DEPARTMENT OF THE NAVY
NAVAL WEAPONS SUPPORT CENTER
CRANE, INDIANA 47522-5000

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27 November 1990

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U.S. Environmental Protection Agency
Region V, 5HR - 13
Attn: Ms. Carol Witt-Smith
230 South Dearborn Street
Chicago, IL 60604

Dear Ms. Witt-Smith:

Submitted for review is the Final Technical Report Dye Trace of Beech Creek Aquifer for the Ammunition Burning Ground (ABG), Solid Waste Management Unit (SWMU) # 03/10. The requirement for submittal of this report was set forth on the Corrective Actions portion of the Hazardous Waste Part B Permit issued to Naval Weapons Support Center Crane (NWSCC) in January 1990.

NWSCC point of contact is Mr. Jim Hunsicker, Code 0924, telephone 812-854-3233.

Sincerely,

J. D. FARIS
Acting Public Works Officer
By direction of the
Commanding Officer

Encl:
(1) Final Technical Report Dye Trace of Beech Creek Aquifer for the ABG SWMU #03/10.
(2) Certification Statement

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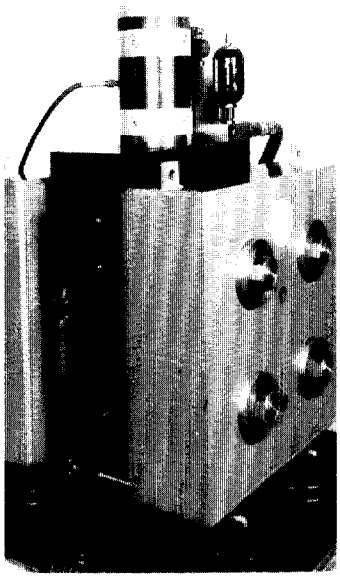

GEOTECHNICAL LABORATORY

TECHNICAL REPORT GL-90-21

DYE TRACE OF BEECH CREEK AQUIFER AMMUNITION BURNING GROUND, NAVAL WEAPONS SUPPORT CENTER CRANE, INDIANA

by

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Philadelphia, Pennsylvania 19112-5094

September 1990

Final Report

Further dissemination of this document only as directed by Department of the Navy, Northern Division, Naval Facilities Engineering Command, Philadelphia, Pennsylvania 19112-5094, or higher DoD Authority, September 1990.

Prepared for DEPARTMENT OF THE NAVY
Northern Division
Naval Facilities Engineering Command
Philadelphia, Pennsylvania 19112-5094

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A 9-day dye tracer test was conducted at Naval Weapons Support Center Crane, Indiana, by the US Army Engineer Waterways Experiment Station and the Naval Facilities Engineering Command. The test was conducted in the Beech Creek limestone of the Ammunition Burning Ground. The test evaluated the use of dyes to confirm the hydraulic connection of the Beech Creek limestone aquifer to nearby springs. Three dyes (fluorescein, direct yellow 96, and optical brightener) were injected into two wells at the Ammunition Burning Ground. Dye detectors were placed in springs north and south of the Ammunition Burning Ground, in Little Sulphur Creek, and in selected monitoring wells. The detectors were analyzed for dye presence before and after dye injection. The test was conducted in January 1990 during a period of high rainfall and high flow. Dye was detected in some springs but not in others. Fluorescein dye was an effective tracer of groundwater flow

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19. ABSTRACT (Continued).

at the Ammunition Burning Ground. Spring A and Little Sulphur Creek were prime outlets for groundwater at the Ammunition Burning Ground. Springs B and C are likely outlets only at high flow. Contamination at the Ammunition Burning Ground could have a ubiquitous dispersion south during periods of high flow.

PREFACE

This study was performed during the period 18 January to 1 March 1990 by the US Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, and Northern Division, Naval Facilities Engineering Command (NAVFAC), Philadelphia, Pennsylvania. The work was performed under authority provided by NAVCOMPT Document No. N62472-90MP0006, dated November 1989 and amended December 1989. The funds were made available through the Department of the Navy's Installation Restoration Program, Defense Environmental Restoration Account (DERA).

The field work and data analysis were performed by Mr. William L. Murphy, WES, and Mr. Jeffrey Ciocco, Northern Division. Field support was provided by the drilling crew under supervision of Mr. Mark Vispi, Chief, In Situ Evaluations Branch, and Mr. Richard Hunt, geologist, Engineering Geology Branch, GL. The report was written by Mr. Murphy and Mr. Ciocco. Mrs. Joyce H. Walker, Information Technology Laboratory, edited the report. Direct supervision was provided by Dr. Lawson M. Smith, Chief, Engineering Geology Branch. Additional supervision was provided by Dr. A. G. Franklin, Chief, Earthquake Engineering and Geosciences Division, WES, and Mr. Richard E. Fini, Head, Restoration Technical Section, Northern Division, NAVFAC. The project was conducted under the general supervision of Dr. William F. Marcuson III, Chief, GL.

COL Larry B. Fulton, EN, was Commander and Director of WES. Dr. Robert W. Whalin was Technical Director.

ACKNOWLEDGEMENT

The authors of this report would like to thank the personnel of the Naval Weapons Support Center Crane, Indiana. The support and coordination of the Public Works Officer, Commander Michael L. Frey, USN, and James Hunsicker, the Environmental Director, made the Dye Tracer Test possible. We would also like to gratefully acknowledge Ms. Carol Witt from the Environmental Protection Agency Region V for her technical reviews and field support.

EXECUTIVE SUMMARY

The purpose of this report is to document field and laboratory work performed in conducting a dye trace of the Beech Creek aquifer of the Ammunition Burning Grounds (ABG), Naval Weapons Support Center (NWSC) Crane, Indiana. The field investigation was conducted 18 January to 26 January 1990.

Groundwater contamination from prior releases has been detected at the ABG. A Corrective Actions Program, per the RCRA Central Storage Facility permit, required the Navy to define groundwater flow pathways at the ABG. A 9-day dye tracer test was conducted by the US Army Corps of Engineers Waterways Experiment Station and the Naval Facilities Engineering Command, Northern Division.

The test evaluated the use of dyes to confirm the hydraulic connection of the primary ABG aquifer to nearby springs. Three dyes (Fluorescein, DY96, Phorwite AR) were injected into two wells at the ABG. Dye detectors were placed in springs north and south of the ABG. Detectors were also placed in monitoring wells and Little Sulphur Creek south of the ABG. The detectors were analyzed for dye before and after injection.

The dyes were injected at the conclusion of a 24-hr, 2-in. rainfall. The springs and streams had nearly two times the normal flow during injection. The water levels in the springs and streams receded to mean flow quickly, except for one spring (Spring B). Lab analysis of preinjection (background) spring and creek samples revealed trace levels of a dye-like color in some samples. Background levels were not considered high enough to preclude successful tracing. Postinjection samples north of the ABG remained at background levels. Dye presence was ubiquitous but weak south of the ABG immediately after injection. Only Springs A/A' and Little Sulphur Creek at the south boundary remained positive throughout the test. The monitoring wells showed only background levels.

Heavy rainfalls at the ABG will rapidly discharge off-base via south springs and subsequently Little Sulphur Creek. The scope of the test did not include off-post sites. Therefore, potential flow from the ABG to outlet springs in Big Sulphur Creek off-post cannot be assessed from present data.

Fluorescein dye was an effective tracer of groundwater flow at the ABG. Spring A, and subsequently Little Sulphur Creek, were prime outlets for groundwater in the aquifer at the ABG. Spring B and C are likely outlets only

at high flow conditions. Contamination at the ABG could have a ubiquitous dispersion south of the ABG at high flow. Test results for springs north of the ABG were generally inconclusive. Direct Yellow 96 and Phorwite AR optical brightener were only marginally effective as tracers. Successful completion of the dye trace justifies an additional dye trace designed to encompass a larger area on and off-post.

Another dye tracer test should be conducted in the ABG aquifer to delineate groundwater flow. The number of detection sites should be increased to include off-post springs in the Little and Big Sulphur Creek valleys. Selected off-post springs should be considered for quarterly groundwater quality monitoring.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square metres
feet	0.3048	metres
feet per mile	0.1893935	metres per kilometre
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres

DYE TRACE OF BEECH CREEK AQUIFER, AMMUNITION BURNING GROUND NAVAL WEAPONS SUPPORT CENTER CRANE, INDIANA

PART I: INTRODUCTION

Purpose

1. This report documents field and laboratory work performed in conducting a dye trace of the Beech Creek aquifer in the vicinity of the Ammunition Burning Ground (ABG) at the Naval Weapons Support Center (NWSC) Crane, Indiana (see Figures 1, 2). The primary goal of the dye tracer test was to confirm hydraulic connection between the solution zones of the Beech Creek aquifer underlying the ABG and the springs in Little Sulphur Creek and elsewhere. Another goal, if connection between the springs and the ABG were confirmed, was to show that particular springs were more efficiently connected to the ABG than others. The existence of a suspected groundwater divide between the ABG and Mountain Spring to the north was also to be investigated. Successful completion of the dye tracer test would provide justification for a follow-up dye trace encompassing a larger geographic area, including off-post sampling sites. The dye trace evaluated the effectiveness of dyes as groundwater tracers in the hydrogeological environment of the ABG. The report also discusses and explains groundwater flow in karst terrains typical of the terrain at the ABG and provides background information on the general use of tracers in assessing groundwater flow.

Background

2. A sequence of remedial investigations and remedial actions have been performed at the Naval Weapons Support Center (NWSC) Crane, Indiana. Investigations began at the NWSC Crane after the initial discovery in early 1981 of a potential hazardous substance release from the Center. The investigations have proceeded since 1981 and continue at the time of this writing. In April 1981, the US Navy implemented the Navy Assessment and Control of Installation Pollutants (NACIP), now known as the Installation Restoration Program (IRP), to identify and control environmental contamination from past use and disposal of hazardous substances at the NWSC Crane. The IRP program is designed to

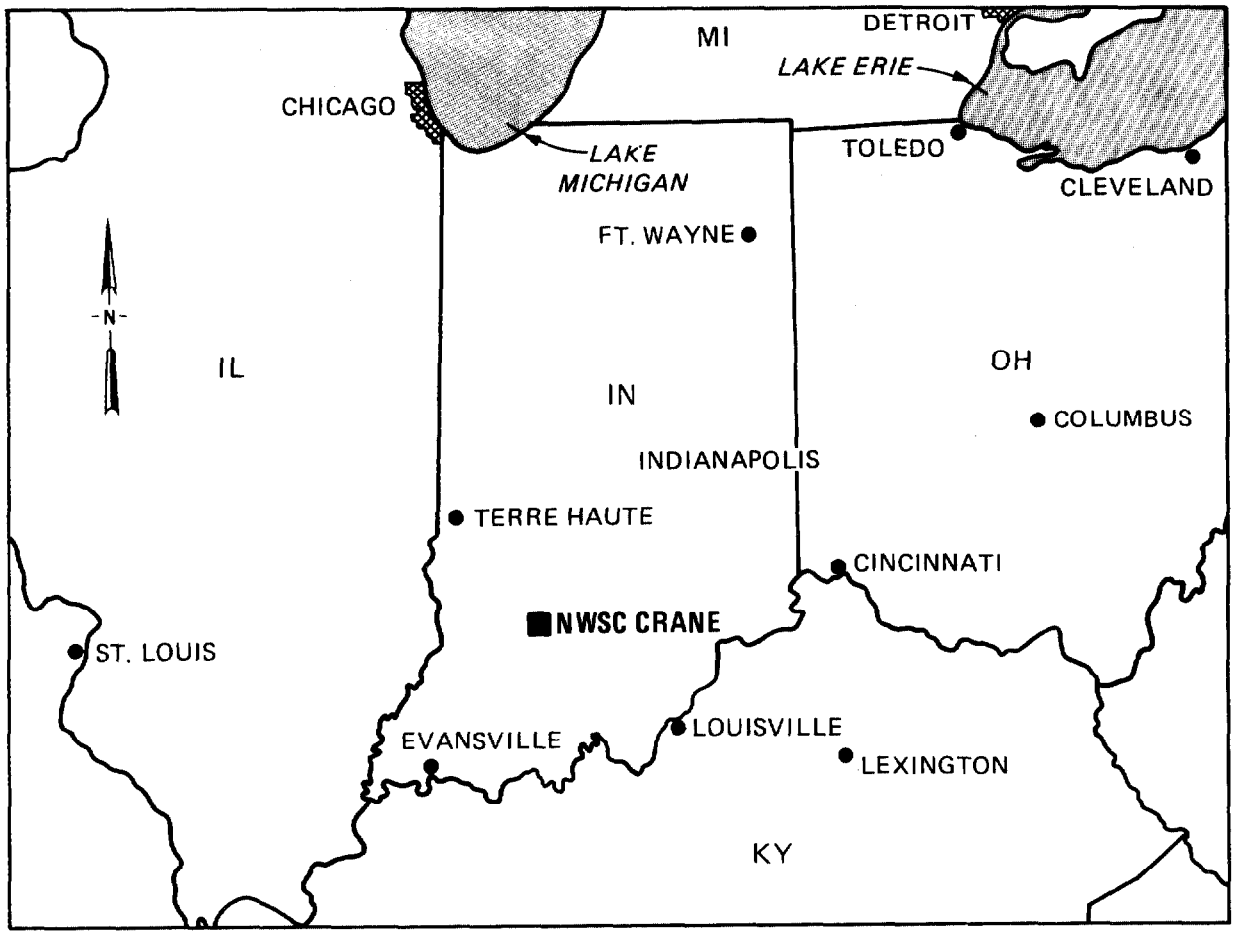

Figure 1. Location of Naval Weapons Support Center (NWSC) Crane (Chesapeake Division Naval Facilities Engineering Command)

