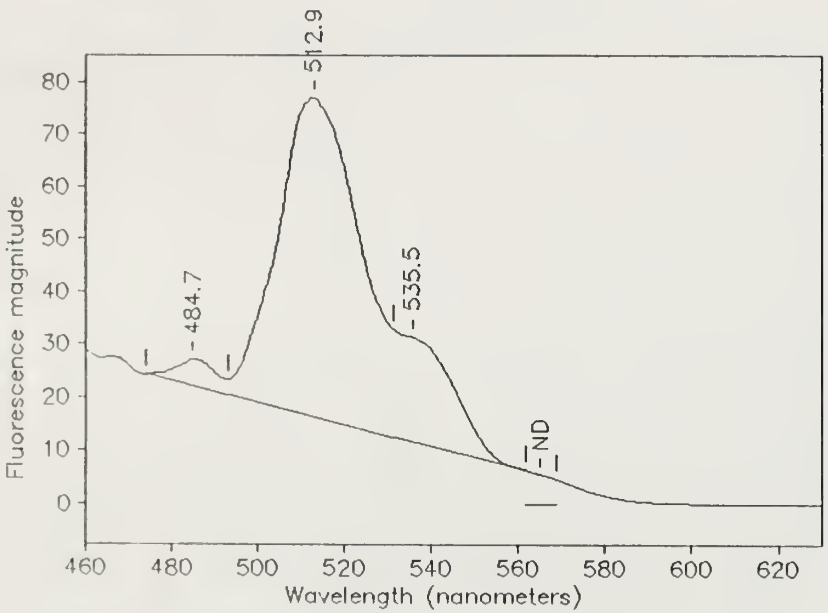

Fluorescence magnitude
Wavelength (nanometers)
514.5
536.7
565.1
Station 102: Fitton Spring Diluted 1: 100
OUL number: G0513 Type: Charcoal Analyzed: 19970414
Date placed: 03/26/97 Date recovered: 04/03/97
Time placed: 1120 Time recovered: 1105



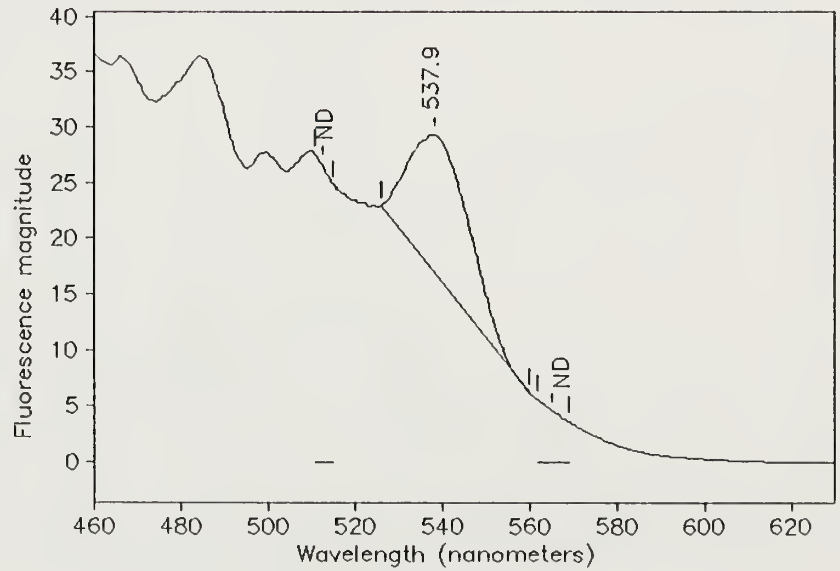
Station 102: Fitton Spring
OUL number: G0588 Type: Charcoal Analyzed: 19970414
Date placed: 04/03/97 Date recovered: 04/11/97
Time placed: 1105 Time recovered: 1250



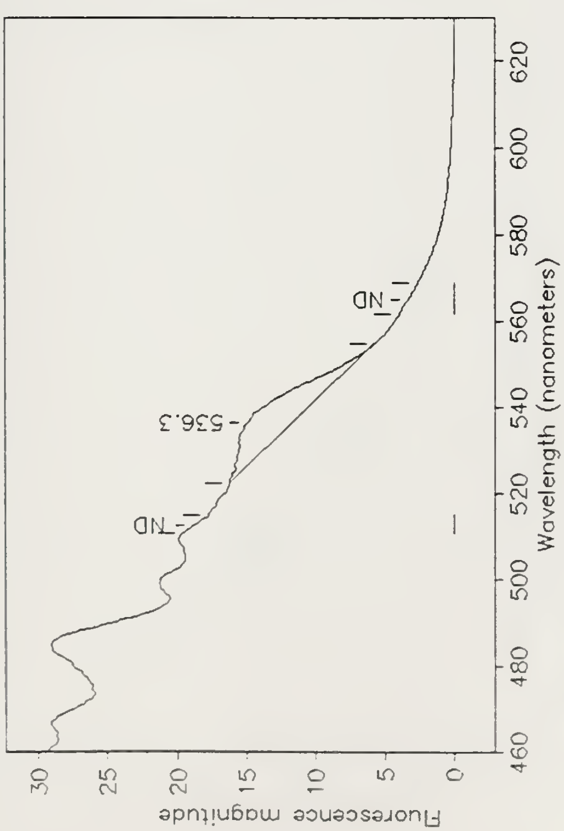
Station 102: Fitton Spring
OUL number: G1755 Type: Charcoal Analyzed: 19970430
Date placed: 04/11/97 Date recovered: 04/17/97
Time placed: 1250 Time recovered: 1710



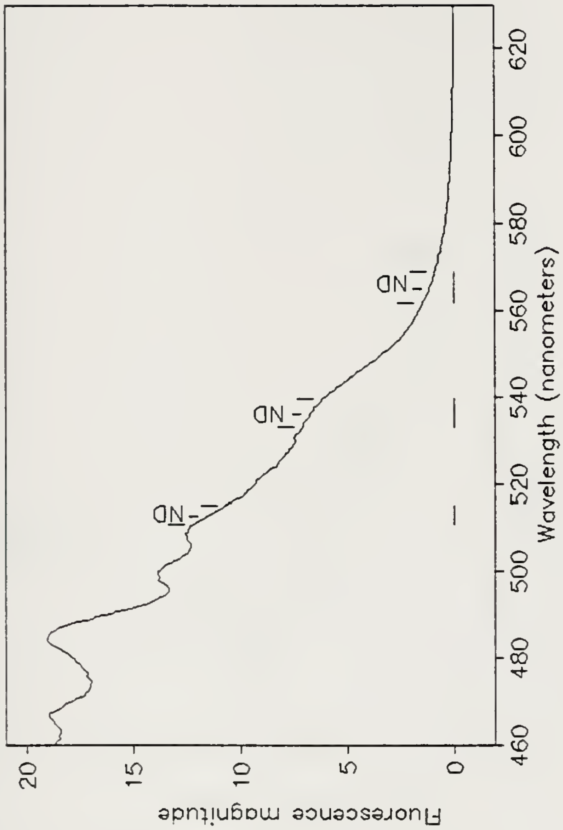
Station 102: Fitton Spring
OUL number: G4047 Type: Charcoal Analyzed: 19970607
Date placed: 04/17/97 Date recovered: 06/03/97
Time placed: 1710 Time recovered: 1325



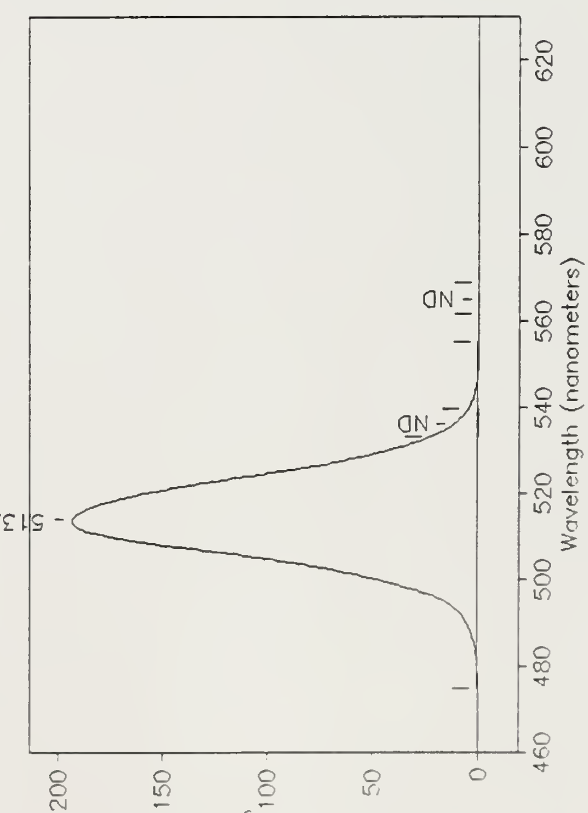
Station 102: Fitton Spring
OUL number: G8894 Type: Charcoal Analyzed: 19970929
Date placed: 06/03/97 Date recovered: 09/13/97
Time placed: 1325 Time recovered: 1110



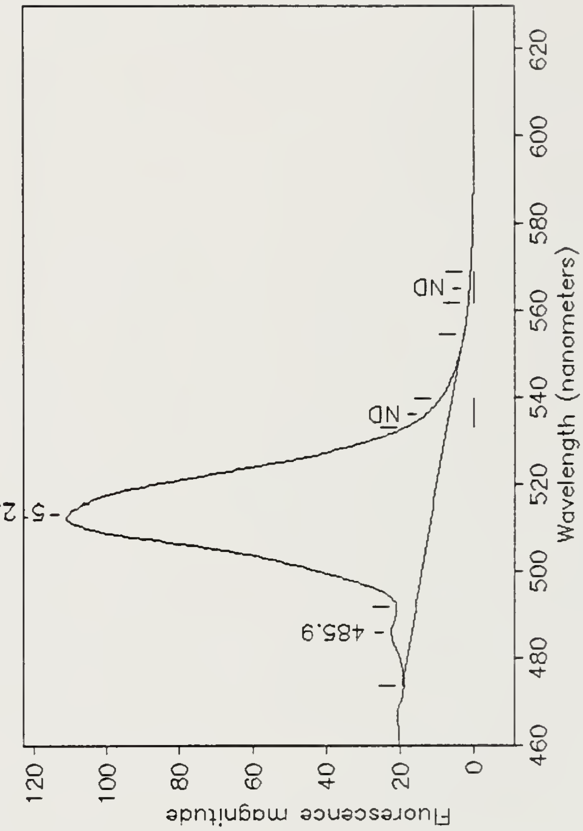
Station 102: Fitton Spring
OUL number: H1130 Type: Charcoal Analyzed: 19980217
Date placed: 09/13/97 Date recovered: 02/12/98
Time placed: 1110 Time recovered: 1700



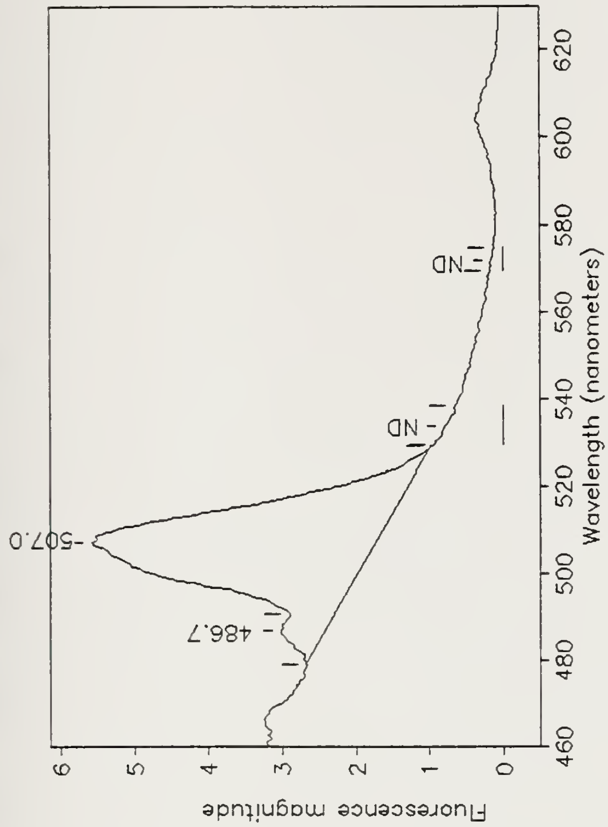
Station 102: Fitton Spring
OUL number: H1207 Type: Charcoal Analyzed: 19980227
Date placed: 02/12/98 Date recovered: 02/25/98
Time placed: 1700 Time recovered: 0940



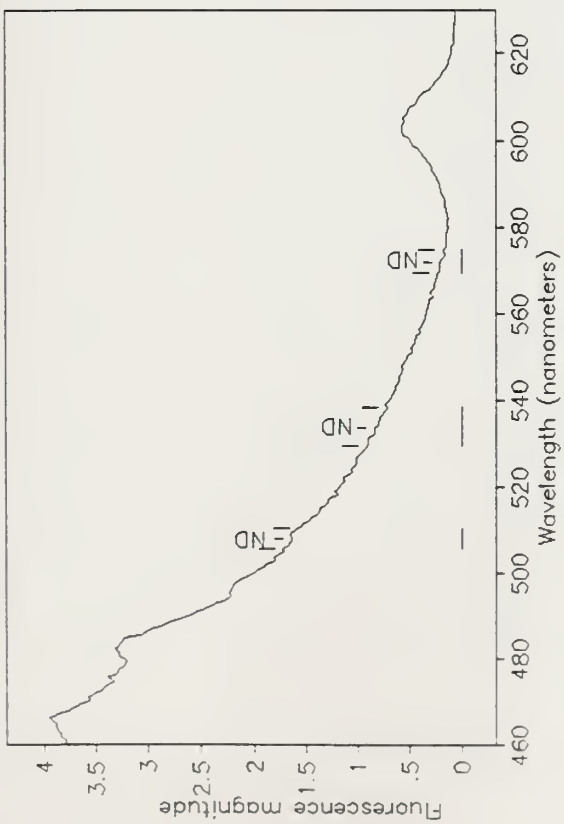
Station 102: Fitton Spring Diluted 1: 100
OUL number: H1309 Type: Charcoal Analyzed: 19980306
Date placed: 02/25/98 Date recovered: 03/03/98
Time placed: 0940 Time recovered: 1300