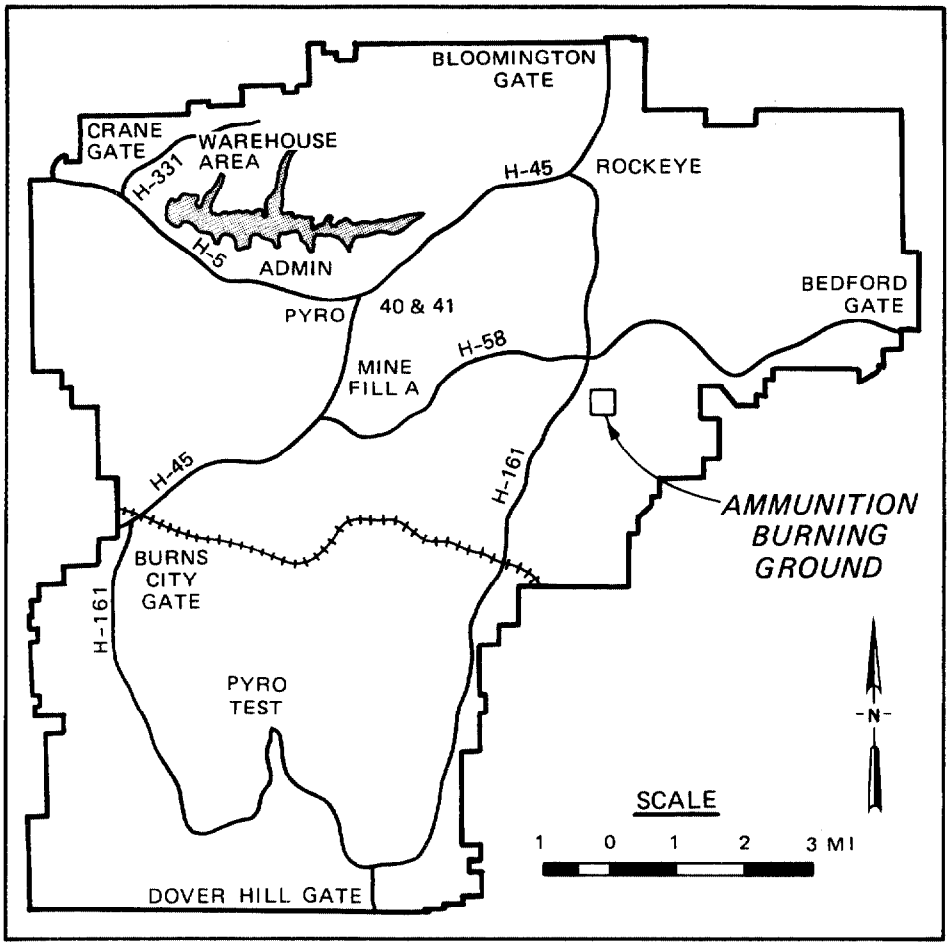

Figure 2. NWSC Crane and location of the Ammunition Burning Ground (ABG)

conform to the scope and purposes of the National Oil and Hazardous Substances Contingency Plan (NCP) established by the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980, and amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986. The IRP consists of 5 major steps; (a) Preliminary Assessment (formerly IAS), (b) Site Inspection (formerly Confirmation Study), (c) Remedial Investigation/ Feasibility Study (RI/FS), and (d) Remedial Design/Remedial Action (RD/RA).

3. An Initial Assessment Study (IAS) for the NWSC Crane began in April 1981 and was completed in May 1983 by the Naval Energy and Environmental Support Agency (NEESA). Assistance was provided by the Ordnance and Environmental Support Agency and the US Army Corps of Engineers Waterways Experiment Station (WES). The IAS recommended site inspections be performed at 14 sites: 9 ordnance sites and 5 non-ordnance sites. The IAS identified the ABG as a site requiring investigation because of past hazardous waste disposal. The on-going hazardous waste management operations at the ABG also mandated compliance with Subtitle C of the Resource Conservation and Recovery Act (RCRA). On 19 May 1980, the United States Environmental Protection Agency (USEPA) finalized Phase I of the RCRA hazardous waste regulatory program, which became effective 19 November 1980. By this date the NWSC Crane had to comply with the codified regulatory sections of the RCRA. In October 1980 the NWSC Crane filed a RCRA Section 3010 notification and a Part A permit application to operate as a treatment, storage, or disposal (TSD) facility. The NWSC Crane was qualified for and obtained Part A "interim status", which allowed the facility to legally operate as though it had a permit. The ABG then became subject to 40 CFR Part 265 (interim status standards). Part 265 (as well as Parts 260 through 280) is divided into Subparts which address the general operating requirements for hazardous waste management facilities and the technical standards applicable to specific units.

4. In August 1981 the NWSC Crane notified the USEPA of four surface impoundments (dewatering beds) at the ABG and one waste impoundment. A "groundwater monitoring program" was required at the ABG pursuant to (a) 40 CFR Part 265-Subpart F, and (b) the IRP. The groundwater monitoring program began at the NWSC Crane in 1981. Through a Military Interservice Procurement Request, the Navy contracted the WES to conduct hydrogeologic investigations at ten sites, eight identified in the IAS, and two new sites. The work was performed under authority provided by NAVCOMPT Document Number

N00164-IMP-04575, dated June 1981 and amended October 1981. The WES installed monitoring wells (Dunbar 1982) from August 1981 to December 1981 at the ABG and provided a report in April 1982. Results of the monitoring program suggested the presence of groundwater contamination at the ABG. Pursuant to 40 CFR 265 Subpart F, WES performed six studies at selected sites from June 1983 to October 1983. The ABG was one of the sites. The final report for the 1983-84 studies at the ABG was provided in April 1984 (Dunbar 1984). Funding was provided by an Order for Work and Services, NAVCOMPT No. N0016483WR0G185, dated May 1983 and amended September 1983.

5. The Naval Facilities Engineering Command-Northern Division (NORTHDIV), pursuant to the IRP, contracted the Hazardous Material Technical Center (HMTC) to perform Confirmation Studies (i.e. SI's) at several sites at the NWSC Crane in November 1984. The ABG was included in the investigation.

6. The Hazardous and Solid Waste Amendments (HSWA) of RCRA established corrective actions programs (CAP), Section 3004, at TSD facilities. The provision required the NWSC Crane to address past releases of hazardous waste or hazardous constituents at solid waste management units (SWMU's) and regulated units. The first step of the CAP required the NWSC Crane to submit a Hazardous Waste Management Report (known as the SWMU report) to the USEPA. The SWMU report listed the ABG and all of the IAS-identified hazardous waste sites as SWMU's, and was submitted to the USEPA in January 1985. The next step of the CAP, a RCRA Facility Assessment (RFA), was conducted by A.T. Kearney, an USEPA contractor. The contractor conducted a file search of the facility and a site visitation and prepared a report in 1987 which characterized possible releases from 100 SWMU's. On 22 June 1987 the USEPA promulgated amendments to allow the information related to detailed corrective action planning to be developed by USEPA Regional Administrators after the issuance of a RCRA permit through the use of compliance schedules included in the permit (see paragraph 10 for a description of the NWSC Crane permit).

7. A hydrogeological investigation of the ABG and surrounding area was conducted by the WES in 1986-87. The Hunt (1988) report identified factors influencing or controlling the flow of potentially contaminated groundwater into and out of the ABG. Work included emplacement of 66 exploration borings and monitoring wells in three aquifers, geologic and hydrologic field mapping, literature survey and consultation with geologists at the Indiana Geological

Survey, Bloomington. The study area included the area surrounding the ABG, especially that to the south.

8. The Hunt (1988) hydrogeological investigation and report are partial fulfillment of the (a) Ground Water Assessment Plan, Ammunition Burning Grounds Hazardous Waste Treatment Site, NWSC, 1986; (b) the 1989 USEPA RCRA Part B Permit's CAP; and (c) the RI phase of the IRP at the ABG. The report by Hunt (1988) concluded that flow through solution passages in the Beech Creek limestone is the primary conduit for groundwater leaving the ABG and that flow through the conduits can be "rapid." The report recommended that increased emphasis be given to monitoring of springs and that injection of tracers (i.e. dye tracer test) be considered to confirm direction and rate of movement away from the ABG through solution conduits.

9. On 3 April 1989 the Navy submitted three documents to the USEPA Region V: (a) an updated Groundwater Assessment Plan for the ABG; (b) a Dye Tracer Test Proposal; and (c) the Hunt (1988) ABG hydrogeologic investigation. Technical review comments (see Appendix 2), dated 22 June 1989, were submitted by the USEPA Region V to the NWSC Crane for the three documents. After discussions in a May 1989 meeting between the USEPA, WES, and the Navy, the WES installed five additional monitoring wells (July and August 1989) in the vicinity of the ABG. As requested by the USEPA comments, the Dye Tracer Test proposal was rewritten and submitted to the EPA in July 1989.

10. Final approval of the Dye Tracer Test Proposal and the Hunt (1988) report were established in the Federal portion of the joint RCRA storage permit issued to the US Navy by the USEPA and the State of Indiana. The Federal portion of the RCRA Permit, dated 20 December 1989, established the HSWA Corrective Action Requirements and Compliance Schedules (RCRA Section 3004). The compliance schedules obligated the NWSC Crane to perform RCRA Facility Investigations (RFI) at 30 SWMU's, and, if contamination were found, to conduct Corrective Measures Studies (CMS) and implement Corrective Measures if needed. The State of Indiana obtained pre-HWSA authorization and issued the State portion of the permit which authorized the NWSC Crane to operate the Central Hazardous Waste Storage Facility, Building No. 2993. The Permit's RFI compliance schedule for the ABG established work plan submittals for the following: (a) Modified RFI Phase III Release Characterization for Groundwater; (b) RFI Phase III Release Characterization for Soil; and (c) RFI Phase II Release Assessment for Surface Water Bodies. In April 1990 the NWSC

Crane submitted the Modified RFI Phase III Release Characterization Work Plan for Groundwater. The Work Plan scheduled the submittal of this Draft Dye Tracer Report, the proposal to conduct a second Dye Tracer Test, progress reports, and the RFI Phase III Final Report for Groundwater. The RCRA Section 3004 Corrective Action Requirements of the Storage Permit have incorporated the IRP. RCRA will be the primary vehicle to further investigate and remediate the IRP sites. At the time of this writing, the NWSC Crane is also pursuing a USEPA, RCRA operating permit for thermal treatment (open burning/ open detonation) of pyrotechnics, explosives, and propellants (PEP) at the following Subpart X units: the ABG, the Demolition Area, and the Old Rifle Range, which are also considered SWMU's.

Scope

11. The dye trace field work, performed 18 January to 26 January 1990, included injection of selected dyes into two monitoring wells emplaced previously at the ABG, daily collection of dye detectors from prearranged collection points, and laboratory analysis of the detectors to determine the presence of dyes. Results were then analyzed to assess the effectiveness of the dye tracing technique in the ABG environment and to delineate primary groundwater flow paths within the Beech Creek limestone. The dye tracing techniques as implemented at the ABG are applicable to evaluation of groundwater problems at other sites having similar geohydrologic conditions.

Study Area Location

12. The NWSC Crane is located in southwest Indiana approximately 75 miles southwest of Indianapolis and 71 miles northwest of Louisville, Kentucky (Figure 1). The NWSC occupies 62,463 acres (approximately 100 square miles) of the northern portion of Martin County and small portions of neighboring Greene, Daviess, and Lawrence Counties. The ABG study area lies in the eastern part of the NWSC (Figure 2) and consists of about 50 acres.

Brief History of Operations at the ABG

13. Ordnance and ordnance-contaminated materials from NWSC production areas have been taken to the ABG for disposal by burning since the 1940's. The burning ground is used extensively for destroying unwanted materials contaminated with explosives, bare explosives, rocket motors, candles, flares, solvents, detonators, and fuse materials. Several separate burning areas are located within the site proper. The largest quantities of materials were destroyed from 1956 to 1960, when 15,000 lbs per day of smokeless powder was destroyed. In the same period, about 46,000 lbs per day of high explosives was burned. The area is also used for flashing the residue from bombs and projectiles after they have been subjected to melt out or drill out operations for removal of the bulk of the explosive.

14. Three surface impoundments were constructed in 1975 to remove liquids from otherwise combustible sludges resulting from the blending and loading of munitions. The impoundments were modified in 1982 to include a liner and leachate collection system for each. Surface burning of ordnance was formerly conducted on the ground surface, but burning pans are now used to prevent contact of burn products with the ground. Plate 1 is a topographic and well-location map of the ABG. The area labeled "Ash Pile" is the site of a former stockpile of burn residue which has been removed under a RCRA closure plan. Surface drainage into and from the ABG is via Little Sulphur Creek, which flows from the north to the southeast through the center of the ABG and formed the valley in which the ABG is situated. A small tributary drainage way joins Little Sulphur Creek near the center of the site from the west-southwest.

PART II: PHYSIOGRAPHY, GEOLOGY, AND HYDROLOGY OF THE AMMUNITION BURNING GROUND

Physiography

Regional physiography.

15. The physiographic divisions of the state of Indiana are shown in Figures 3 and 4. The NWSC is in an unglaciated area of the Crawford Upland, a rugged dissected plateau bounded on the east by the Mitchell Plain and on the west by the Wabash Lowland. The Mitchell Plain is a low, dissected limestone plateau characterized by sinkhole topography and other typical karst* features (see Figure 5). The Chester Escarpment, an irregular east-facing cuesta, separates the Crawford Upland and the Mitchell Plain. The escarpment trends NW-SE, passing a few miles east of the NWSC. Numerous springs, caverns and caves occur along the Chester Escarpment and in the eastern part of the Crawford Upland. Some solution features are found in the eastern portion of the NWSC. The Crawford Upland grades into the Wabash Lowland near the western NWSC boundary. Elevations on the Crawford Upland at the NWSC range from less than 500 ft MSL to greater than 850 ft** msl. Relief on the upland varies from about 100 to 350 ft, with higher elevations and greater relief occurring generally in the eastern part of the NWSC. Surface drainage in the upland is to the south and southwest.

Local physiography.

16. The topography of the ABG study area is shown in Plate 2, a map compiled from United States Geological Survey (USGS) 7-1/2 min. quadrangles. The topography is rugged, with steep sided, narrow ridges and valleys. The topography is a product of erosional incision into gently dipping strata of varying resistance. A major drainage divide extends southwest-northeast through the area and is approximately coincident with NWSC Road 161. East of the divide, approximately two-thirds of the area drains to the south through Little Sulphur and Sulphur Creeks. The area west of the divide drains ultimately into Turkey Creek to the west. The east-west, northwest-southeast, and

---

* "Karst" signifies a terrain of limestone, dolomite or gypsum with a type of topography that is formed by dissolving or solution and that is characterized by sinkholes, caves, and underground drainage.