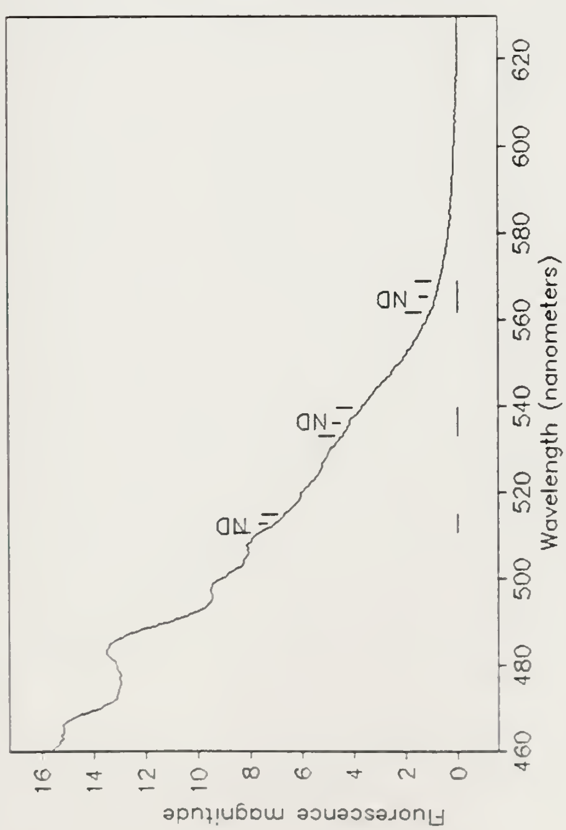
Station 102: Fitton Spring
OUL number: H1656 Type: Charcoal Analyzed: 19980325
Date placed: 03/03/98 Date recovered: 03/23/98
Time placed: 1300 Time recovered: 1200



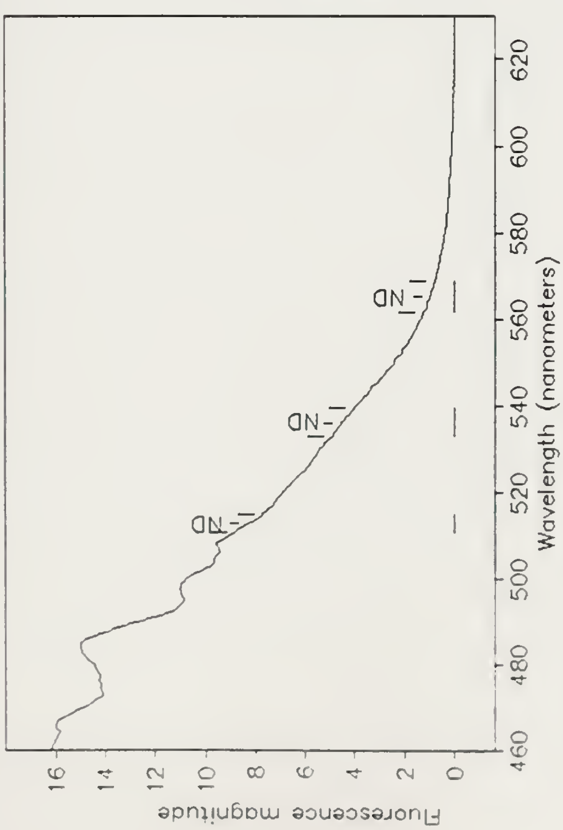
Station 102: Fitton Spring
OUL number: H1396 Type: Water Analyzed: 19980310
Date collected: 03/03/98 Time collected: 1300



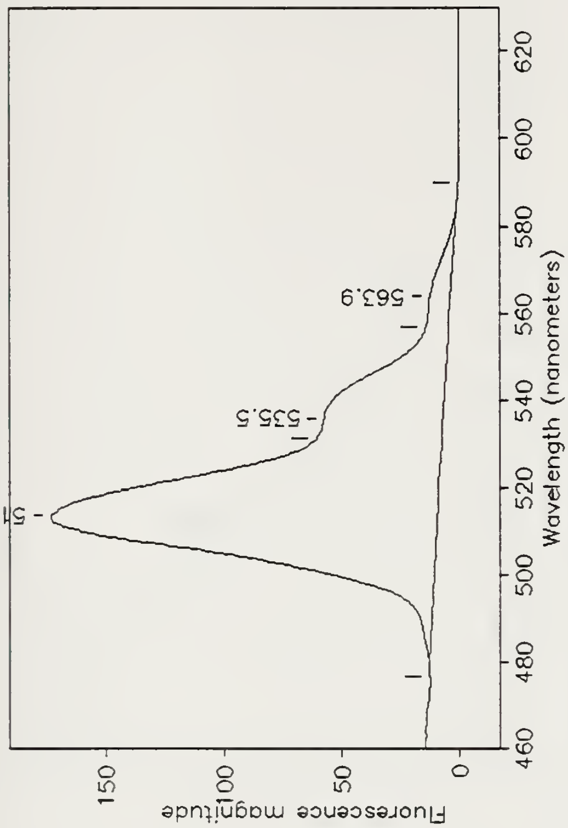
Station 102: Fitton Spring
OUL number: F9719 Type: Water Analyzed: 19970321
Date collected: 03/20/97 Time collected: 1230



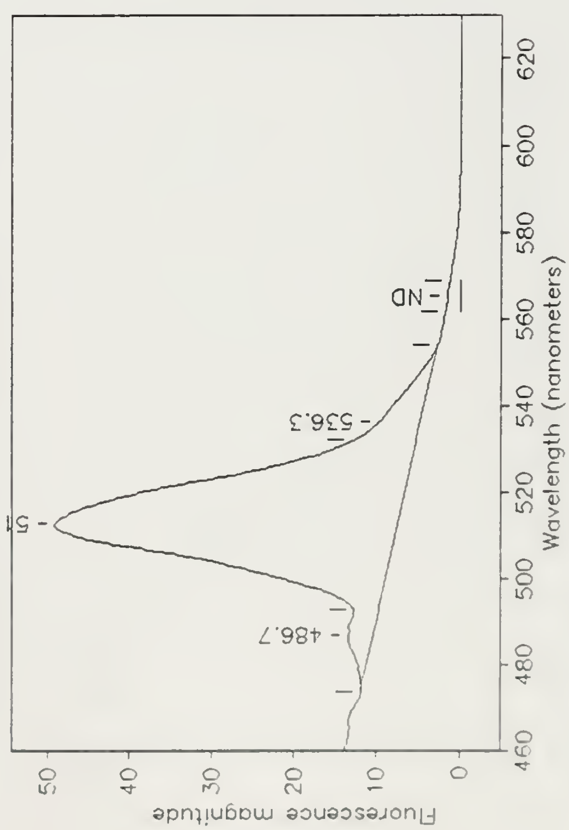
Station 103: Cecil Creek upstream Fitton Spring
OUL number: F6841 Type: Charcoal Analyzed: 19960920
Date placed: 08/30/96 Date recovered: 09/11/96
Time placed: 1520 Time recovered: 1150



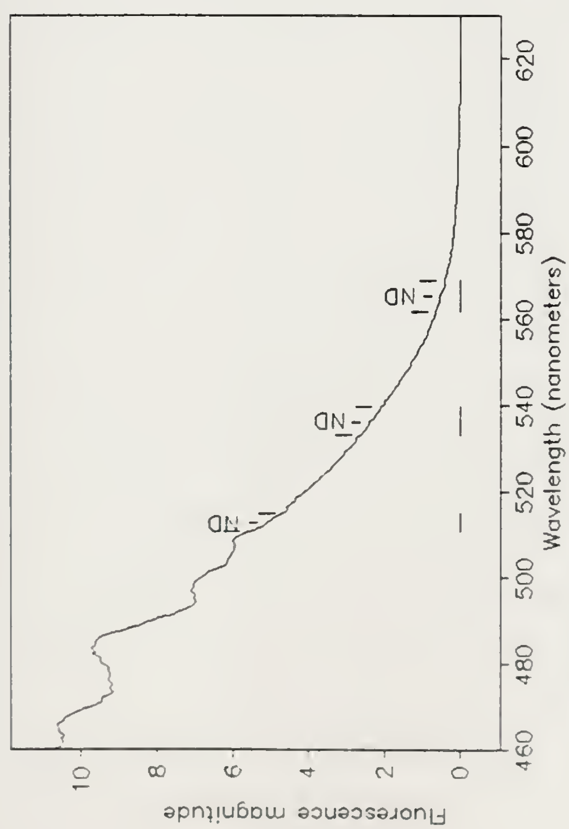
Station 105: Cecil Creek upstream Cove Creek
OUL number: F6842 Type: Charcoal Analyzed: 19960920
Date placed: 08/30/96 Date recovered: 09/11/96
Time placed: 1430 Time recovered: 1100



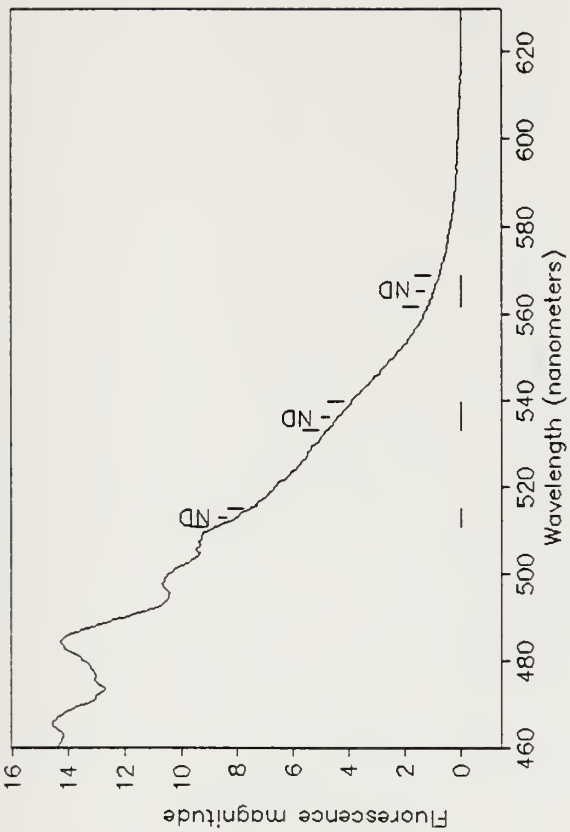
Station 105: Cecil Creek upstream Cove Creek
OUL number: G0516 Type: Charcoal Analyzed: 19970414
Date placed: 03/26/97 Date recovered: 04/03/97
Time placed: 1430 Time recovered: 1045



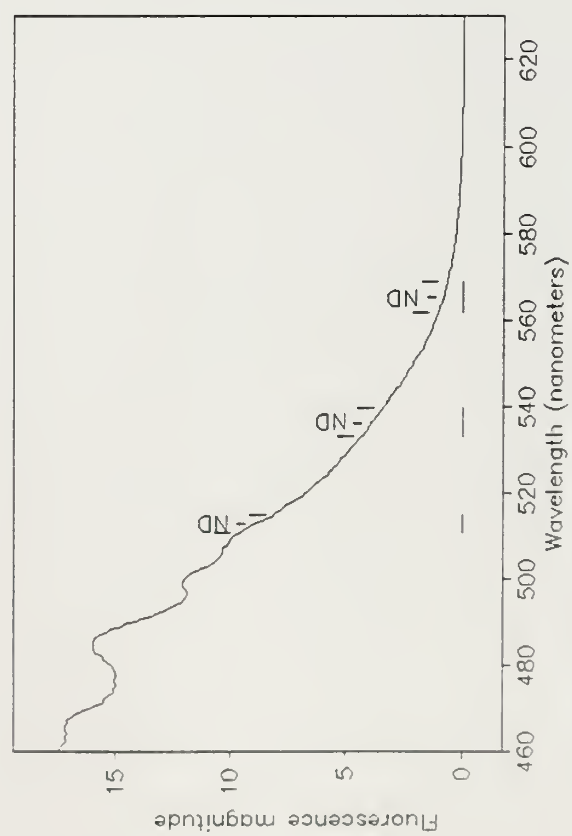
Station 105: Cecil Creek upstream Cove Creek
OUL number: G0587 Type: Charcoal Analyzed: 19970414
Date placed: 04/03/97 Date recovered: 04/11/97
Time placed: 1045 Time recovered: 1225



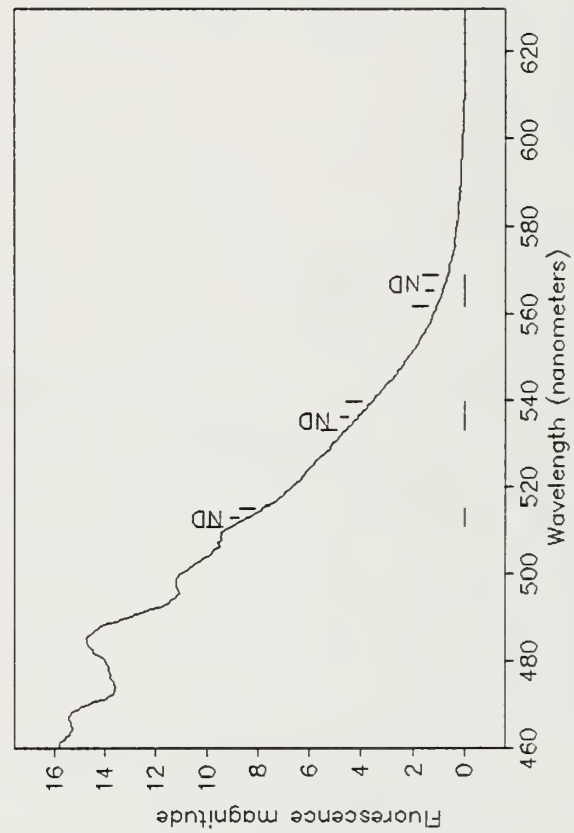
Station 106: Cove Creek at Mouth
OUL number: F6843 Type: Charcoal Analyzed: 19960920
Date placed: 08/30/96 Date recovered: 09/11/96
Time placed: 1440 Time recovered: 1110



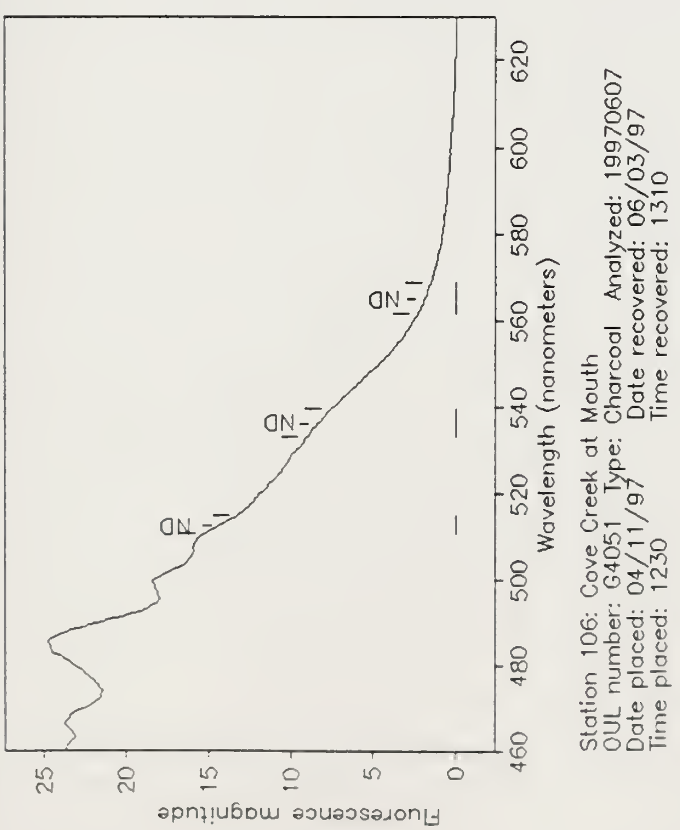
Station 106: Cove Creek at Mouth
OUL number: F9989 Type: Charcoal Analyzed: 19970331
Date placed: 03/20/97 Date recovered: 03/26/97
Time placed: 1211 Time recovered: 1105

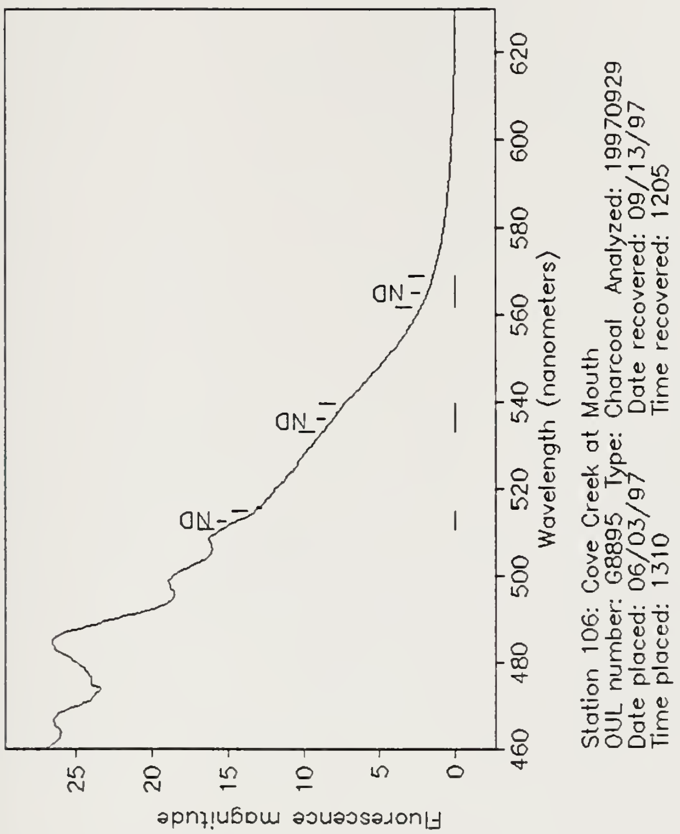


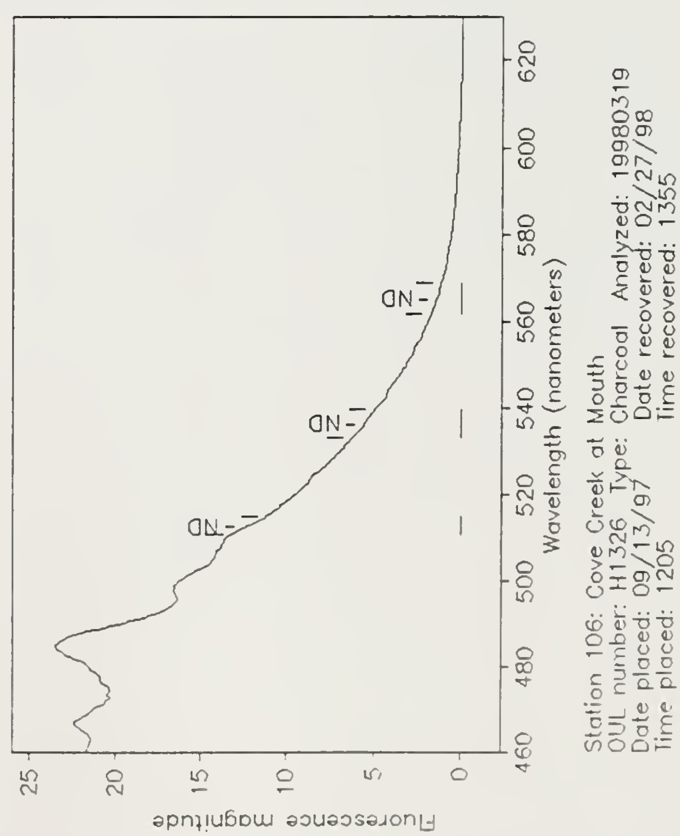
Station 106: Cove Creek at Mouth
OUL number: G0512 Type: Charcoal Analyzed: 19970414
Date placed: 03/26/97 Date recovered: 04/03/97
Time placed: 1105 Time recovered: 1050

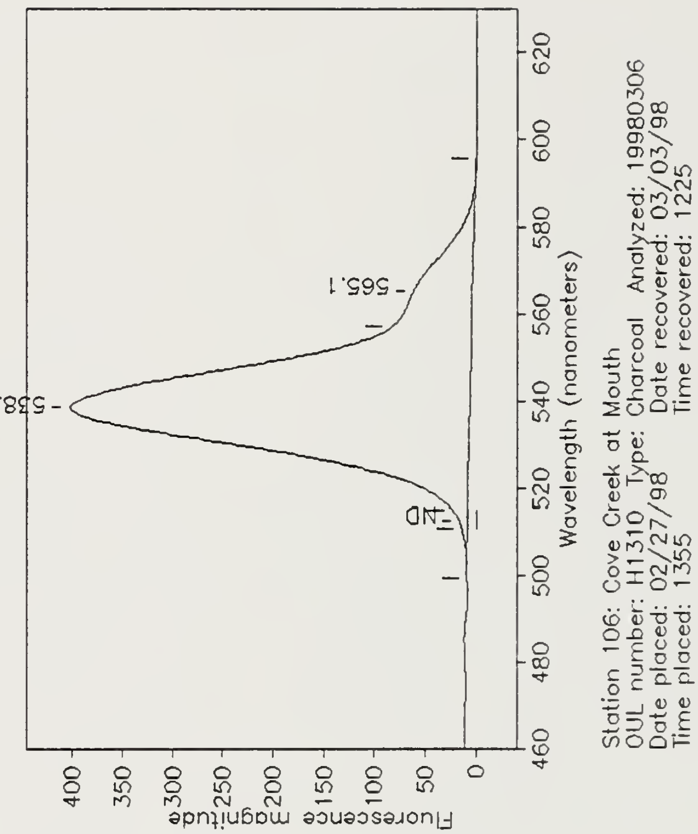


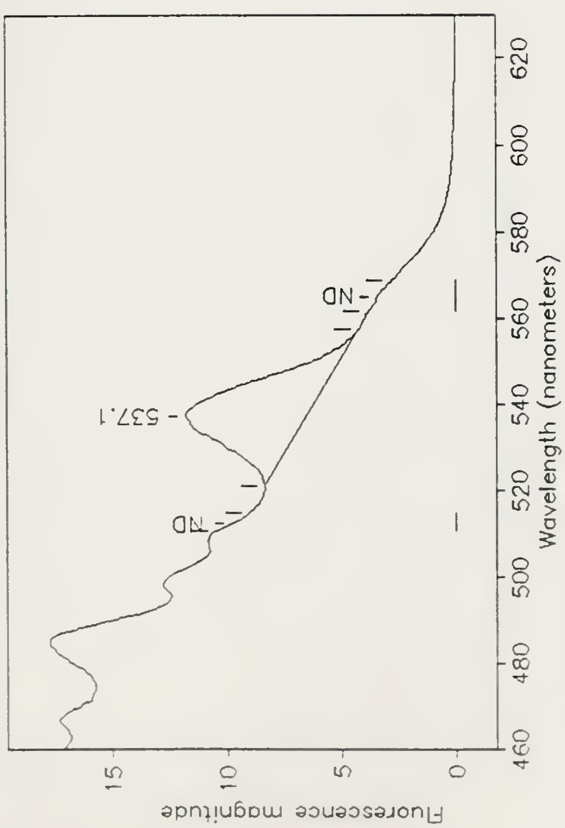
Station 106: Cove Creek at Mouth
OUL number: G0586 Type: Charcoal Analyzed: 19970414
Date placed: 04/03/97 Date recovered: 04/11/97
Time placed: 1050 Time recovered: 1230


Fluorescence magnitude
Wavelength (nanometers)
ND
ND
ND
Station 106: Cove Creek at Mouth
OUL number: G4051 Type: Charcoal Analyzed: 19970607
Date placed: 04/11/97 Date recovered: 06/03/97
Time placed: 1230 Time recovered: 1310

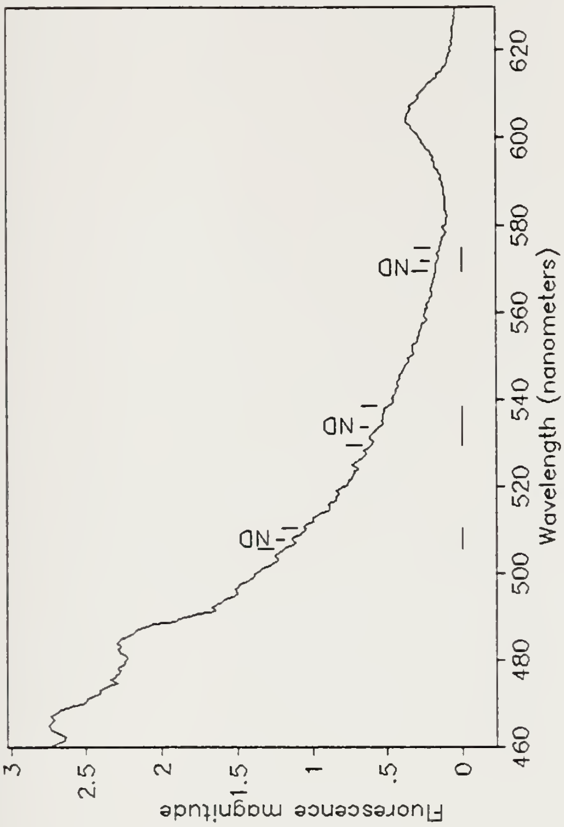

Fluorescence magnitude
Wavelength (nanometers)
ND
ND
ND
Station 106: Cove Creek at Mouth
OUL number: G8895 Type: Charcoal Analyzed: 19970929
Date placed: 06/03/97 Date recovered: 09/13/97
Time placed: 1310 Time recovered: 1205


Fluorescence magnitude
Wavelength (nanometers)
ND
ND
ND
Station 106: Cove Creek at Mouth
OUL number: H1326 Type: Charcoal Analyzed: 19980319
Date placed: 09/13/97 Date recovered: 02/27/98
Time placed: 1205 Time recovered: 1355

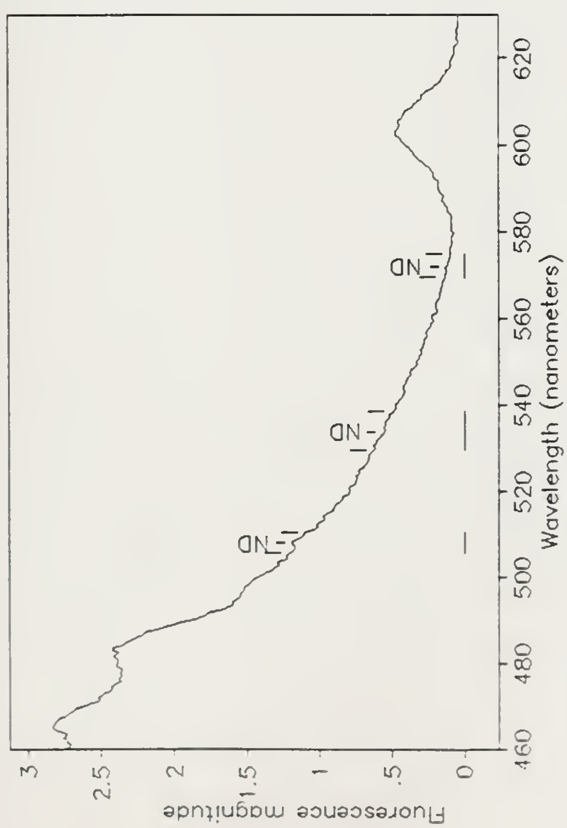

Fluorescence magnitude
Wavelength (nanometers)
538.8
565.1
ND
Station 106: Cove Creek at Mouth
OUL number: H1310 Type: Charcoal Analyzed: 19980306
Date placed: 02/27/98 Date recovered: 03/03/98
Time placed: 1355 Time recovered: 1225