** A table for converting non-SI to SI (metric) units of measurement is presented on page 7.

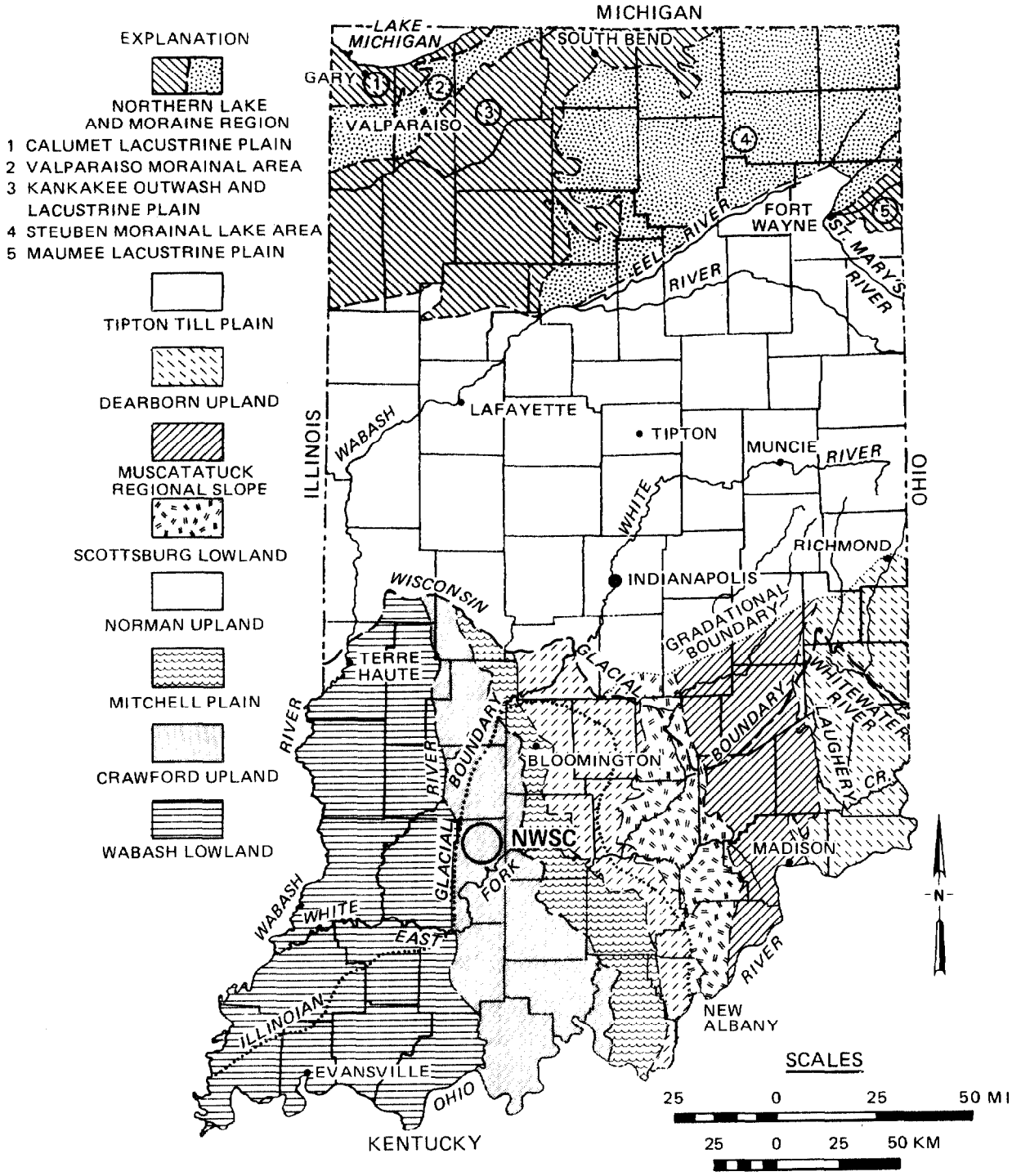

Figure 3. Physiographic divisions of the State of Indiana (Perry and Smith 1958)

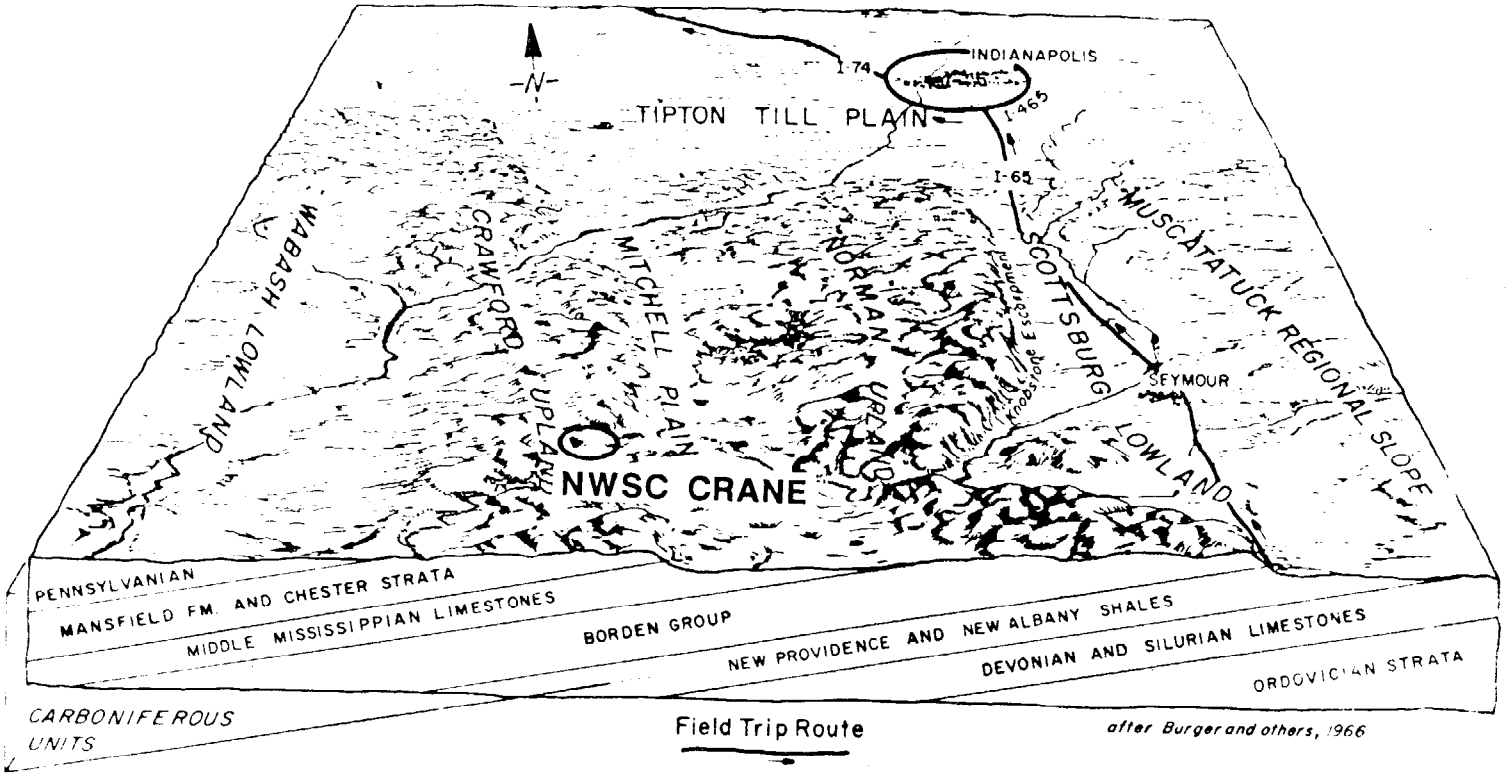

Figure 4. Physiography of south-central Indiana showing the underlying geologic formations (Ettensohn and Dever 1979)

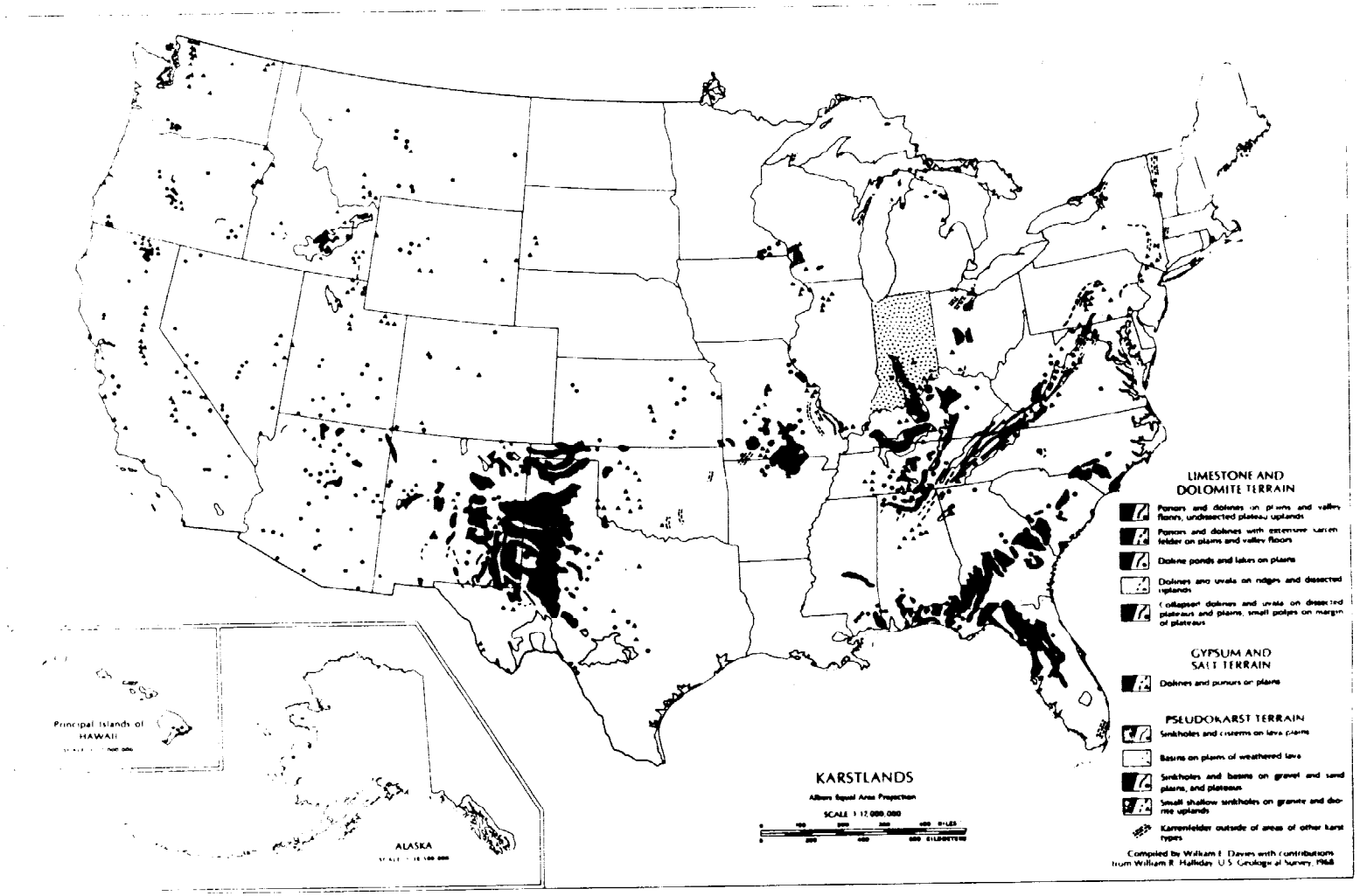

Figure 5. Karst areas of the United States. State of Indiana is shaded (USGS 1970)

northeast-southwest trending valleys reflect joint trends in the underlying rock. Joints having strikes similar to the drainage trends were measured at several outcrops in the earlier work by Hunt (1988). A regional photogeologic fracture trace analysis revealed several lineaments in the ABG area trending NNE and WNW*. Elevations across the study area range from about 480 ft msl in the lower drainage valleys to a maximum of 845 ft msl along the major drainage divide.

17. The ABG lies near the head of Little Sulphur Creek valley (see Plates 1 and 2). The site is approximately 2,000 ft long by 1,000 ft wide with the long axis oriented east-west. Elevations in the valley portion of the site range from 620 ft msl at the western end to 580 ft msl at the eastern end. Elevations on ridges around the site range from 720 to 810 ft msl. Surface drainage flows into the site from the west and northwest, and flows out of the site to the east. Little Sulphur Creek turns south at the east end of the site and continues off the NWSC boundary 1-1/2 miles south of the ABG.

Geology and Hydrology

Regional geology.

18. Hunt 1988 described the geology of the NWSC and the region. Southwest Indiana and the NWSC are in an area of the Midwest with underlying sedimentary rocks of Paleozoic age which have been gently deformed into a structure known as the Illinois Basin (Figure 6). The sedimentary rocks have accumulated to thicknesses exceeding 13,000 ft in the Basin. The NWSC lies in the eastern flank of the Illinois Basin where the underlying strata dip west-southwest approximately 50 ft per mile (a little over 1/2 degree). The rocks immediately underlying the NWSC are of lower Pennsylvanian and upper Mississippian age (roughly 300 million years old) and are predominantly marine or paludal sandstones, shales, coal, and limestone. A generalized stratigraphic column of the NWSC area is presented in Figure 7. Mississippian strata of the Chester Series are exposed in the valley walls along the eastern portions of the NWSC and in the lower elevations of deeper valleys farther

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* US Army Engineer District, St. Louis. 1989. "Fracture Trace Study, Naval Weapons Support Center, Crane, Indiana," Letter Report to Northern Division, Naval Facilities Engineering Command, Philadelphia, PA.