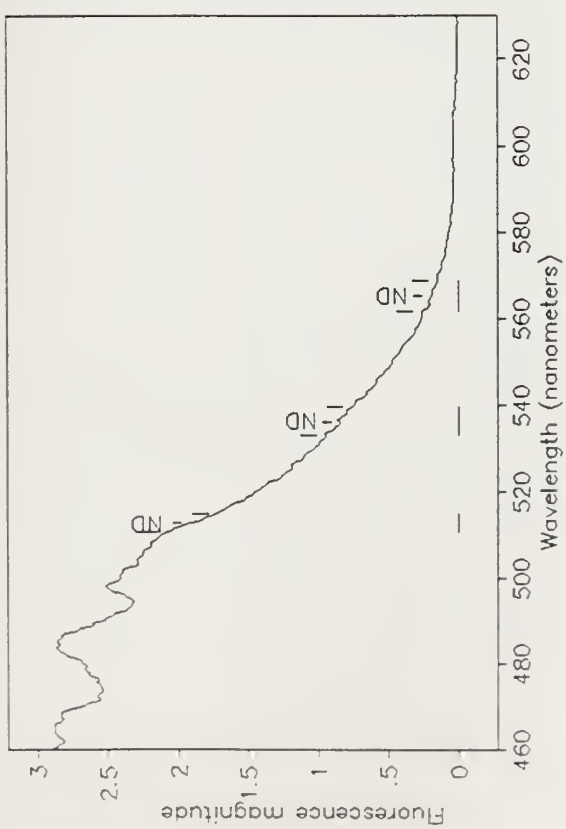
Station 106: Cove Creek at Mouth
OUL number: H1657 Type: Charcoal Analyzed: 19980325
Date placed: 03/03/98 Date recovered: 03/23/98
Time placed: 1225 Time recovered: 1145



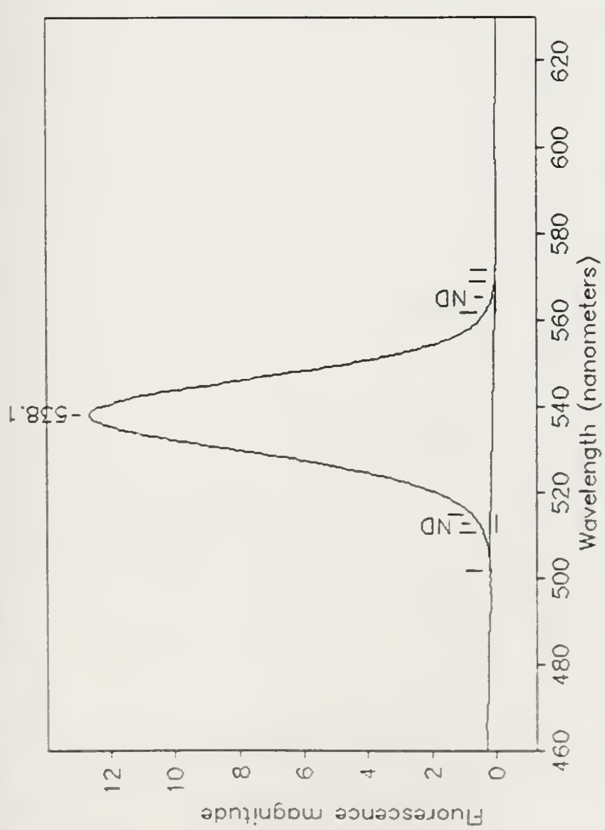
Station 106: Cove Creek at Mouth
OUL number: H1397 Type: Water Analyzed: 19980310
Date collected: 03/03/98 Time collected: 1225



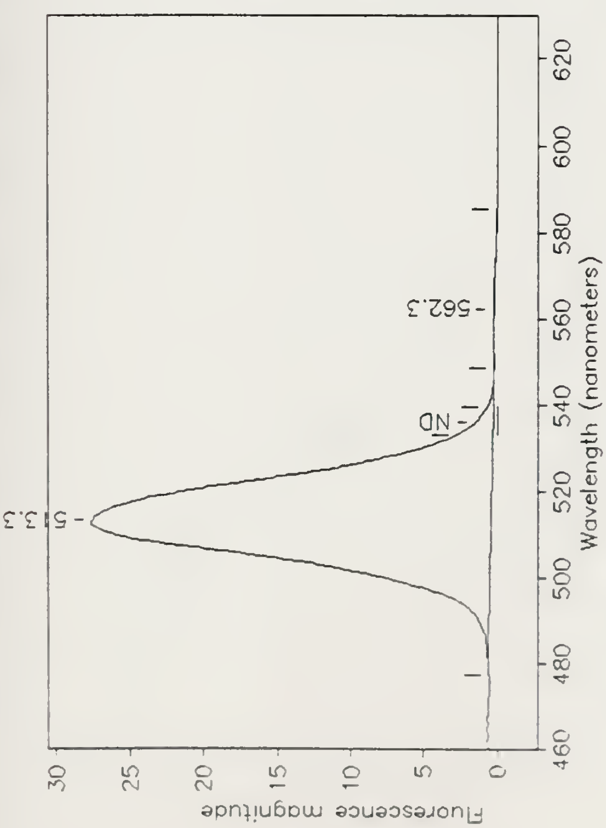
Station 106: Cove Creek at Mouth
OUL number: F9715 Type: Water Analyzed: 19970321
Date collected: 03/20/97 Time collected: 1211



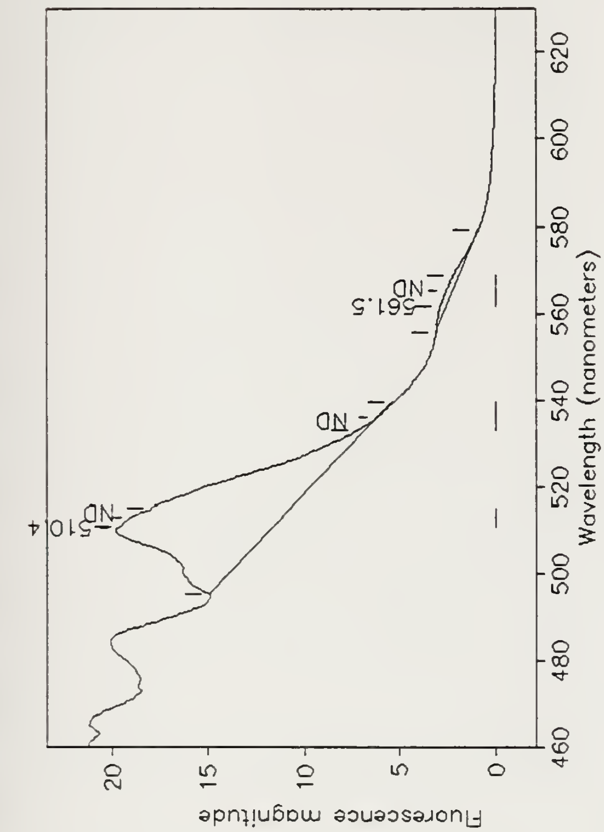
Station 107: Rippled Slab
OUL number: F6844 Type: Charcoal Analyzed: 19960920
Date placed: 08/30/96 Date recovered: 09/11/96
Time placed: 1500 Time recovered: 1120



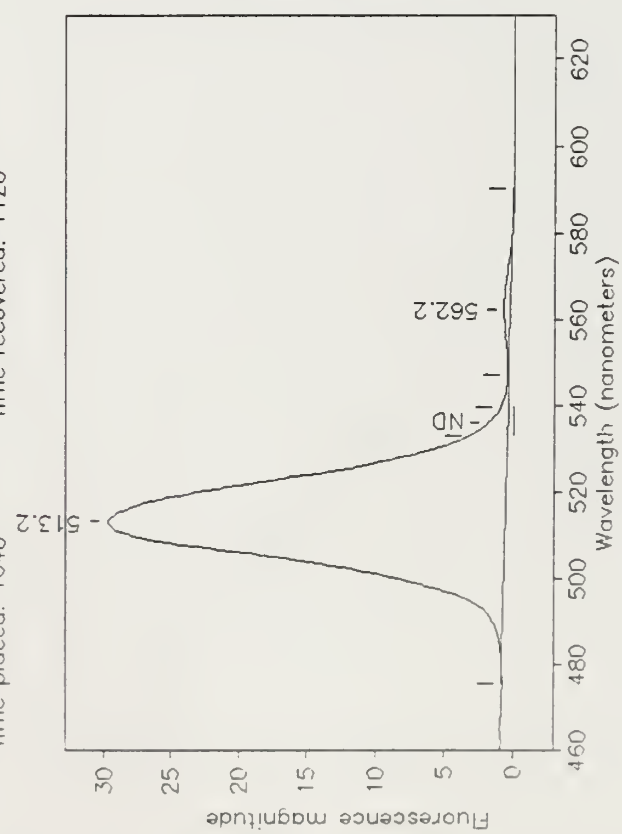
Station 108: First Tributary d/s of Van Diluted 1: 100
OUL number: F7622 Type: Charcoal Analyzed: 19961115
Date placed: 11/08/96 Date recovered: 11/14/96
Time placed: 1700 Time recovered: 1140



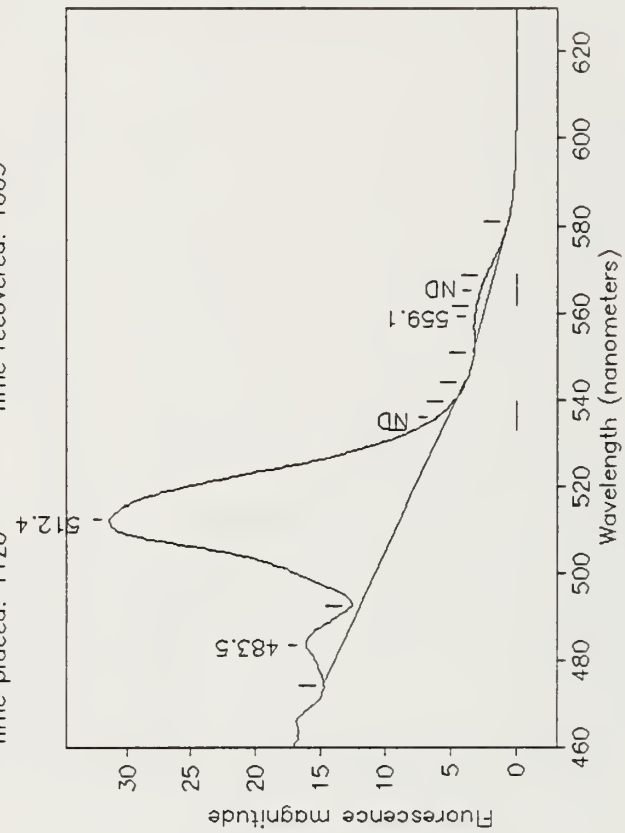
Station 109: Cecil Creek Overflow near VDiluted 1: 100
OUL number: F7623 Type: Charcoal Analyzed: 19961115
Date placed: 11/08/96 Date recovered: 11/14/96
Time placed: 1640 Time recovered: 1120



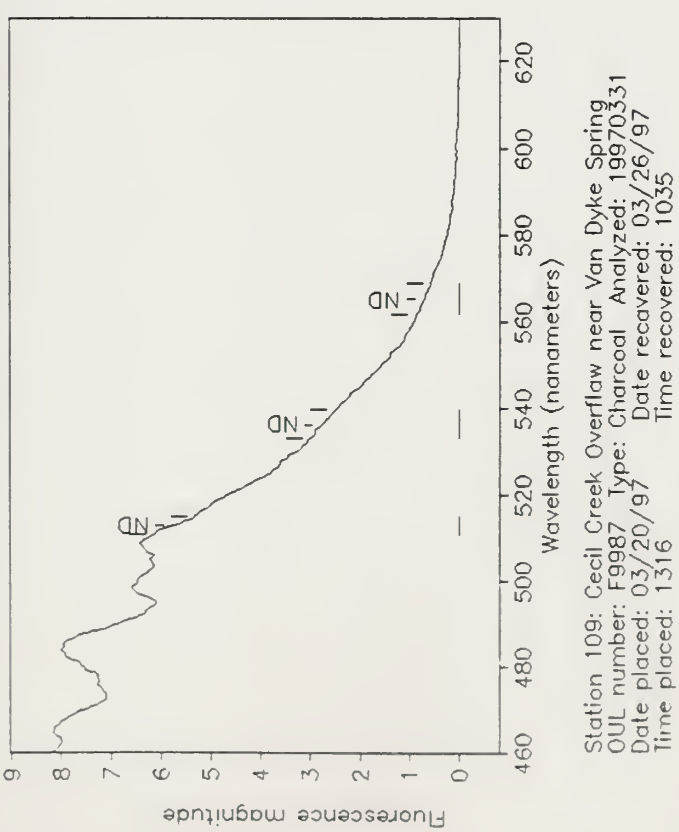
Station 109: Cecil Creek Overflow near Van Dyke Spring
OUL number: F7832 Type: Charcoal Analyzed: 19961211
Date placed: 11/14/96 Date recovered: 12/06/96
Time placed: 1120 Time recovered: 1005

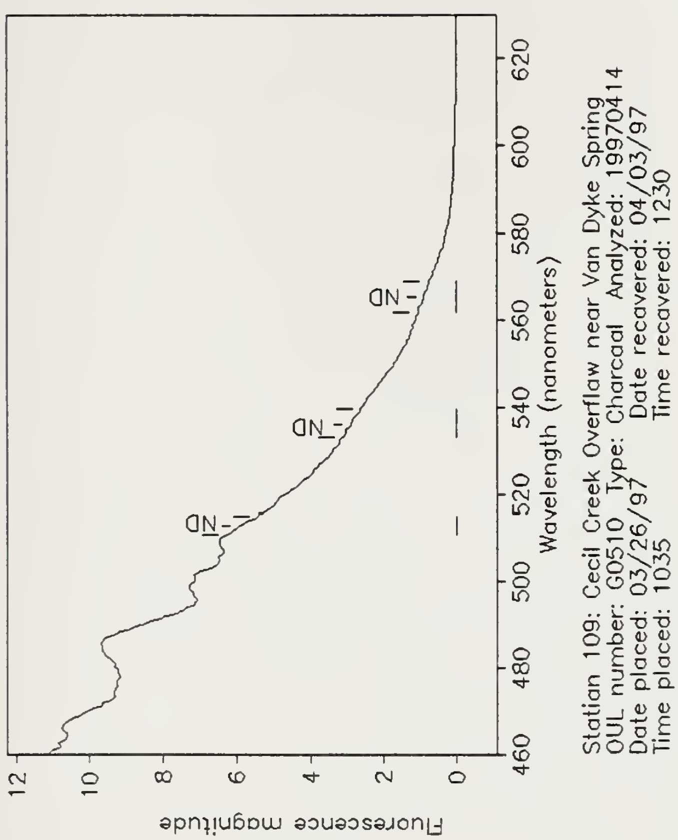


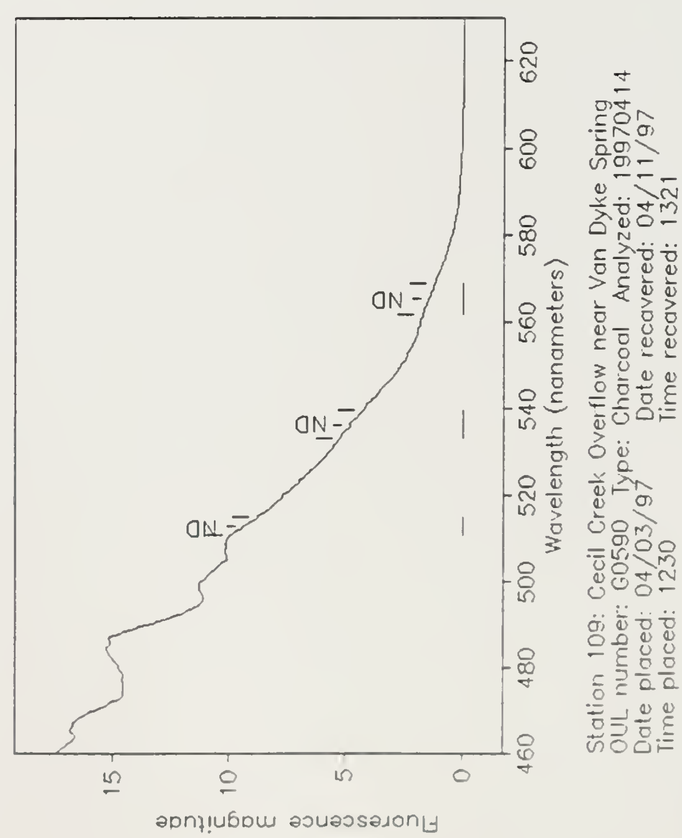
Station 109: Cecil Creek Overflow near VDiluted 1: 100
OUL number: F7884 Type: Charcoal Analyzed: 19961217
Date placed: 12/06/96 Date recovered: 12/16/96
Time placed: 1005 Time recovered: 1250

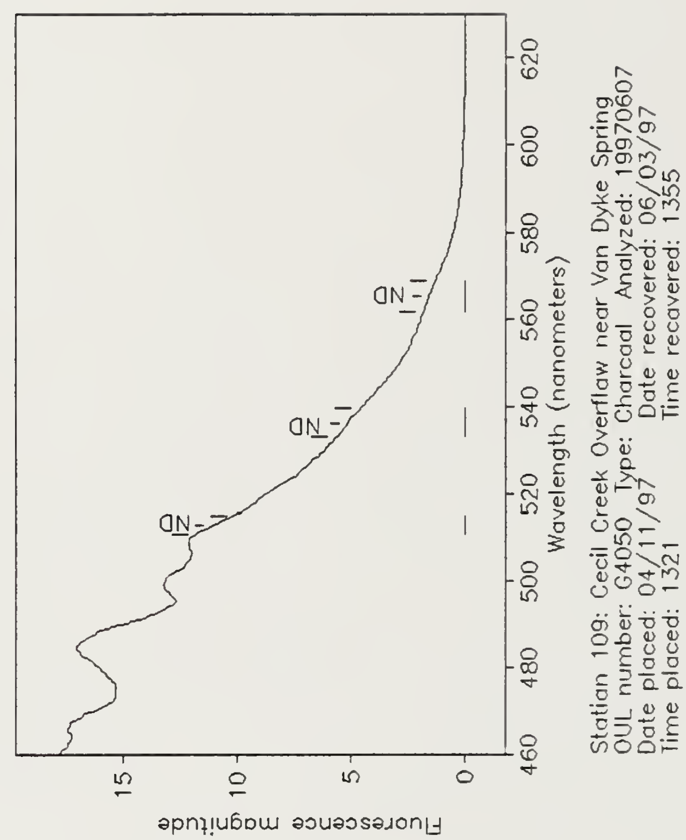


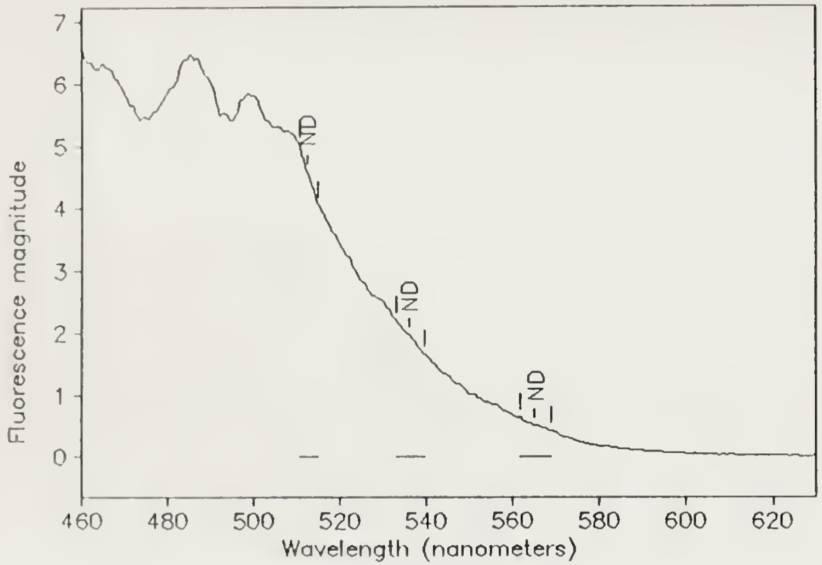
Station 109: Cecil Creek Overflow near Van Dyke Spring
OUL number: F9718 Type: Charcoal Analyzed: 19970321
Date placed: 12/16/96 Date recovered: 03/20/97
Time placed: 1250 Time recovered: 1316


Fluorescence magnitude
Wavelength (nanameters)
Station 109: Cecil Creek Overflow near Van Dyke Spring
OUL number: F9987 Type: Charcoal Analyzed: 19970331
Date placed: 03/20/97 Date recovered: 03/26/97
Time placed: 1316 Time recovered: 1035

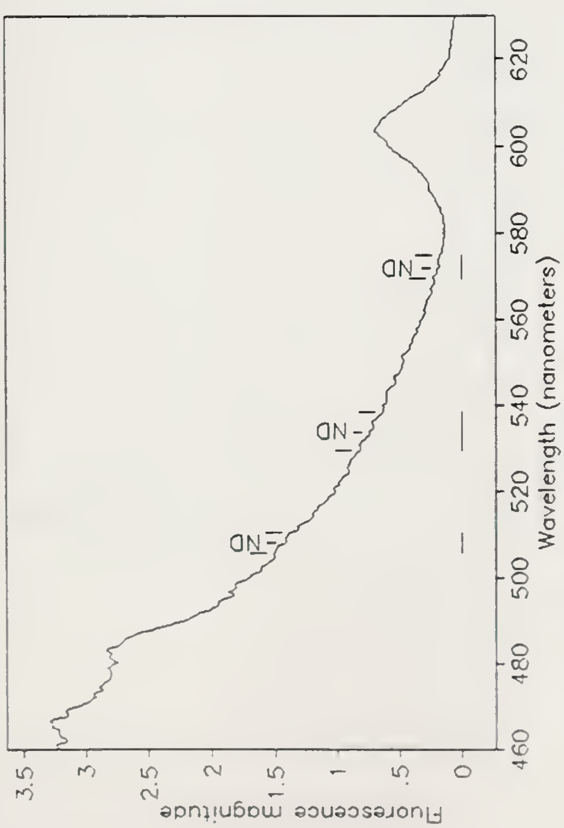

Fluorescence magnitude
Wavelength (nanometers)
Station 109: Cecil Creek Overflow near Van Dyke Spring
OUL number: G0510 Type: Charcoal Analyzed: 19970414
Date placed: 03/26/97 Date recovered: 04/03/97
Time placed: 1035 Time recovered: 1230


Fluorescence magnitude
Wavelength (nanameters)
Station 109: Cecil Creek Overflow near Van Dyke Spring
OUL number: G0590 Type: Charcoal Analyzed: 19970414
Date placed: 04/03/97 Date recovered: 04/11/97
Time placed: 1230 Time recovered: 1321

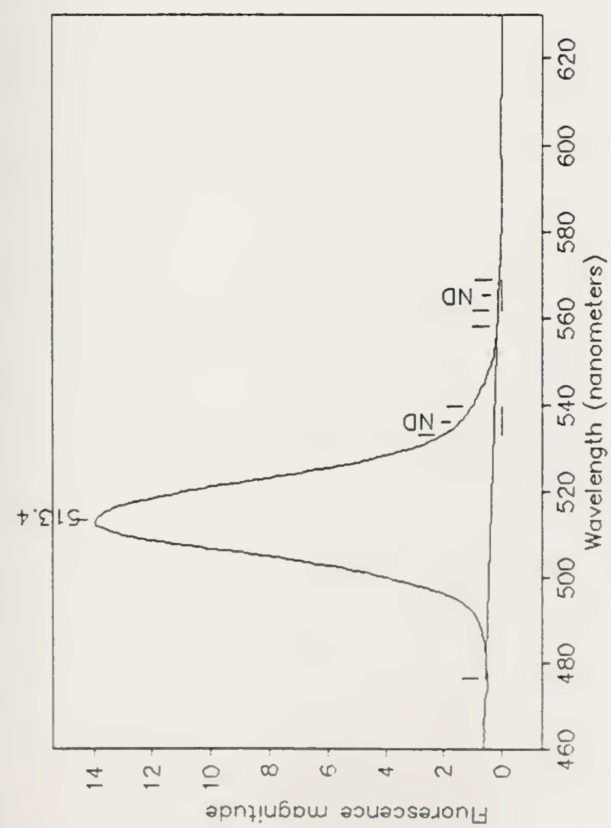

Fluorescence magnitude
Wavelength (nanometers)
Station 109: Cecil Creek Overflow near Van Dyke Spring
OUL number: G4050 Type: Charcoal Analyzed: 19970607
Date placed: 04/11/97 Date recovered: 06/03/97
Time placed: 1321 Time recovered: 1355



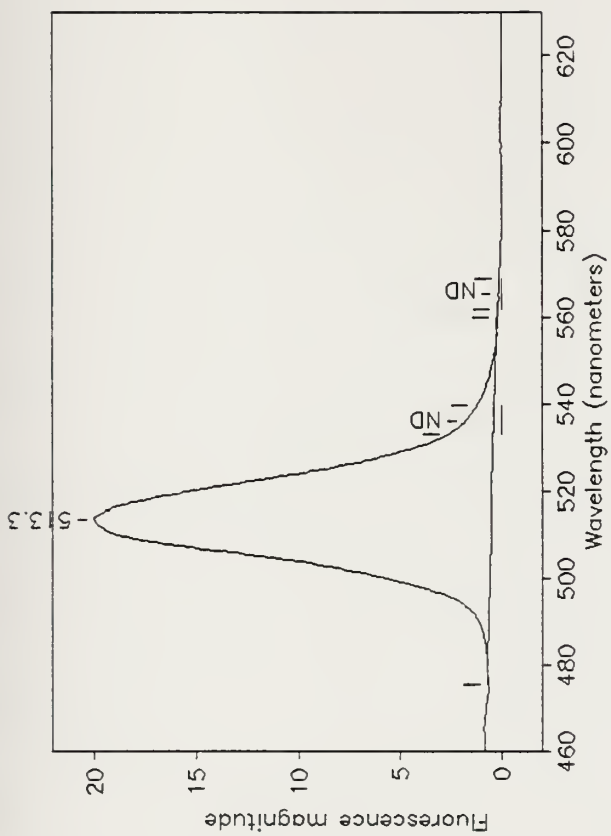
Station 109: Cecil Creek Overflow near Van Dyke Spring
OUL number: G8896 Type: Charcoal Analyzed: 19970929
Date placed: 06/03/97 Date recovered: 09/13/97
Time placed: 1355 Time recovered: 1030



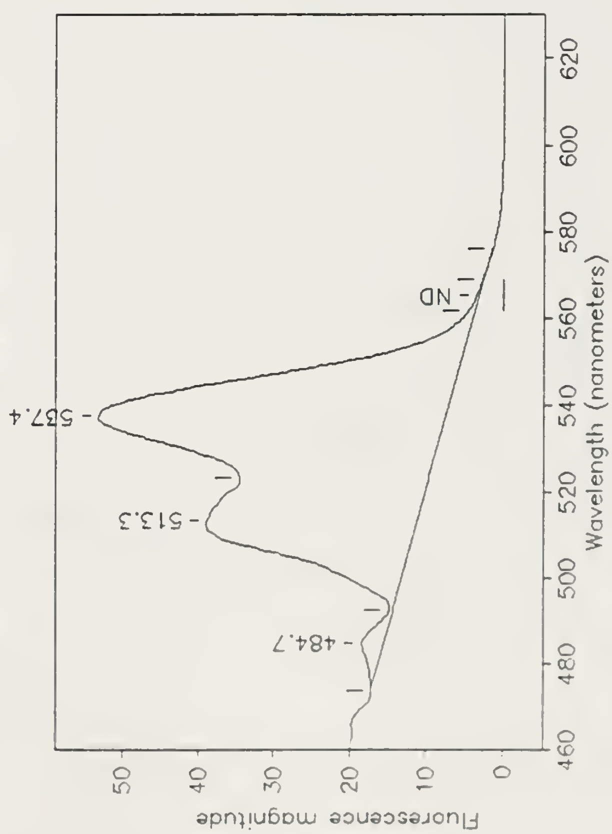
Station 109: Cecil Creek Overflow near Van Dyke Spring
OUL number: F9722 Type: Water Analyzed: 19970321
Date collected: 03/20/97 Time collected: 1316