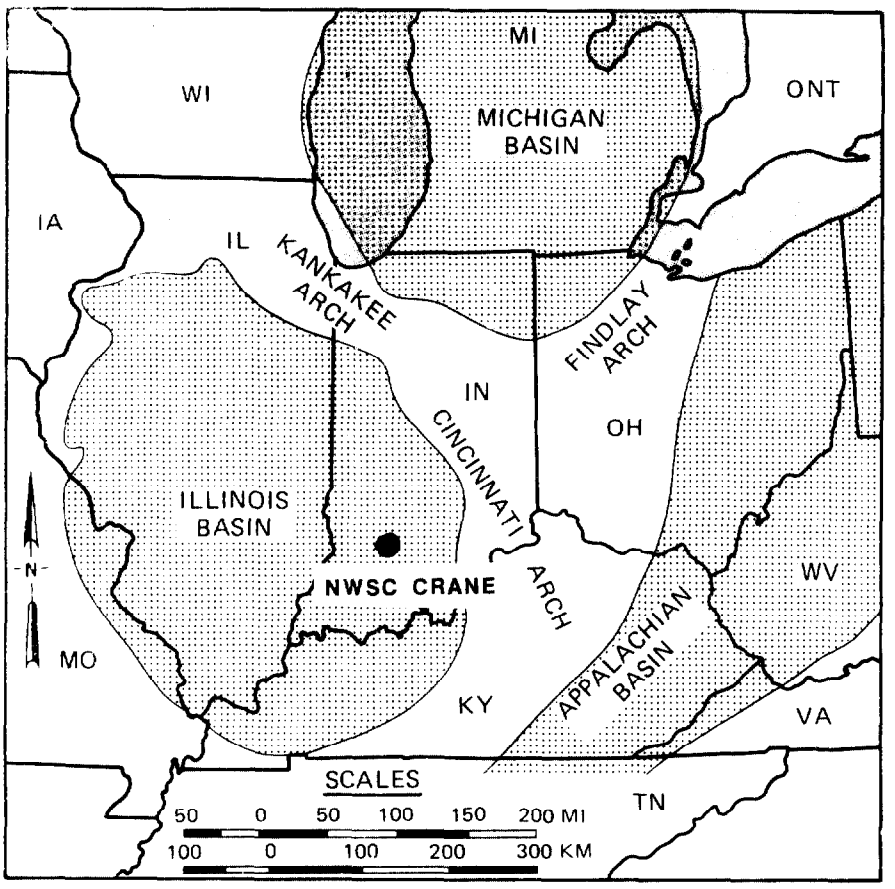

Figure 6. Major structural provinces of Midwestern United States (Carpenter et al 1975)

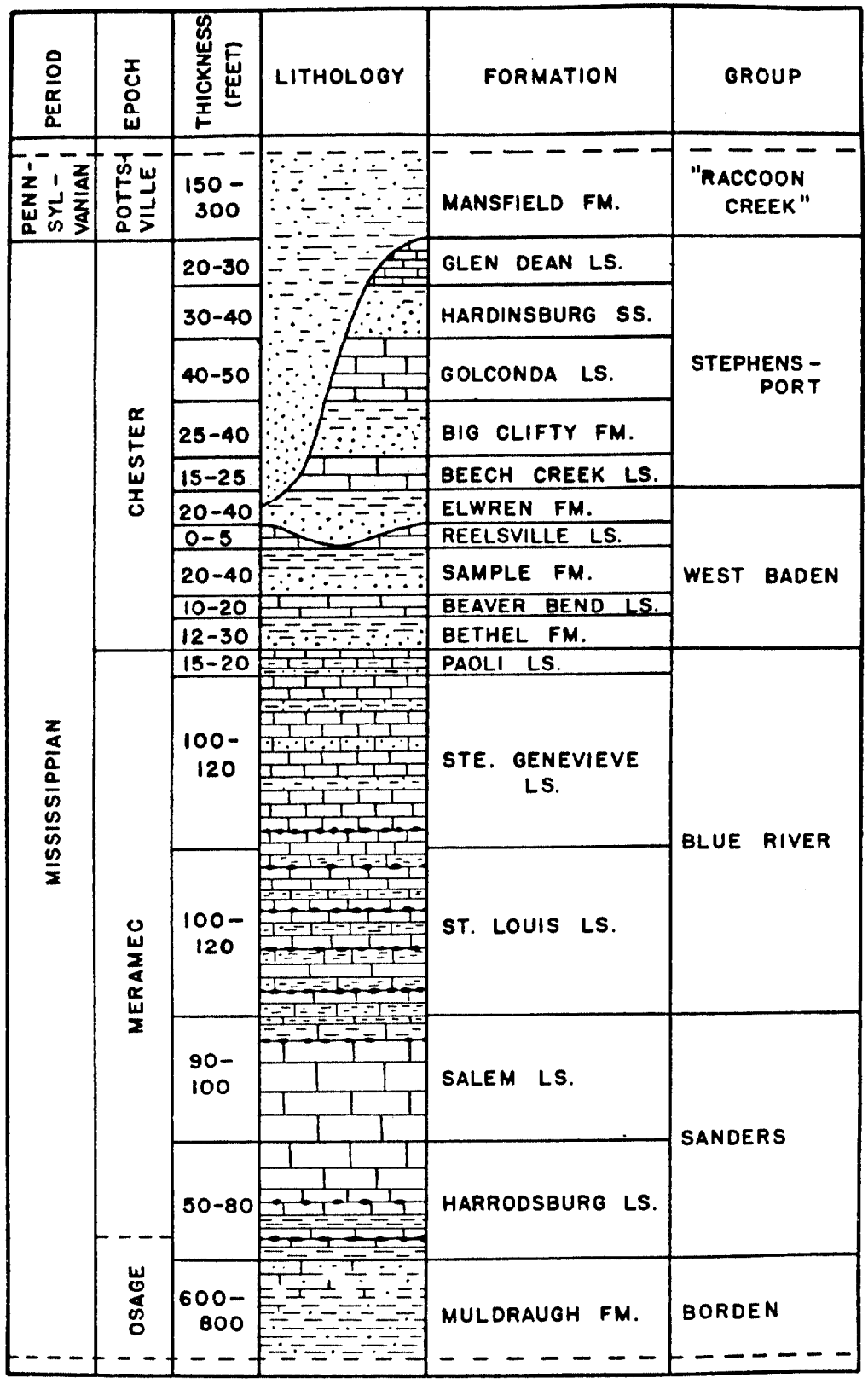

Figure 7. Stratigraphic column for rock units encountered at NWSC (Palmer 1969)

west. Pennsylvanian strata cap most of the hills and ridges along the eastern side of the NWSC and comprise the predominant surface rocks to the west.

19. The Mississippian strata are alternating sequences of limestones, shales, and sandstones that were deposited in shallow seas. The Pennsylvanian rocks are interfingered sandstones, shales, claystones, and siltstones with occasional coal beds deposited in cyclic seas and swamps. The contact between the Mississippian and the Pennsylvanian is an unconformity formed by erosion of the Mississippian surface over a long period of time. Local relief along the unconformity is as much as 150 ft in some areas (see Lithology column of Figure 7).

Local geology.

20. Stratigraphy. The geologic units of importance in the dye tracer study (Figure 7) are the Raccoon Creek Group of the Pennsylvanian and the Hardinsburg, Golconda/Haney, Big Clifty, Beech Creek and Elwren Formations of the Mississippian. The units were cored extensively in previous ABG investigations and have been amply characterized (see Hunt 1988). They are described briefly here.

a. Raccoon Creek Group (Pennsylvanian Mansfield Formation). The Mansfield Formation caps the hills and ridges in the study area and varies from 0 to 65 ft thick in borings. The formation consists of interfingered sandstones, thin-bedded and laminated shale and sandstone, thin-bedded to massive carbonaceous shale, massive claystone, siltstone, and occasional thin seams of coal. The strata tend to "lens out" laterally.

b. Hardinsburg Formation. The Hardinsburg was encountered immediately below the unconformity in many of the borings. Its maximum observed thickness in the ABG study area is 46.6 ft. The formation consists of thick, laterally varying beds of fine-grained, friable sandstone, thickly bedded sandstone and shale, and carbonaceous shale.

c. Golconda/Haney Formation. The Golconda/Haney was encountered immediately below the unconformity in several borings where the Hardinsburg had been removed by erosion. The Golconda/Haney varies from a few to 14 ft in thickness. It consists of crystalline, very hard limestone in beds 2 to 14 ft thick with interbeds of shaley limestone. The Golconda/Haney forms the uppermost aquifer in the ABG study area.

d. Big Clifty Formation. The Big Clifty is divided into two distinct lithologic members. The upper member is the Indian Springs shale and

consists of 20 ft of dark gray, platey to fissile carbonaceous shale. The Indian Springs serves locally as an aquiclude at the base of the Golconda/ Haney aquifer in the western portion of the ABG but is absent by erosion in the eastern portion. The Indian Springs is an important hydrologic feature of the ABG. The lower member of the Big Clifty Formation consists of 40 ft of tan, massive fine-grained permeable sandstone that is cut by abundant intersecting joints. The lower portion of the Big Clifty and the underlying Beech Creek limestone form the middle aquifer of the ABG study area.

e. Beech Creek Formation. The Beech Creek consists of very hard and dense limestone ranging from 18 to 22 ft thick except in areas where dissolution has removed the upper portion. The limestone has numerous intersecting joints. Core borings in the Beech Creek limestone encountered voids interpreted as solution cavities indicating that dissolution of the formation has produced buried karst conditions in the valley areas southeast and southwest of the ABG. The Beech Creek was considered by Hunt (1988) to be the primary outlet of groundwater at the ABG. Dye injection for the tracer test was conducted in the Beech Creek limestone. Most of the springs mapped in the ABG study area flow from the Beech Creek.

f. Elwren Formation. The Elwren is a 20-ft thick unit of relatively impervious shale with claystone. It forms an effective aquiclude at the base of the Beech Creek limestone and forces infiltrating groundwater from the ABG to move laterally through the soluble Beech Creek. The base of the Beech Creek (top of the Elwren) is exposed in several outcrops in the valleys within the ABG study area. Groundwater can be seen flowing freely along the top of the Elwren and forms springs at those locations.

21. Geology of the ABG. The distribution of rock units near the surface in the ABG study area is shown in the geologic map of Plate 3. Plate 3 is complementary to Plate 2 (the topographic map). The base of the Pm group is the unconformity between the Pennsylvanian and Mississippian rocks. The base of the Msp group in Little Sulphur Creek is the Beech Creek limestone. The top of the Mwb group is the Elwren shale. The general trend of the geologic units is indicated by the structure contours on top of the Beech Creek limestone. The regional dip of the strata is to the southwest at about 50 ft/mile.

22. A geologic map of the ABG site, constructed from boring and outcrop data, is presented in Plate 4. The map is an overlay to the topographic map

of Plate 1. The Indian Springs shale and Big Clifty sandstone occupy the floor of the valley at the ABG beneath an overburden of 1 to 15 ft of clayey soil that is breached in places by gullies. The wells in which dye was injected for the tracer test, WES 3-C3-P2 and WES 3-C2-P2* penetrate the sandstone and are screened in the Beech Creek limestone. Cross-section G-G' (see Plate 4) is a vertical profile of the subsurface along the axis of the valley from west to east (Figure 8). The screens for wells WES 3-C3-P2 and C2-P2 and the respective piezometric levels are shown at position "2" on the logs for those wells. The Indian Springs shale influences the rate of infiltration and direction of migration of surface water leaving the ABG. The importance of the Indian Springs to the hydrology of the site is discussed in a later section.

23. Several borings emplaced by Hunt (1988) penetrated cavities in the Beech Creek limestone as evidenced by loss of drilling fluid and by dropping of the drill rods upon penetration. The cavities in the Beech Creek were interpreted to be conduits formed in the soluble limestone by percolation of water infiltrating through joints and along bedding planes. The interpolated map position of the solution cavities is shown by the cross-hatches of Plate 4 and schematically in profile in Figure 8. Blocks of the overlying Big Clifty sandstone were noted to have fallen into some of the solution cavities. Surface exposures of the solution cavities were observed in outcrops of the sandstone and limestone in the walls of the valley of Little Sulphur Creek south of the ABG. Dissolution is hypothesized to have occurred primarily in the major drainage valleys of Little Sulphur Creek and Johnson Hollow where erosion has subjected the Big Clifty sandstone and Beech Creek limestone to weathering and rapid infiltration by water. Drilling logs and field mapping substantiate that hypothesis. The estimated extent of the dissolution zone in the Big Clifty/Beech Creek in the ABG study area is indicated by the shaded boundary in Plate 2.

24. Copies of the boring logs for wells WES 3-C2 and 3-C3, the cored borings of the well clusters, are presented in Appendix 2. Well installation

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* The well numbering system identifies the drilling agency (WES), the Site number (WES-3), the well cluster number (WES 3-C3-), the particular screened interval of the cluster (WES 3-C3-P2-) and the year installed (WES 3-C3-P2-86). Wells shown on cross sections are identified only by cluster number (as C17) for space limitations.