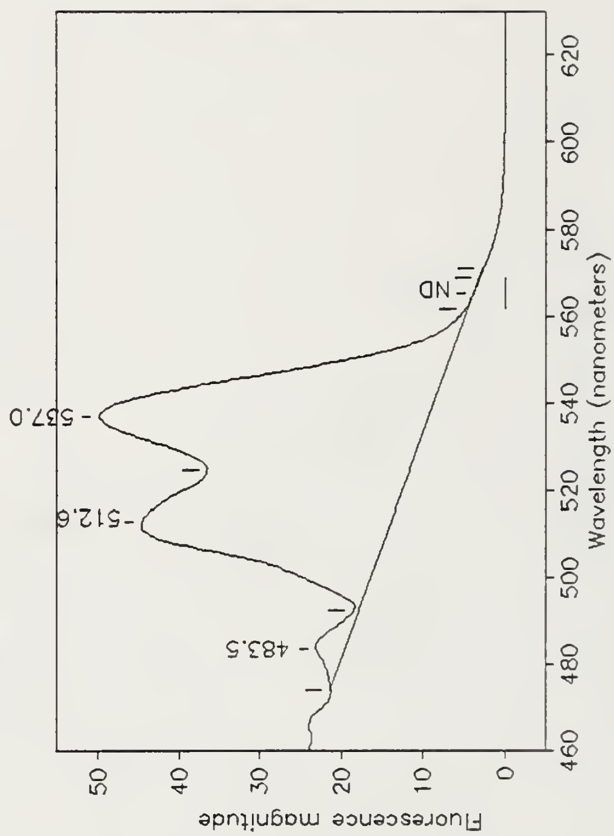
Station 110: Van Dyke Spring Diluted 1: 100
OUL number: F7625 Type: Charcoal Analyzed: 19961115
Date placed: 11/08/96 Date recovered: 11/14/96
Time placed: 1630 Time recovered: 1130



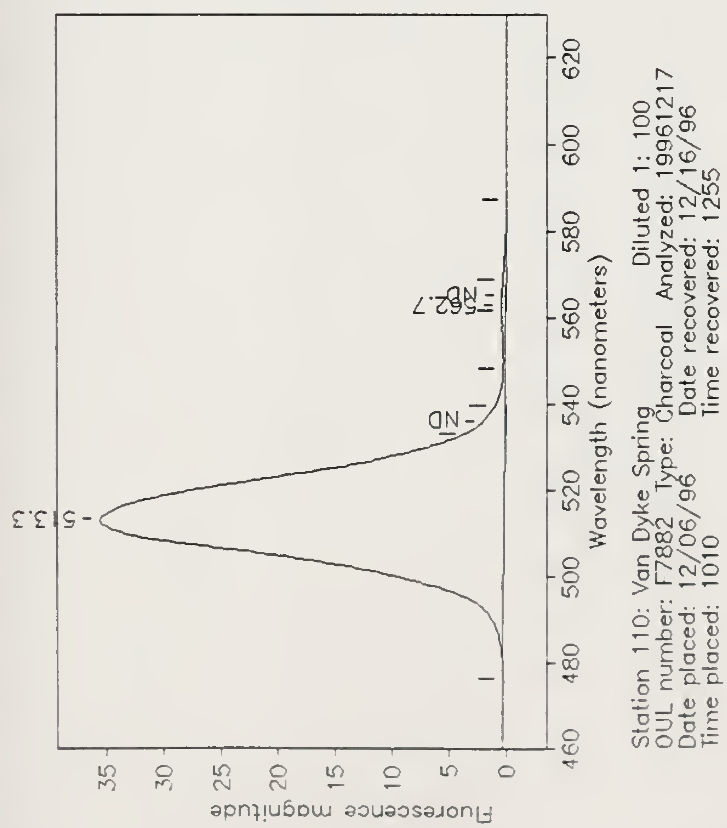
Station 110: Van Dyke Spring Diluted 1: 100
OUL number: F7625D Type: Charcoal Analyzed: 19961211
Date placed: 11/08/96 Date recovered: 11/14/96
Time placed: 1630 Time recovered: 1130

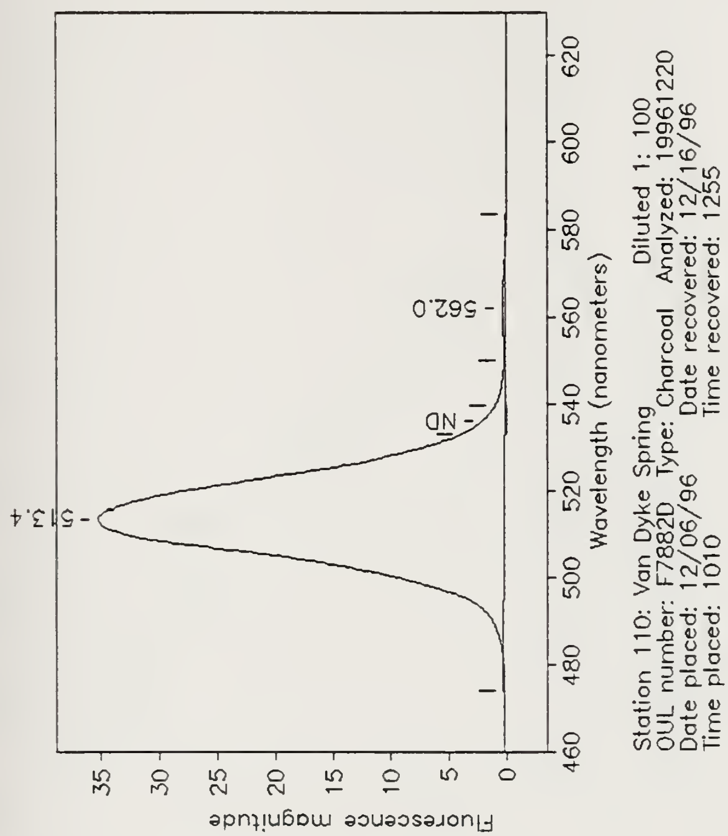


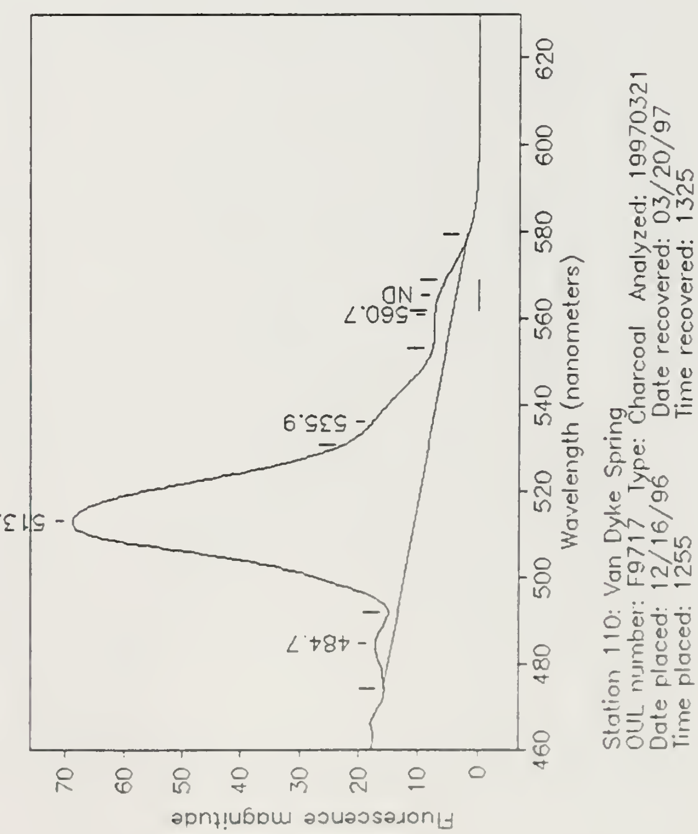
Station 110: Van Dyke Spring
OUL number: F7830 Type: Charcoal Analyzed: 19961211
Date placed: 11/14/96 Date recovered: 12/06/96
Time placed: 1130 Time recovered: 1010

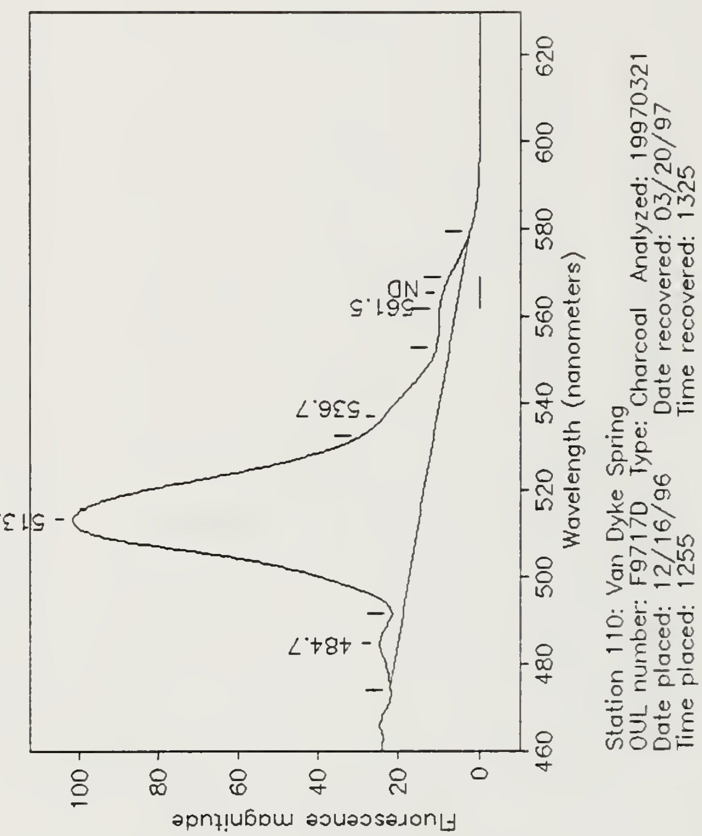


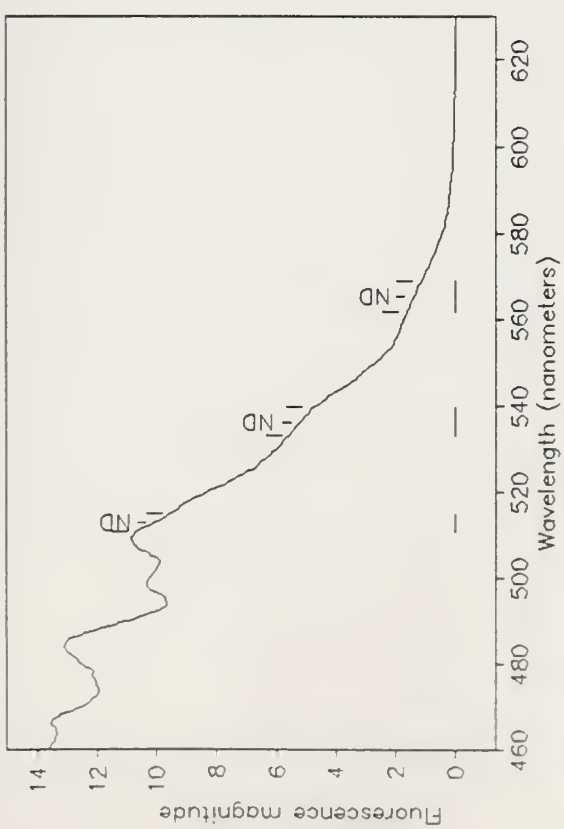
Station 110: Van Dyke Spring
OUL number: F7830D Type: Charcoal Analyzed: 19961211
Date placed: 11/14/96 Date recovered: 12/06/96
Time placed: 1130 Time recovered: 1010


Station 110: Van Dyke Spring Diluted 1: 100
OUL number: F7882 Type: Charcoal Analyzed: 19961217
Date placed: 12/06/96 Date recovered: 12/16/96
Time placed: 1010 Time recovered: 1255
Wavelength (nanometers)
Fluorescence magnitude
513.3
562.7
ND

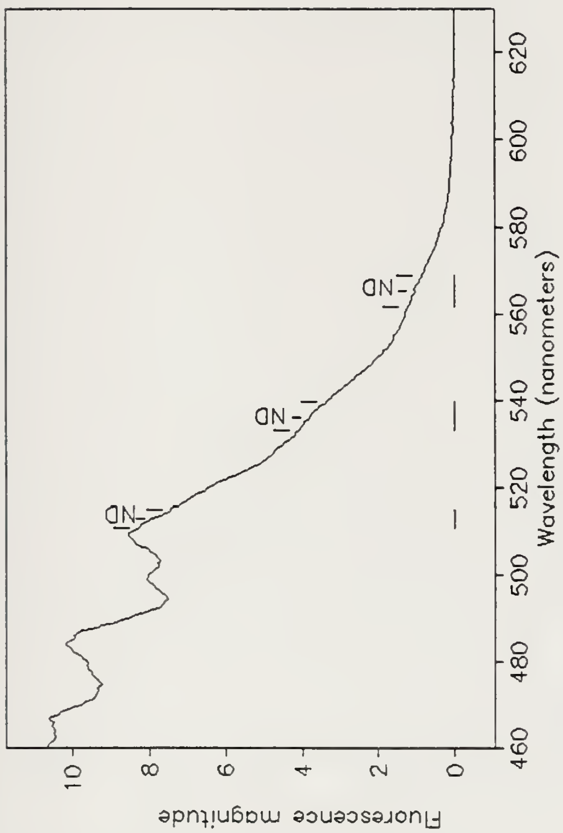

Station 110: Van Dyke Spring Diluted 1: 100
OUL number: F7882D Type: Charcoal Analyzed: 19961220
Date placed: 12/06/96 Date recovered: 12/16/96
Time placed: 1010 Time recovered: 1255
Wavelength (nanometers)
Fluorescence magnitude
513.4
562.0
ND