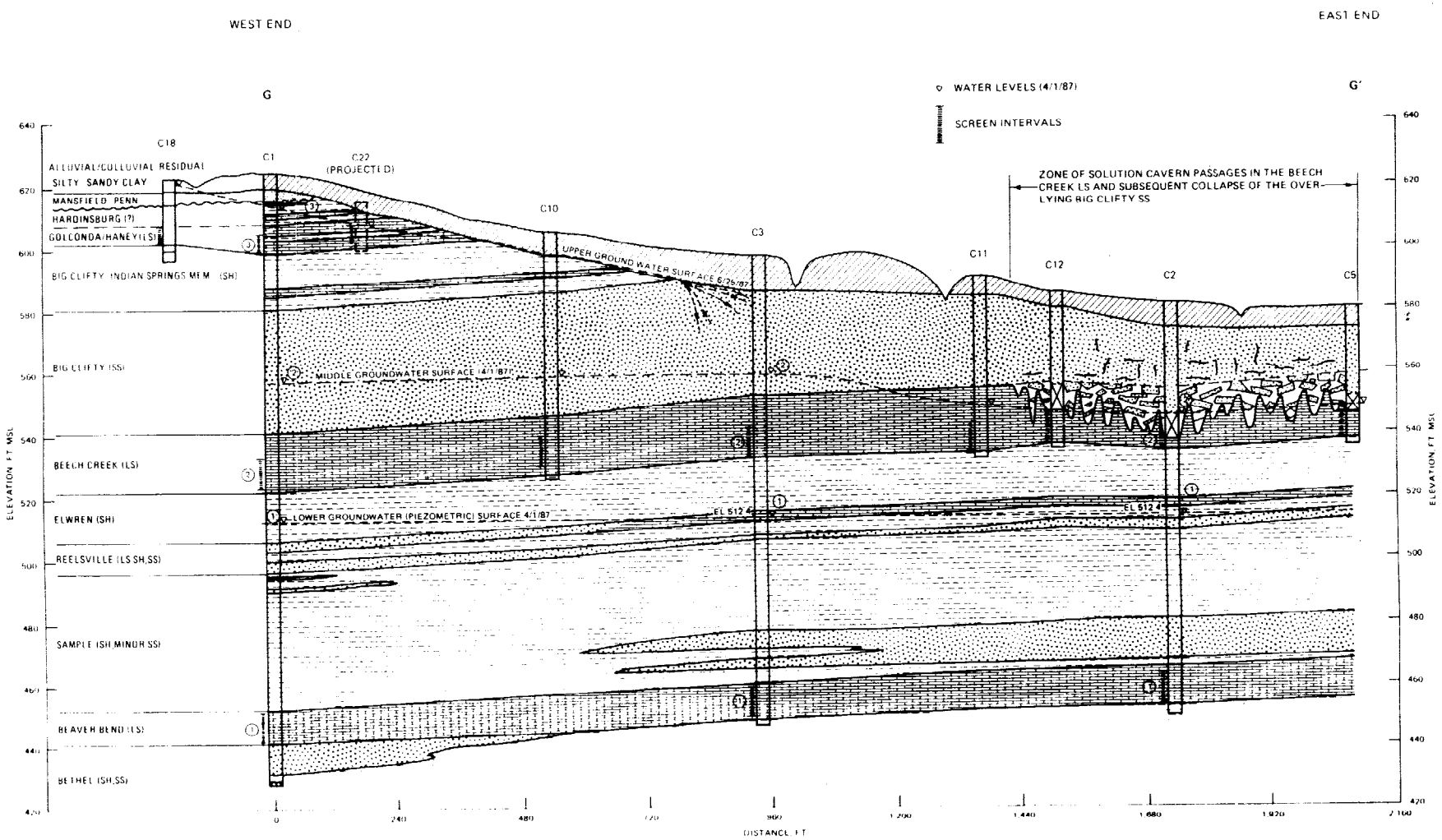


Figure 8. Profile of subsurface geology and hydrology along ABG valley floor

diagrams for Beech Creek limestone wells WES 3-C2-P2 and 3-C3-P2, the dye-injected wells, are included in Appendix 2. A summary lithologic log of the well borings is also presented. The summary logs show the location of the well screens of the two Beech Creek wells. The zone of core loss (open zone) in boring WES 3-C2 is approximately 8 ft thick, but the geologist observed that portions of the overlying Big Clifty sandstone had settled into the void left by solution of the limestone. A distinctive solution-formed surface was observed on the top of the limestone core recovered at the bottom of the void. No voids or core loss zones were encountered in boring WES 3-C3, but occasional open joints were present that caused some loss of water while drilling. The openings from which the springs issue in Little Sulphur Creek valley below the ABG were generally 1 ft or less in diameter. Figure 9 is a photograph of the Spring A' area. The oval opening above the present spring is the outlet for a former conduit that probably has ceased flowing as the valley has down-cut.

25. Three types, or degrees, of porosity and permeability are believed to be present in the rock underlying the ABG. The primary, or intergranular porosity of the Big Clifty sandstone is sufficient to readily collect and transmit water contacting its upper surface. Joints and bedding planes (discontinuities) in the sandstone and Beech Creek limestone vary in width from tight to perhaps 1 in. and constitute a secondary porosity and permeability. Open conduits form the third type of porosity and permeability. Intergranular porosity and the narrower discontinuities produce a diffuse-flow groundwater system. Solution-widened discontinuities and solution passages produce conduit flow. Quinlan and Ewers (1985) described typical karst systems as "mixed flow" aquifers, characterized by a combination of diffuse and conduit flow. Figure 10 is their representation of a mixed flow aquifer. The diagram is analogous to the subsurface at the ABG if the rock above the water table is sandstone of the Big Clifty Formation and the limestone is the Beech Creek. However, the karst at the ABG and elsewhere within the NWSC has not progressed to the stage where sinkholes are present. White (1988) classified types of porosity in karst terrains on the basis of morphology and size (Figure 11). The Big Clifty/Beech Creek system at the ABG is probably represented by all classes of porosity in Figure 11 except major trunk conduits.

26. Cross-section M-M' (Figure 12) is a geologic profile of the valley of Little Sulphur Creek from just north of the ABG to the south boundary of

Figure 9. Photograph of Spring A' area, south of ABG

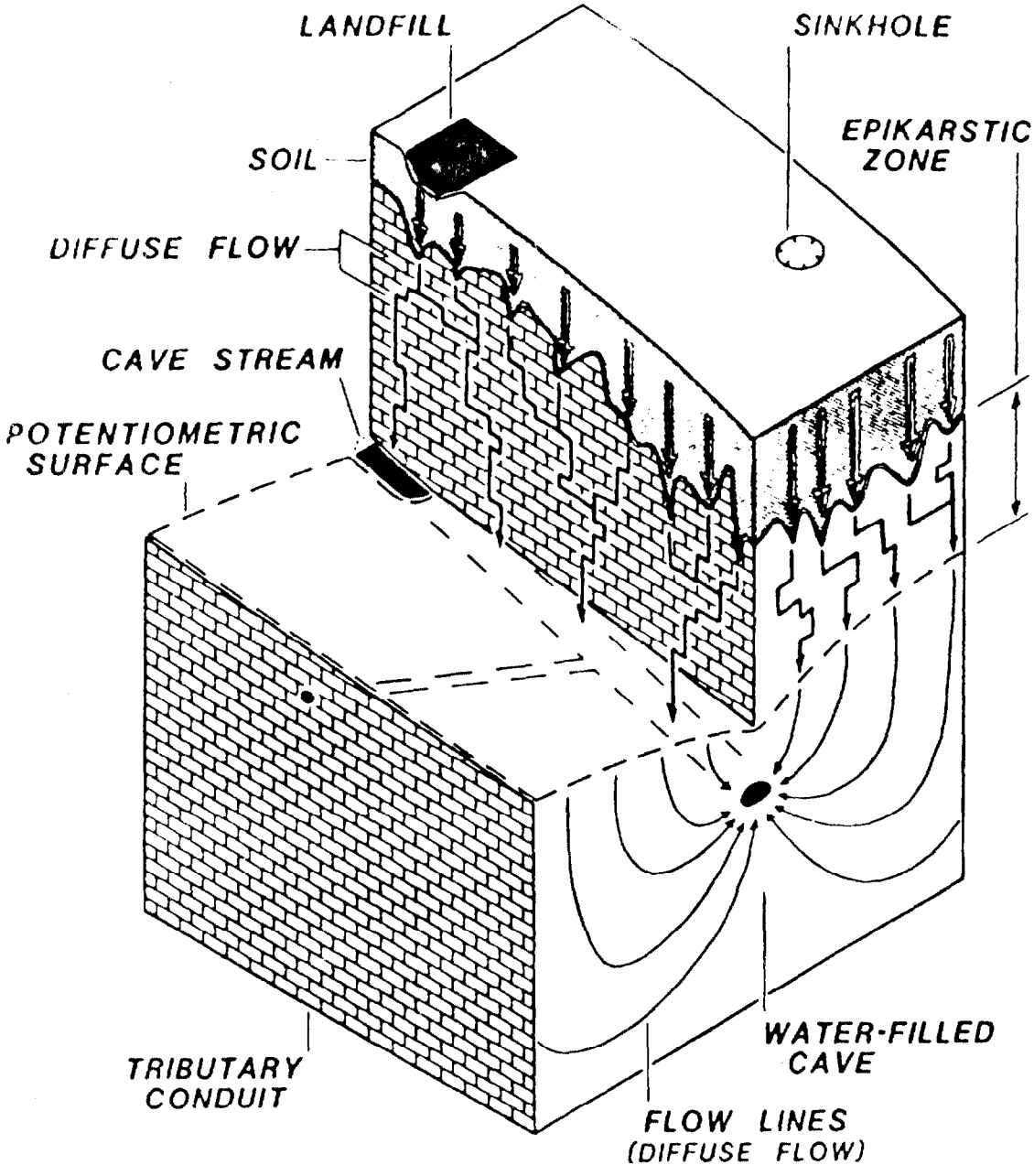


Figure 10. Mixed flow aquifer in karst system (Quinlan and Ewers 1985)

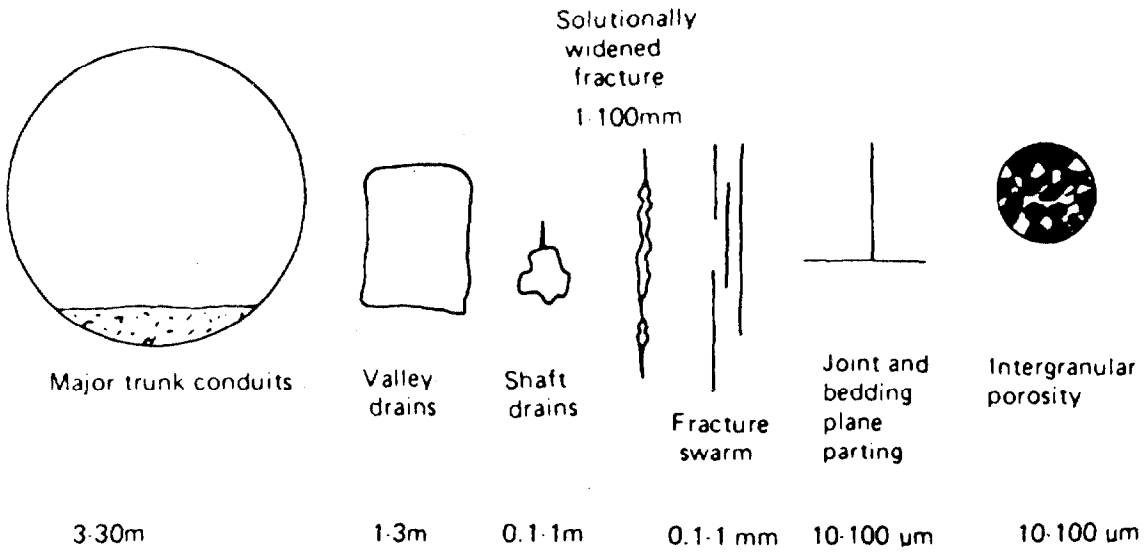


Figure 11. Types of porosity in karst terraces (White 1988)

NWSC (see Plate 2 for location). Little Sulphur Creek flows in the solution zone of the Big Clifty sandstone/Beech Creek limestone for a little more than one-half mile below the ABG and then on top of the Elwren shale to the south boundary. However, the Beech Creek and the solution zone are exposed in the valley wall of Little Sulphur all the way to the south boundary, as shown by the dashed contact in Figure 12 and on Plate 2. The Beech Creek in the valley walls gives rise to springs "C" on the east and "A"/"A'" and "B" on the west valley wall. Cross-section M-M' illustrates the general geologic environment in which the dye tracer test was conducted. The geologic profile along Johnson Hollow to the west of Little Sulphur Creek is shown in Figure 13.

27. Hydrology of the ABG. Surface drainage from the NWSC ultimately flows into the White River and thence to the Wabash to the southwest. The five major drainage basins within the NWSC are shown in Figure 14. The ABG is located in Basin III. Three separate aquifers were identified by Hunt (1988) as significant to the ABG study area. Referring to Figure 8, the lower aquifer is the Beaver Bend limestone, the middle is the Beech Creek limestone and overlying Big Clifty sandstone, and the upper is the Golconda/Haney limestone. The Beaver Bend aquifer is not discussed in this report.

28. Piezometric elevation contours on the Golconda/Haney and Beech Creek aquifers for December 14, 1987, are displayed in Figure 15 (Hunt 1988). The Golconda/Haney limestone occurs on the west side of the ABG and is

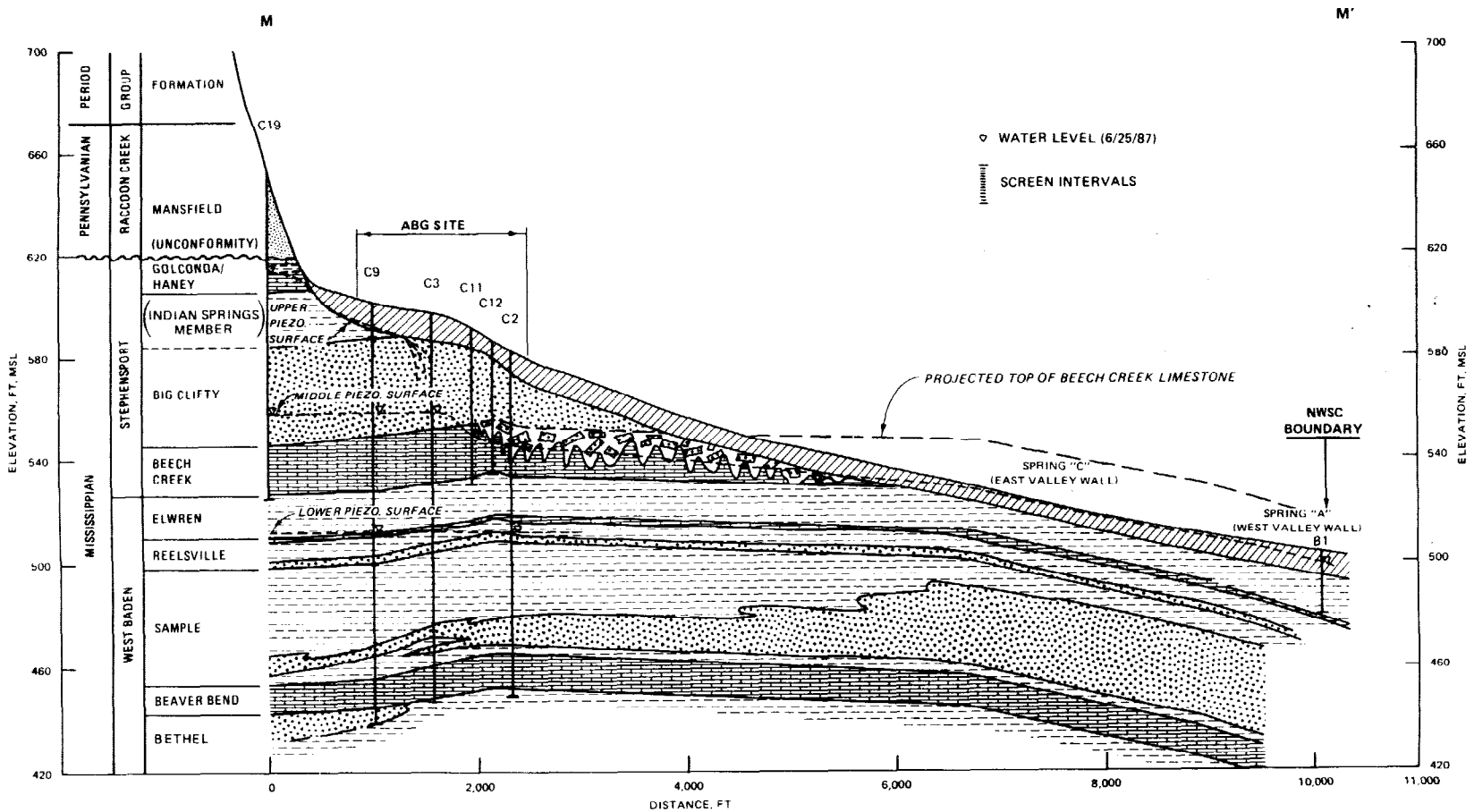


Figure 12. Geologic profile of valley of Little Sulphur Creek, Ammunition Burning Ground to NWSC boundary