Station 110: Van Dyke Spring
OUL number: F9717 Type: Charcoal Analyzed: 19970321
Date placed: 12/16/96 Date recovered: 03/20/97
Time placed: 1255 Time recovered: 1325
Wavelength (nanometers)
Fluorescence magnitude
484.7
513.1
535.9
560.7
ND

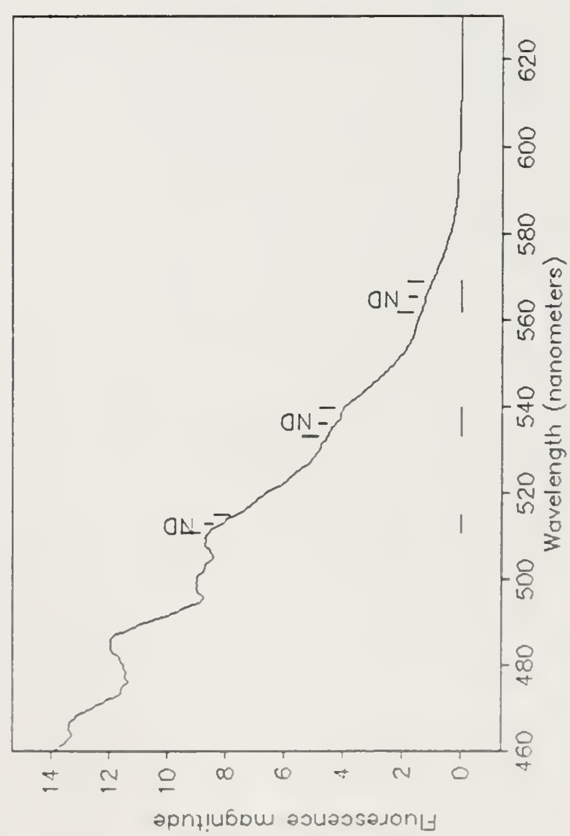

Station 110: Van Dyke Spring
OUL number: F9717D Type: Charcoal Analyzed: 19970321
Date placed: 12/16/96 Date recovered: 03/20/97
Time placed: 1255 Time recovered: 1325
Wavelength (nanometers)
Fluorescence magnitude
484.7
513.3
536.7
561.5
ND



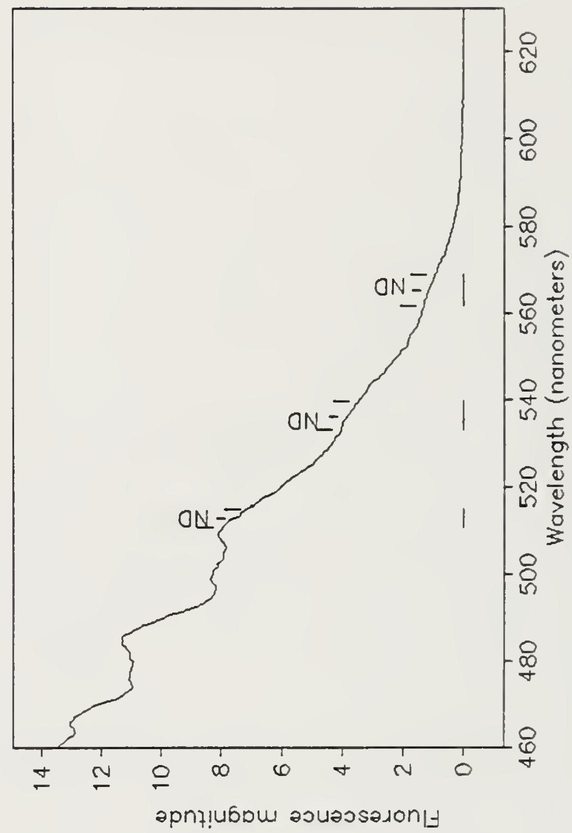
Station 110: Van Dyke Spring
OUL number: F9988 Type: Charcoal Analyzed: 19970331
Date placed: 03/20/97 Date recovered: 03/26/97
Time placed: 1325 Time recovered: 1040



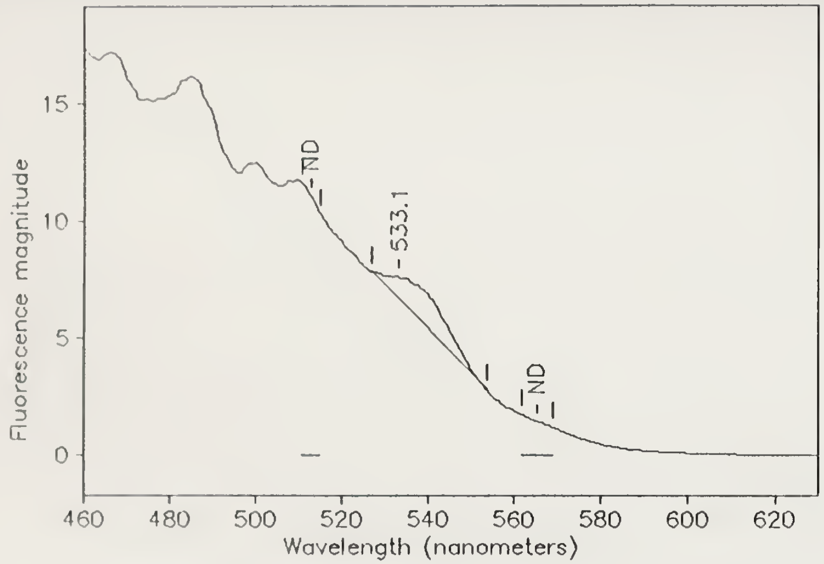
Station 110: Van Dyke Spring
OUL number: F9988D Type: Charcoal Analyzed: 19970331
Date placed: 03/20/97 Date recovered: 03/26/97
Time placed: 1325 Time recovered: 1040



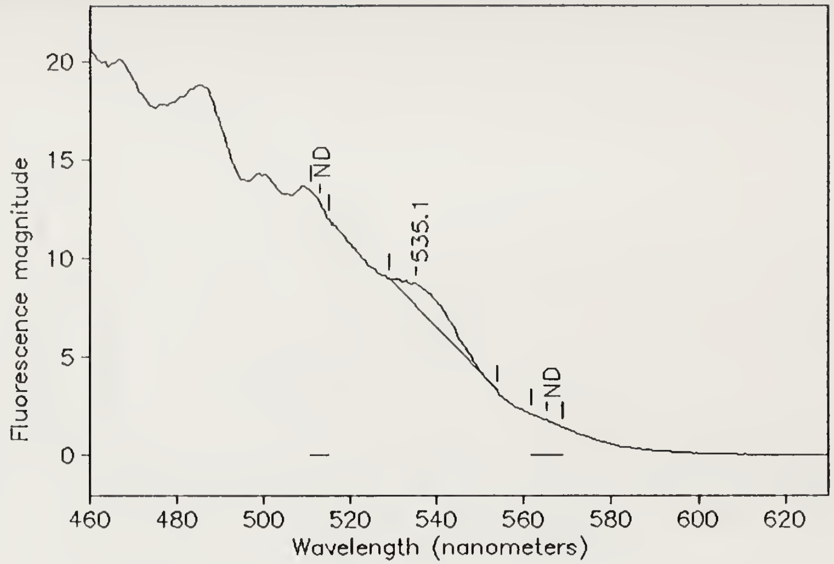
Station 110: Van Dyke Spring
OUL number: G0511 Type: Charcoal Analyzed: 19970414
Date placed: 03/26/97 Date recovered: 04/03/97
Time placed: 1040 Time recovered: 1235



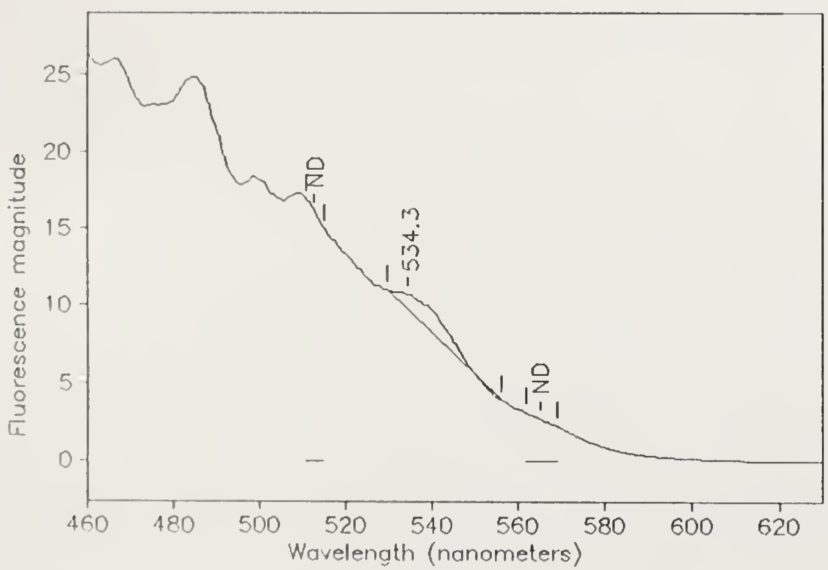
Station 110: Van Dyke Spring
OUL number: G0511D Type: Charcoal Analyzed: 19970414
Date placed: 03/26/97 Date recovered: 04/03/97
Time placed: 1040 Time recovered: 1235



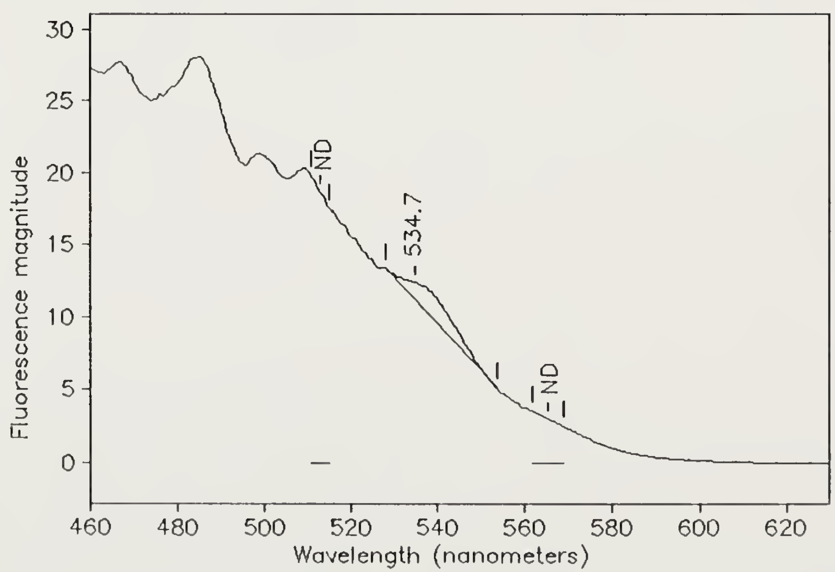
Station 110: Van Dyke Spring
OUL number: G0589 Type: Charcoal Analyzed: 19970414
Date placed: 04/03/97 Date recovered: 04/11/97
Time placed: 1235 Time recovered: 1325



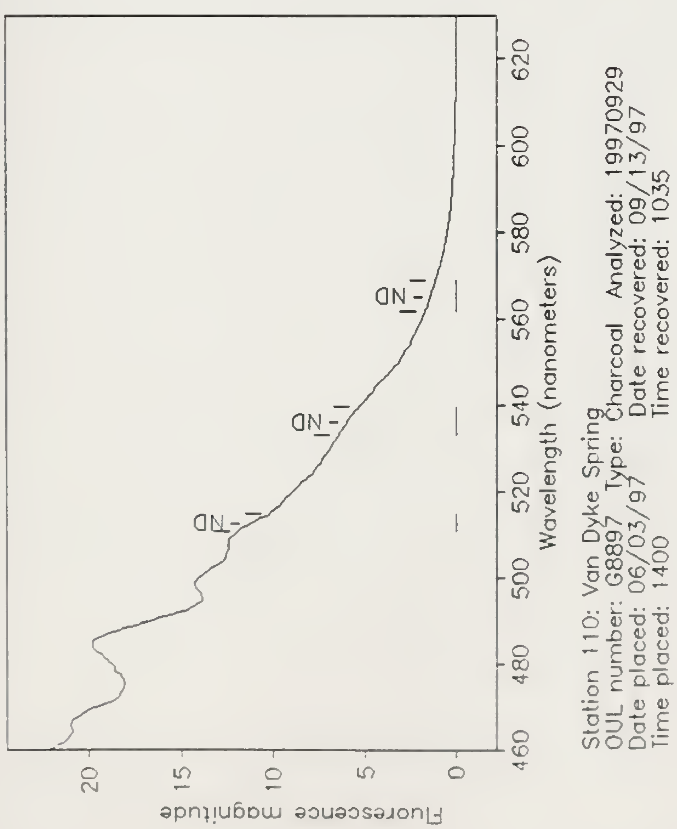
Station 110: Van Dyke Spring
OUL number: G0589D Type: Charcoal Analyzed: 19970414
Date placed: 04/03/97 Date recovered: 04/11/97
Time placed: 1235 Time recovered: 1325

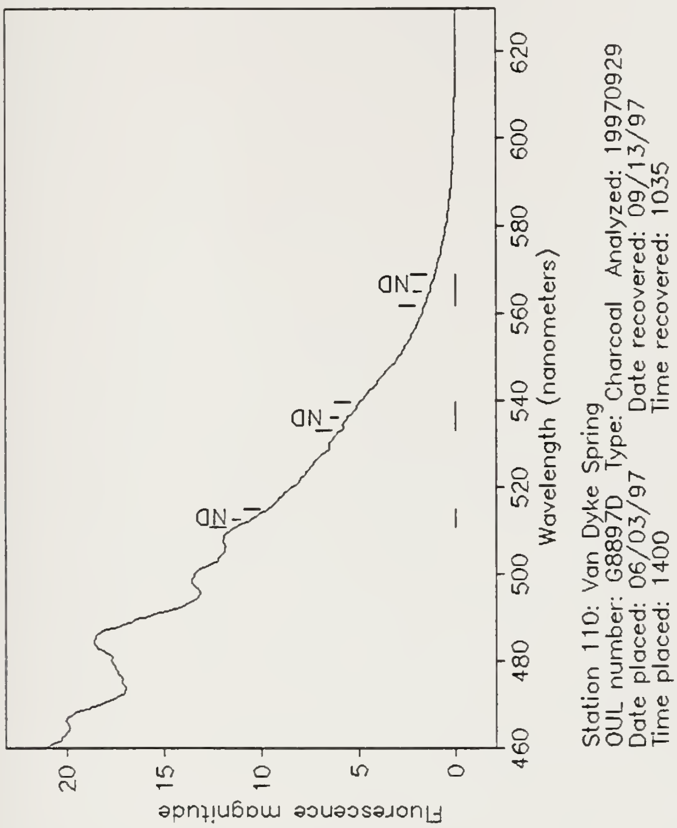


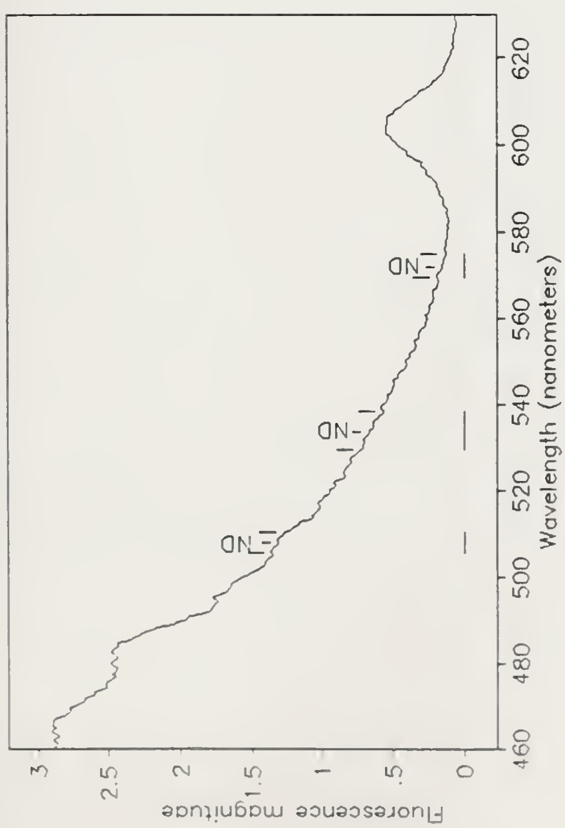
Station 110: Van Dyke Spring
OUL number: G4049 Type: Charcoal Analyzed: 19970607
Date placed: 04/11/97 Date recovered: 06/03/97
Time placed: 1325 Time recovered: 1400



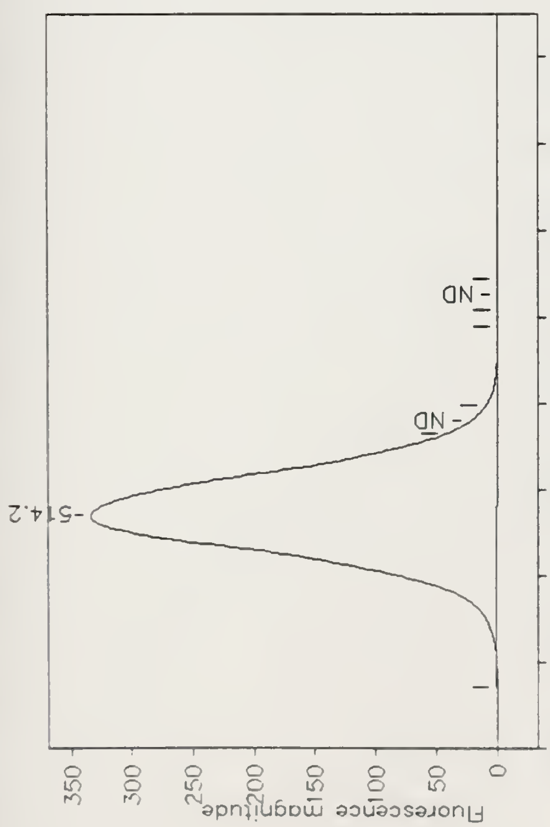
Station 110: Van Dyke Spring
OUL number: G4049D Type: Charcoal Analyzed: 19970607
Date placed: 04/11/97 Date recovered: 06/03/97
Time placed: 1325 Time recovered: 1400


Fluorescence magnitude
0
5
10
15
20
ND
ND
ND
460
480
500
520
540
560
580
600
620
Wavelength (nanometers)
Station 110: Van Dyke Spring
OUL number: G8897 Type: Charcoal Analyzed: 19970929
Date placed: 06/03/97 Date recovered: 09/13/97
Time placed: 1400 Time recovered: 1035

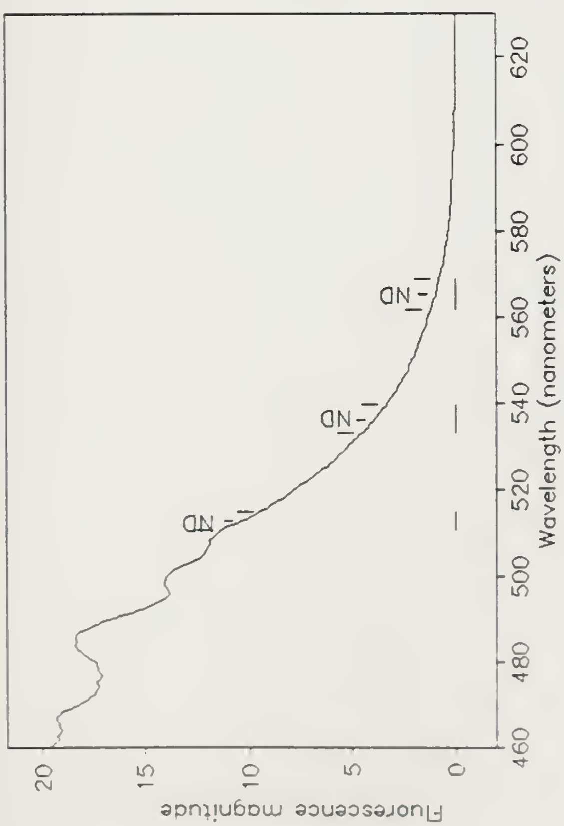

Fluorescence magnitude
0
5
10
15
20
ND
ND
ND
460
480
500
520
540
560
580
600
620
Wavelength (nanometers)
Station 110: Van Dyke Spring
OUL number: G8897D Type: Charcoal Analyzed: 19970929
Date placed: 06/03/97 Date recovered: 09/13/97
Time placed: 1400 Time recovered: 1035



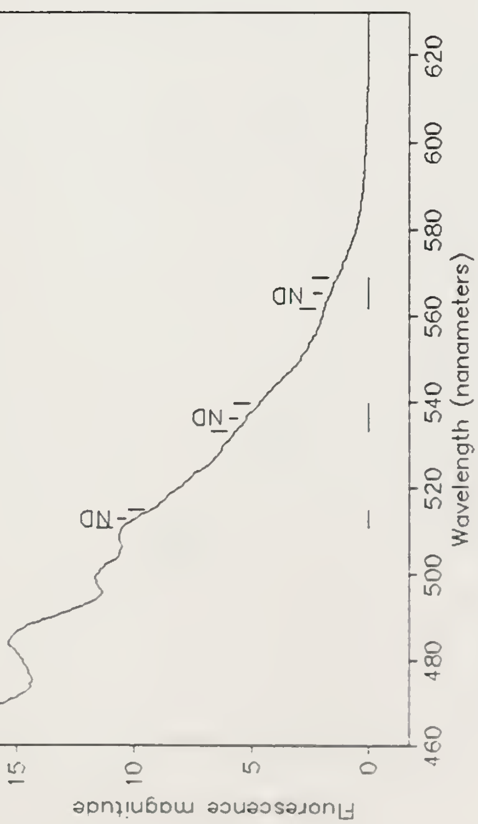
Station 110: Van Dyke Spring
OUL number: F9721 Type: Water Analyzed: 19970321
Date collected: 03/20/97 Time collected: 1325



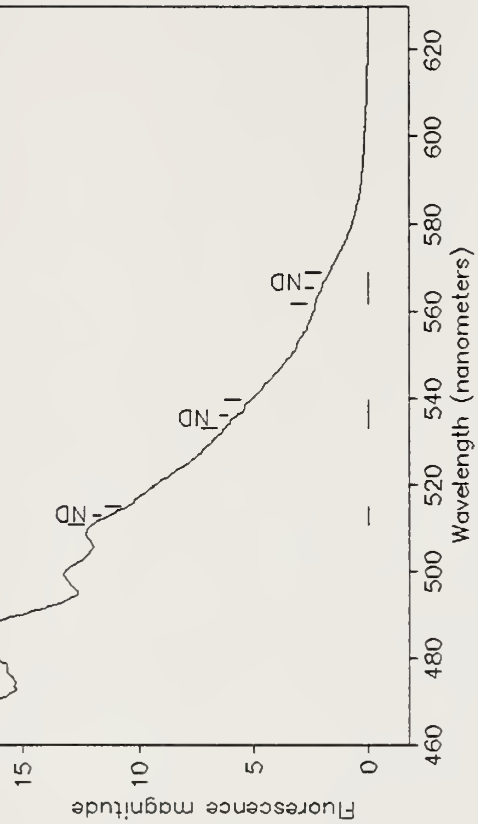
Station 111: Trib to Cecil Crk @ Rd XingDiluted 1: 100
OUL number: G0514 Type: Charcoal Analyzed: 19970414
Date placed: 03/26/97 Date recovered: 04/03/97
Time placed: 1400 Time recovered: 1120



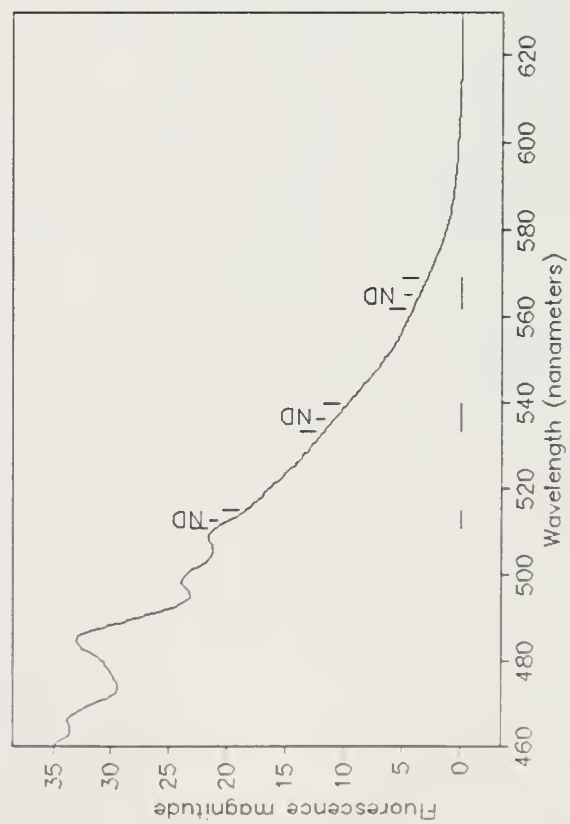
Station 112: Little Spring Branch
OUL number: G0515 Type: Charcoal Analyzed: 19970414
Date placed: 03/26/97 Date recovered: 04/03/97
Time placed: 1413 Time recovered: 1125



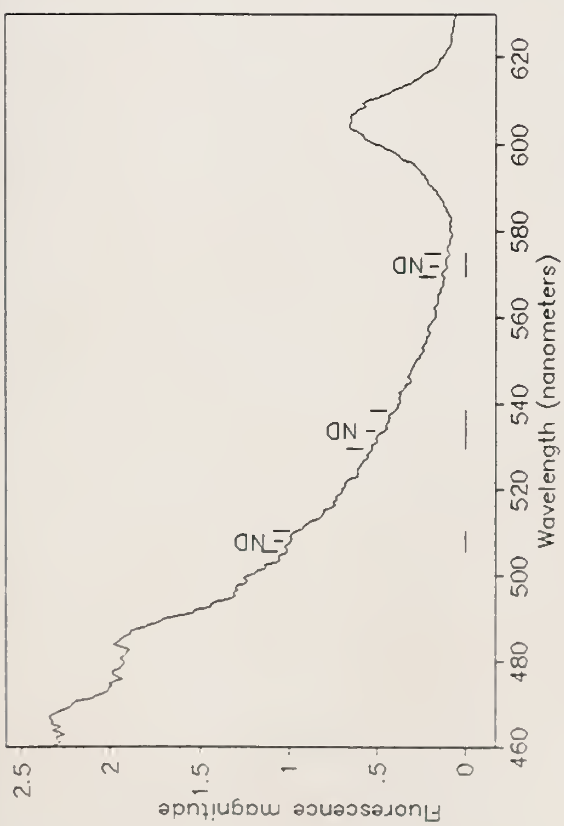
Station 113: Main Stem Cecil Cr just u/s Van Dyke Spring
OUL number: G0591 Type: Charcoal Analyzed: 19970414
Date placed: 04/03/97 Date recovered: 04/11/97
Time placed: 1240 Time recavered: 1315



Station 113: Main Stem Cecil Cr just u/s Van Dyke Spring
OUL number: G4048 Type: Charcoal Analyzed: 19970607
Date placed: 04/11/97 Date recovered: 06/03/97
Time placed: 1315 Time recovered: 1405



Station 113: Main Stem Cecil Cr just u/s Van Dyke Spring
OUL number: G8898 Type: Charcoal Analyzed: 19970929
Date placed: 06/03/97 Date recovered: 09/13/97
Time placed: 1405 Time recovered: 1045



Station 113: Main Stem Cecil Cr just u/s Van Dyke Spring
OUL number: G0517 Type: Water Analyzed: 19970414
Date collected: 04/03/97 Time collected: 1240