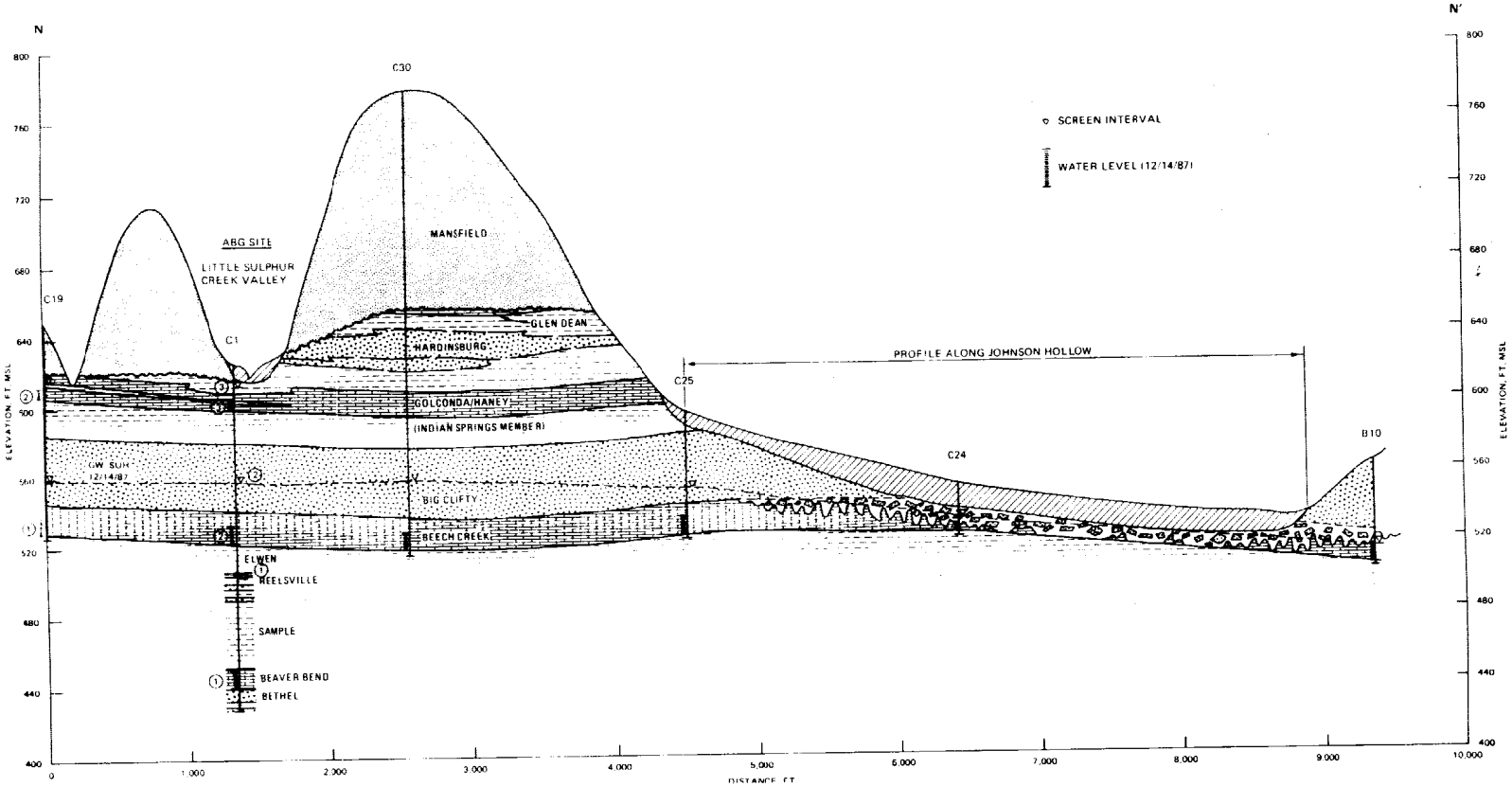


Figure 13. Geologic profile along Johnson Hollow

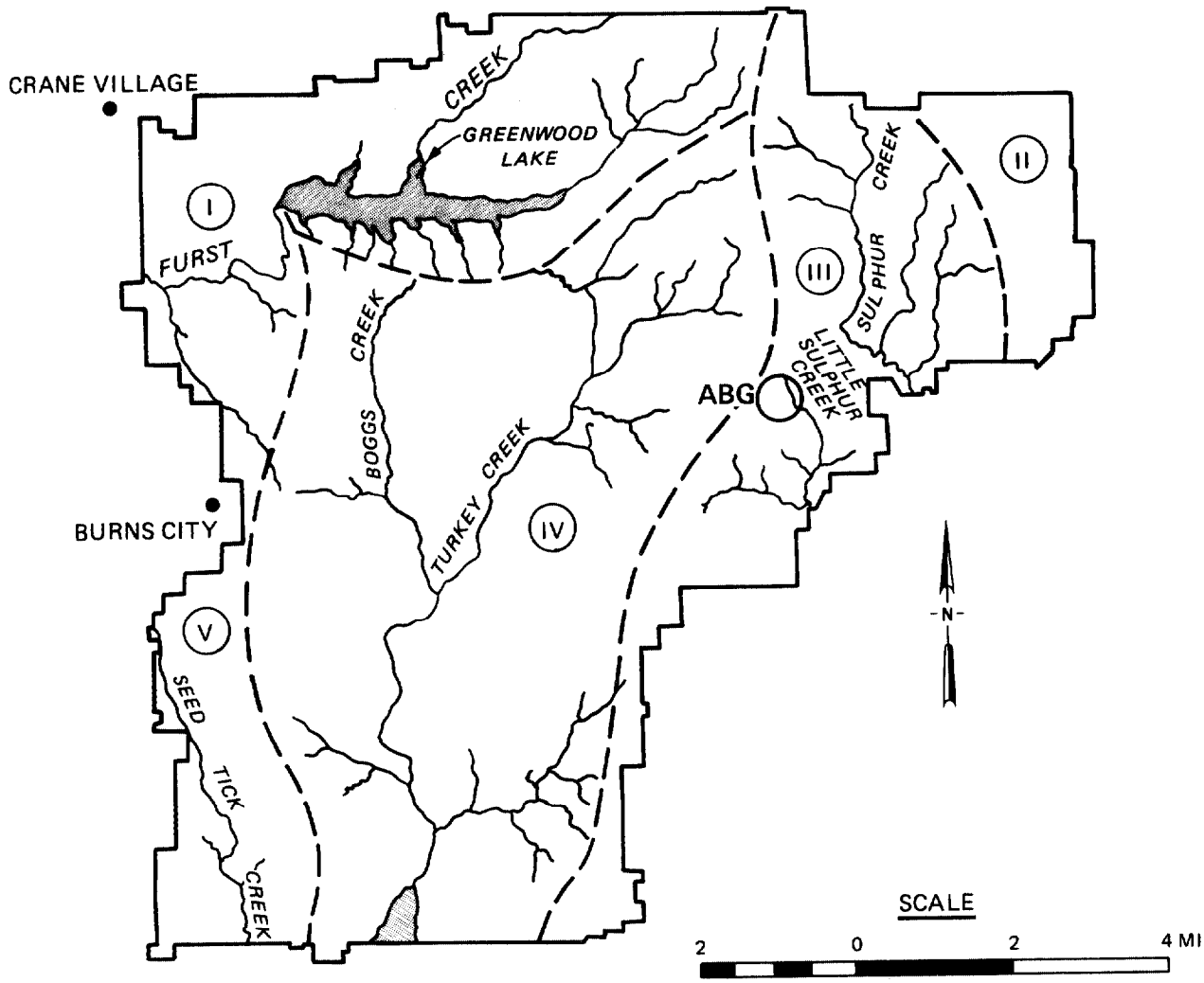


Figure 14. Surface drainage at the NWSC Crane, Indiana (Chesapeake Division Naval Facilities Command 1979)

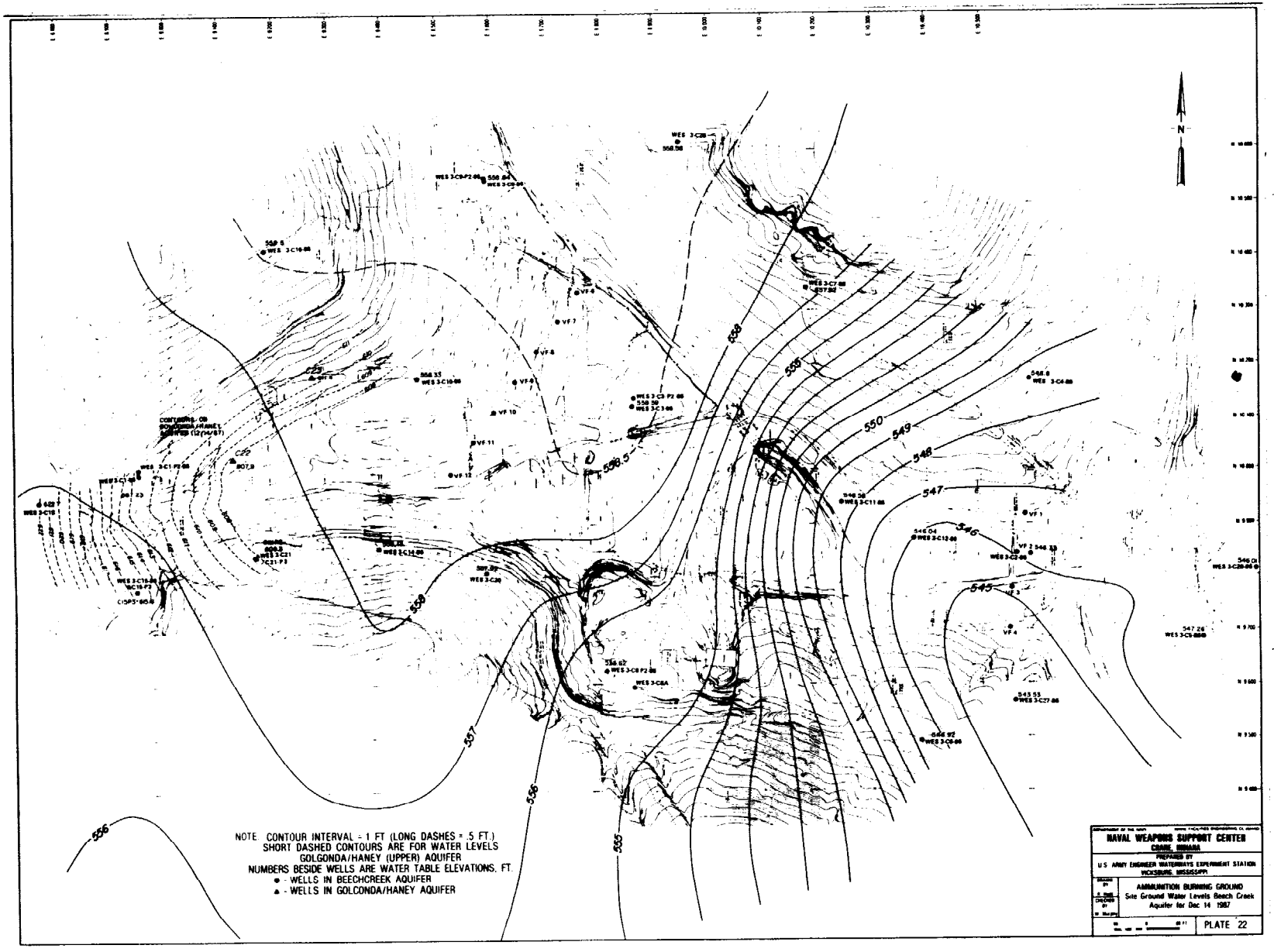


Figure 15. Groundwater contours on the Golconda/Haney (dashed) and Beech Greek (solid) aquifers at the ABG for 14 Dec 1987

breached in the valley slopes. It is underlain by the Indian Springs shale aquiclude (see Plate 4). Groundwater contours were constructed from data from the seven wells completed in the Golconda/Haney (dashed contours, elevation 608 to 622 of Figure 15). Flow is to the east through the Golconda/Haney and along the surface of the Indian Springs shale and ultimately into the Big Clifty/Beech Creek system (see Figure 8). In the central and eastern portions of the ABG, erosion has breached the Indian Springs and exposed a large area of Big Clifty Sandstone. Observation of surface runoff in Little Sulphur Creek in the ABG has shown the Big Clifty to be permeable and capable of taking most of the water that comes in contact with its surface. Once the water reaches the top of the sandstone, it seeps rapidly downward until it reaches the water table in the Beech Creek aquifer and continues out of the ABG to the east.

29. Groundwater seeping from the Golconda/Haney limestone into the ABG valley flows along the Indian Springs shale and into the Big Clifty similarly to surface runoff. Surface water and groundwater from the Golconda/Haney are prevented from direct percolation into the Beech Creek aquifer in the western and west central portion of the ABG by the underlying Indian Springs shale. The shale forces water to the east of a drainage divide near the center of the ABG and thence out to the east. Therefore, groundwater and surface-water contaminants from ABG activities are much less likely to flow out to the southwest through Johnson Hollow (Hunt 1988).

30. During dry periods and in light to moderate rains, all of the surface water accumulating in the ABG valley is captured by the Big Clifty sandstone and becomes groundwater in the Beech Creek aquifer. Heavier rainfall allows the surface water to flow off site down Little Sulphur Creek. Normally, the bed of Little Sulphur Creek just south of the ABG remains dry until the Elwren shale is encountered about 3/4 mile downstream near Spring "C" (see Figure 12). Spring "C" issues a volume of groundwater from the Beech Creek sufficient to start a new source of surface water flowing in Little Sulphur Creek. Springs "A" and "B" on the west valley wall discharge additional water into the surface flow in Little Sulphur before the creek leaves the NWSC boundary. Groundwater contours in the Beech Creek in the ABG study area for December 1989 are presented in Figure 16. The contour map incorporates data from ABG wells, wells emplaced for the Dye Burial Ground

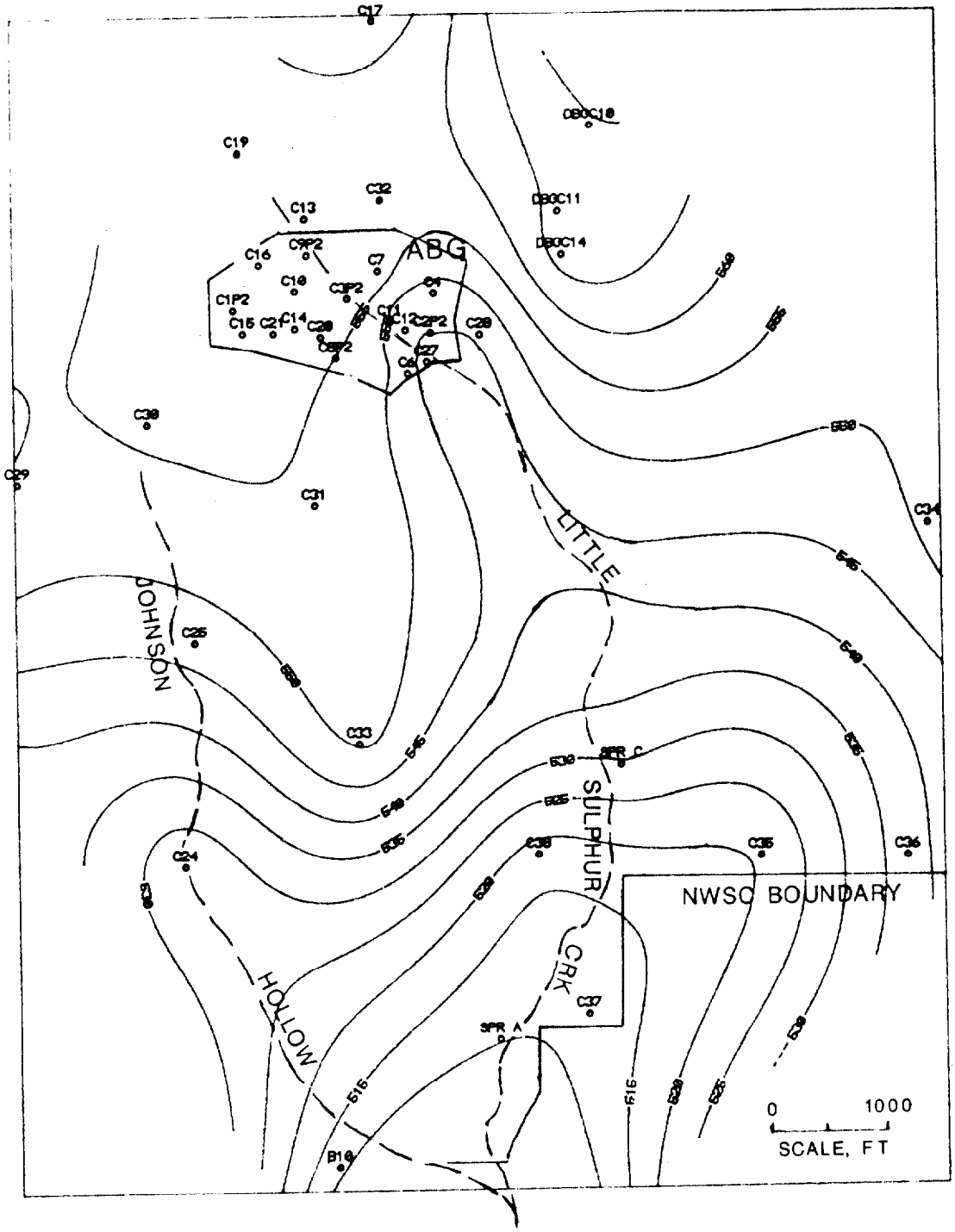


Figure 16. Groundwater contours in the Beech Creek aquifer, ABG study area, for December 1989

site, and Springs A and C. Elevations are approximate, pending confirmation by a survey in progress.

31. Hunt (1988) concluded that groundwater in the Beech Creek aquifer in the eastern half of the ABG flows rapidly away from the ABG through the solution passages in the limestone and issues from the springs in Little Sulphur Creek. Evidence for the rapid transfer of surface waters through the solution passages in the Beech Creek was observed by Hunt during two periods of heavy rainfall. The outflows from Springs "C" and "A" were observed to increase dramatically following the heavy rains. The water issuing from the springs was also noted to have turned murky and to be charged with sediment. Both springs cleared up and returned to their normal flow by the next day. As stated earlier, the primary objective of the dye tracer test was to corroborate the conclusion that the springs and solution zones at the ABG are hydraulically connected.

32. Johnson Hollow, which drains the western side of the ridge south of the ABG via an ephemeral stream (Plate 2), flows only during and after substantial rainfall. The stream bed of Johnson Hollow is in Beech Creek limestone from its confluence with Little Sulphur Creek near the NWSC boundary to just north of well WES 3-C24 and in Big Clifty sandstone upstream to near well WES 3-C25 (Plate 2 and Figure 13). A 2-day period of moderate rainfall that occurred before and during the dye tracer test caused the ephemeral stream in Johnson Hollow to flow for several days. No springs were observed to issue from the valley walls in Johnson Hollow but substantial surface runoff from the ridge west and east of the Hollow fed the stream. The absence of springs is presumably a result of the base of the Beech Creek (top of Elwren shale) lying buried beneath the stream bed. The Beech Creek probably feeds the stream from below during high rainfall but carries the normal flow below ground. Flow in the stream bed of Johnson Hollow varied at different positions within the valley. A preliminary observation made during the dye tracer field work was that the flow significantly decreased in the stream bed just south of well WES 3-C25 and then resumed some distance downstream, indicating that the surface stream flow was captured by the Big Clifty sandstone, which is breached just below well WES 3-C25. Accumulation of runoff and raising of the Beech Creek water table downstream then recharged the stream bed to permit flow again.

33. Several observations concerning spring and stream hydrographs were made in the study area during the rains of the dye tracer test period. Most of the springs mapped in the area issue from one outlet during normal or low flow. After several hours of moderate rainfall, however, the spring sites issued from the valley walls from a number of outlets above and adjacent to the primary, or normal, outlet. Presumably, the main groundwater conduit fills to capacity and then overflows to secondary conduits through which discharge occurs through secondary, or flood overflow, springs. Springs A, A' and C in the valley of Little Sulphur Creek displayed several overflow springs during the rains but had returned to normal single-outlet flow within 24 hr after the rains stopped. These springs had a rapid response to rainfall: a sharply peaked hydrography with rapid recession. Spring B, however, had a delayed response to the rainfall with a moderate increase in discharge, and a delayed return to normal flow (i.e. it continued to flow in secondary overflow outlets for another day after the rains stopped). Apparently, Spring B is fed through a different conduit system (and/or percolation and seepage water), perhaps from the west and Johnson Hollow, than the system that feeds Springs A, A' and C. Another indication that Spring B is fed through a separate system is that Spring B was negative to very weakly positive for fluorescein dye during the same sampling period in which Springs A and A' were very strongly positive. The Springs B and A/A' are only about 1000 ft apart and are situated on the same side of the valley on the same ridge and at about the same elevation.

34. Other hydrologic factors considered during the design of the tracer test are discussed below.

PART III: USE OF TRACERS TO DEFINE GROUNDWATER FLOW

General Procedures

35. A tracer is any compound or material that can be introduced into a fluid and then detected in some way as it is transported through the system. Tracers can also be measurable natural properties of the fluid such as temperature, salinity, or volume of flow (discharge). Tracer tests can be qualitative; whereby, the presence of dye is monitored, or quantitative; whereby, the concentration and change in concentration with time are monitored. The general procedure for tracing groundwater flow routes is to inject a tracer into the aquifer or into the vadose (unsaturated) zone above the aquifer and then to place detectors at potential discharge points down-gradient from the source. Detectors are materials capable of adsorbing and concentrating tracers present in the groundwater. Alternatively, groundwater can be extracted through wells at selected points and analyzed directly for the presence of tracer materials. Quantitative tracer detection devices can also be installed at selected points to detect and measure quantity or concentration of tracer in the groundwater. Tracer tests have been conducted in both diffuse flow (Darcian or porous media flow) and in conduit flow (karst) aquifers. In well-developed karst terrains in which sinkholes and swallow holes (depressions in the ground surface through which surface water is captured by subsurface flow) the usual procedure is to inject the tracers directly into the point of capture. Because there were no surface expressions of karst in the ABG study area, it was necessary to introduce the tracers into the subsurface system through wells.

36. Presence of tracers in the flow system is measured or sampled at preselected time intervals determined by the estimated discharge velocity, distance of the sampling point from the source, and time required to measure or analyze the presence of the tracer. A continuous-sampling quantitative device can sample the flow at a much higher rate than detectors requiring collection, replacement, and lab analysis for each measurement. For both qualitative and quantitative tests, the sampling continues until sufficient positive indications of tracer presence are obtained or until a decision is made to halt the test because of negative results.

37. Procedures for conducting tracer tests in karst aquifers have been established from field trials by several investigators. They include Aley and Fletcher (1976), Atkinson and Smart (1981) and Quinlan (1986). Davis et al. (1985) reviewed the use of tracers for the National Water Well Association. Documentation of dye tracer techniques was compiled into a "manual" for the (USEPA), Region IV by Mull et al, (1988). The USEPA publication generally reiterates the procedures established by Quinlan and colleagues. A treatise on monitoring of groundwater in karst terrains was prepared for USEPA by Quinlan (1989).

Types of Tracers

38. Davis et al. (1985) reviewed groundwater tracers and described several types. Categories of tracers included:

a. Temperature. A pulse of water injected into the aquifer or stream is detected by change in temperature as it passes the detection point.

b. Biological. These include yeast, bacteria, spores, and viruses. Lycopodium spores have been used for many years and have the advantages of not being adsorbed by fine grained soils, pose no health threat, travel at approximately the velocity of the water, and are easily detectable under the microscope. Disadvantages of spores are the extensive preparation necessary for their use and a requirement for turbulence in the water to keep them moving, a situation not always present in poorly developed karst.

c. Ionic compounds. These include salts which yield free ions in water (Cl, NO3, CrO7, NH4, Br, Ca, K, e.g.). An electrical conductivity/resistivity meter is used to detect the passage of the ion-rich water. Ionic tracers are cheap, relatively safe and simply detected but must be injected in relatively large quantities. Their concentration must be well above background levels, which may be high in groundwater contamination areas.

d. Various water soluble compounds, including acids, ethyl alcohol, glycerol and sugars. Limited use.

e. Gases. These are dissolved gases such as inert gas (helium, radon, xenon, e.g.) and fluorocarbons. They require special equipment for deployment and detection.

f. Stable isotopes. Require expensive mass spectrometers for analysis.

g. Radioactive isotopes (radionuclides). Use generally prohibited in United States.

h. Dyes. Include both fluorescent and non-fluorescent dyes. Fluorescent dyes, especially fluorescein, pyranine, lissamine FF, rhodamines, and optical brighteners are the most commonly used.

39. Fluorescent dyes have certain advantages over other types of tracers. They are detectable by relatively simple qualitative means in extremely small concentrations (they do not have to be visible to the unaided eye to be detected). Most are nontoxic and can be approved for injection into streams and aquifers. Fluorescent dyes have proved to be effective tracers of karst groundwater systems in the field. Quinlan 1987, classified the commonly used fluorescent dyes by their recovery methods: (a) dyes recovered on cotton and (b) dyes recovered on charcoal. Dyes recovered on cotton include Tinopal 5BM and Phorwite (liquid optical brighteners) and Direct Yellow 96 (DY 96), a powder. Dyes recovered on charcoal include fluorescein and rhodamine. The procedures established by Quinlan and the materials recommended by him for conducting dye tracing tests were adopted for the initial NWSC tracer work because the field and laboratory analytical procedures are well documented, the qualitative sampling and analysis procedures can be performed relatively inexpensively with easily obtained equipment and supplies, and the methods have been successfully applied in geologic environments similar to those of the NWSC study area.

40. Fluorescence is a property of some compounds whereby energy from sunlight or from an ultraviolet (UV) lamp is absorbed by the compound and causes its atoms to be excited to a higher energy state. The atoms then relax to a lower energy state and release photons of energy which are detected as fluorescence. A long-wavelength UV lamp is used to artificially excite fluorescent dyes adsorbed onto detectors.

41. Three dyes were selected for the tracer test of the ABG study area: sodium fluorescein, DY 96, and Phorwite AR. Fluorescein is a generic name for a class of compounds. The type used in this test was sodium fluorescein, also called acid yellow 73, trade name 15174 Uranine concentrate. The powdered concentrate is dark red-brown but turns a distinctive kelly green in low aqueous solution. The DY 96 is labeled "Type: Stilbene" and is bright yellow in powder form and in solution. Phorwite AR solution is a liquid fluorescent whitening agent that is a dull yellow in concentrate and brilliant blue in

dilute solutions. The material safety data sheets supplied by the manufacturers are presented in Appendix C. The data sheets provide chemical, physical, and safety information on the dyes.

Methods of Analyzing Dye Tracers

42. Dye tracers can be detected or analyzed by qualitative or by quantitative means. Qualitative analysis looks for the presence of dye in the dye collector at any detectable concentration (a positive indication). A pseudo-quantitative analysis assesses the relative degree of positive indications of dye on the detectors, but is nevertheless a qualitative assessment. A pseudo-quantitative analysis was used for the ABG tracer tests. The optical brightener and DY 96, collected on cotton, were analyzed in a UV examination cabinet under long-wave UV light. The fluorescein was eluted from the charcoal with a saturated solution of potassium hydroxide dissolved in alcohol and analyzed under high-intensity (focused) visible light. Details of the analytical procedures are discussed later in this report (Part IV).

43. Quantitative analysis of tracer data can be made but requires the use of special measurement devices known as fluorometers. The filter fluorometer, or fluorimeter, provides a selection of narrow bandwidths of light to permit scanning for particular dyes. The fluorimeter also provides a quantitative of fluorescent intensity. The spectrophotofluorometer is a more sophisticated device capable of scanning a sample for an entire range of tracer chemicals, quantifying and producing hardcopy printouts of the results. Dedicated samplers left in place for extended time periods provide graphs of dye concentration versus time (breakthrough curves), permitting calculation of rate of flow from the source to the detection point. Fluorometers also permit the detection and recognition of multiple dyes simultaneously. The fluorimeter is a field instrument; the spectrophotofluorometer is a laboratory research grade instrument. Fluorometers are expensive devices (roughly $7500 for fluorimeter and $25,000 for spectrophotofluorometer). Quinlan (1986) states that in most cases adequate groundwater tracing can be done qualitatively. Consulting services are also available for running quantitative analysis of dye tracings obtained in the field (Aley, personal communication). Only qualitative tracer analysis was performed in the ABG tests.

PART IV: TEST PROCEDURES

Preliminary Site Assessment and Test Design

44. The geology and hydrology of the ABG study area had to be understood before a dye tracer test could be designed. The previous hydrogeological investigation and report by Hunt (1988) provided much of the required information. Hunt's work included field mapping of all known outlets of groundwater (springs and seeps) from the aquifers beneath the ABG on-post. Hunt mapped seven springs within the NWSC boundaries that were identified from outcrops as issuing from the base of the Beech Creek limestone near the top of the Elwren shale. No springs issuing from other than the Beech Creek aquifer were identified within the study area within the NWSC boundary. Plate 2 shows the locations of the springs, which Hunt labeled as springs A through F. Mountain (Mtn) Spring is an historically significant spring which supplied water to former residents of the area. Hunt also mapped several springs off-base in the valley of Sulphur Creek, some of which issued from the Beech Creek and others from the deeper Beaver Bend aquifers. He also located one spring off-post in the valley of Little Sulphur Creek just outside the NWSC boundary. The test reported in this document was limited to the confines of the NWSC. Springs A, B, C and Mountain Spring issue from distinct openings in the valley wall; springs D, E, and F might better be described as seeps because a distinct opening is not present. Mountain Spring and Spring C produce the greatest normal flows (estimated but not measured at several gallons per minute) of the seven springs. The seven springs were made dye sampling stations for the tracer test. Two additional sampling stations were established in Little Sulphur Creek. Little Sulphur Creek North station was in Little Sulphur Creek downstream of Spring C about 500 ft below the mouth of a tributary to the main channel of Little Sulphur Creek. The tributary originated at Spring C approximately 1000 ft north of the sampling site. Little Sulphur Creek South was in the main channel of Little Sulphur Creek approximately 40 ft upstream of the NWSC south boundary fence, and downstream of Springs A through C. The locations of all sampling sites are shown in Plate 2. Figure 17 is a map of the south sampling sites at a larger scale. Photographs of all of the sampling sites except Spring B are presented in Appendix D. Spring A' is also pictured in Figure 9.

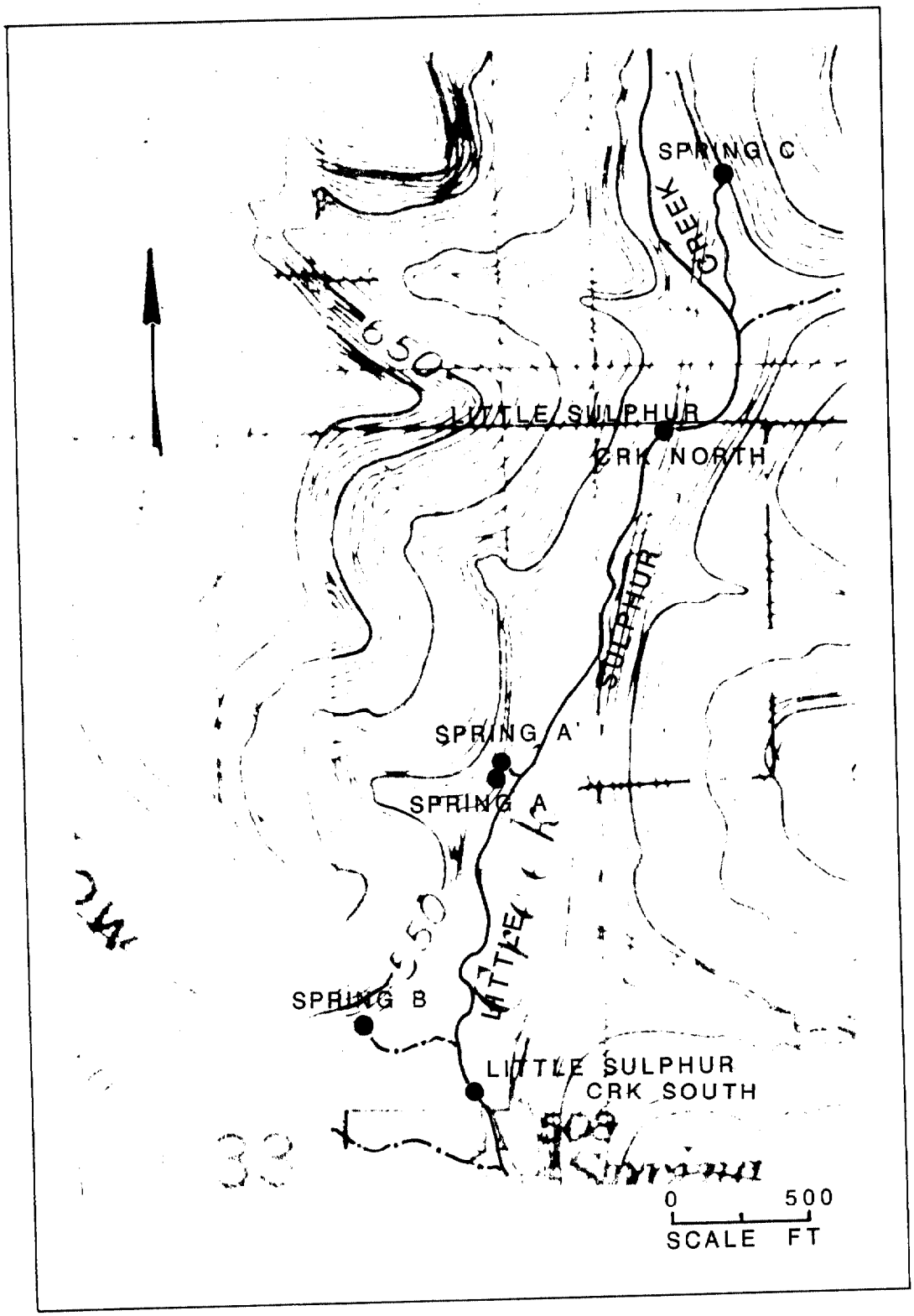


Figure 17. Dye trace sampling sites south of the ABG

45. Certain assumptions concerning groundwater flow characteristics of the study area were made prior to conducting the tracer test. It was assumed that a groundwater divide existed in the Beech Creek aquifer to the north of the ABG between the ABG and springs D, E, F, and Mountain Spring. Figure 18 is a geologic cross section running N-S from Mountain Spring through wells WES 3-C17 and -C32 to the ABG site. The dashed line in the Big Clifty/Beech Creek Formations represents the potentiometric surface of the Beech Creek aquifer. The assumed groundwater divide (the question mark) is beneath the high topographic ridge between Mountain Spring and well WES 3-C17. One purpose of the tracer test was to provide data that would confirm the existence of the divide or, conversely, establish that a hydraulic connection does exist between Mountain Spring and the ABG. For these reasons dye collectors were also set in the springs north of the ABG.

46. Hunt (1988) also observed the action of surface waters leaving the ABG and spring and stream discharges south of the ABG during two periods of heavy rainfall. The observations were made at springs C and A, where shortly following the rainfall the discharge had greatly increased above normal. The greater volume of water issuing from the springs had turned murky. In each case, by the next day after cessation of the rains, the springs had cleared up and returned to their normal flow (similar activity was observed during the tracer test period). Seasonal changes in rainfall also produced a gradual increase and decrease in the total volume of outflow from the springs. Hunt concluded that there was a rapid transfer of surface waters at the ABG site through the solution conduit groundwater system and thence to the springs, particularly springs C, A and B.

47. An assessment of dye injection methods had to be made prior to selection of the best method. Simulating a surface-source contamination of groundwater ideally would consist of "spilling" the modeling material (the dye) on the ground surface and letting it work its way down to the aquifer. The time required for the dye pulse to reach the water table, the dilution (dispersion) of the pulse during its percolation through the soil column, and the probable adsorption of much of the dye by soil and rock, make such an application impractical. It was known that the Big Clifty sandstone beneath the ABG was capable of capturing surface water (see paragraph 25, above) and that the infiltrating water eventually would be drawn into the Beech Creek

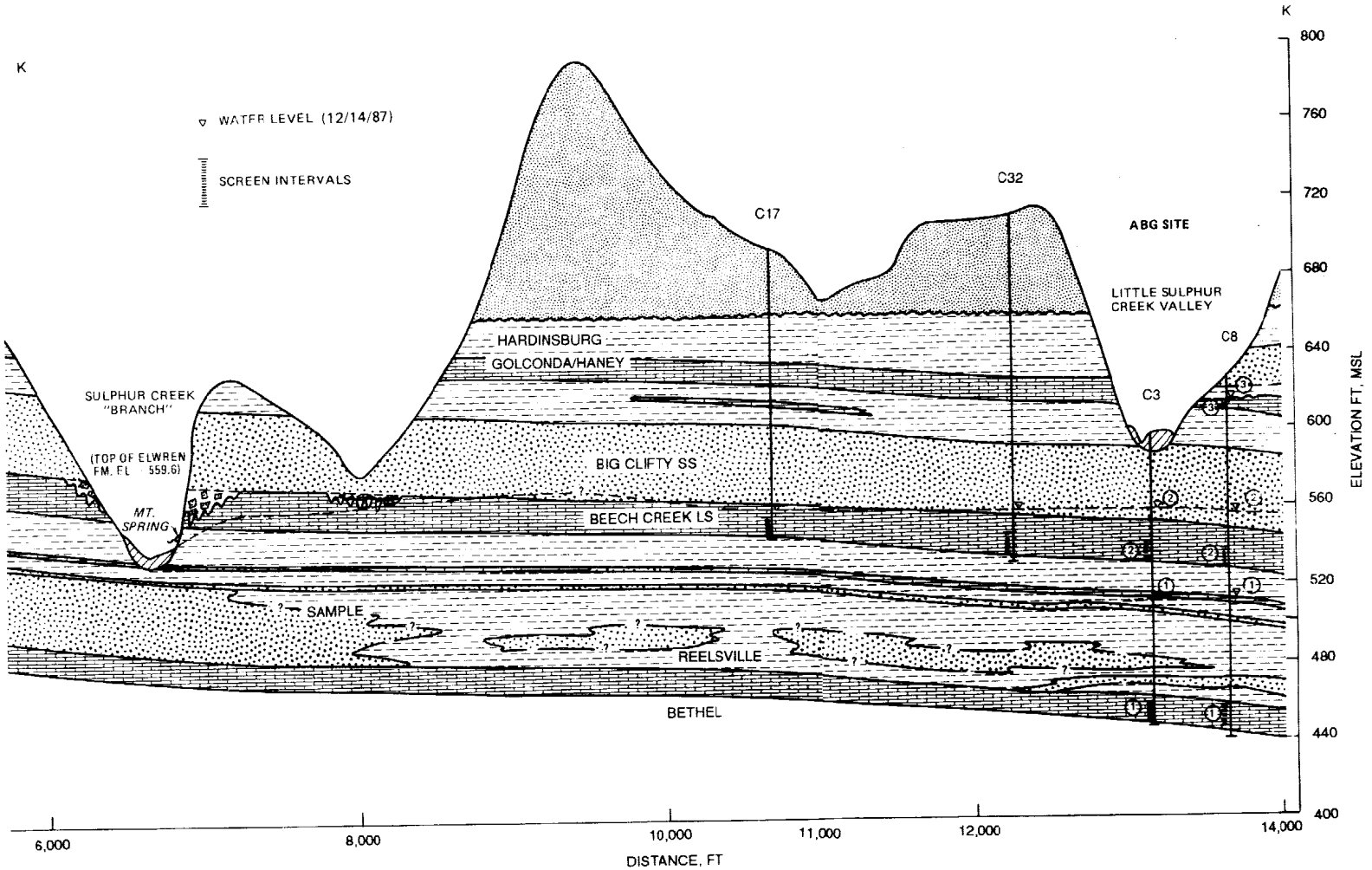


Figure 18. Geologic profile from ABG to Mountain Spring

aquifer by the steep hydraulic gradient imposed on the system by the conduits. The best source for injection of the dyes was therefore wells penetrating the Beech Creek aquifer directly beneath the ABG. Wells WES 3-C12 and WES 3-C2-P2 are suitably located with respect to potential contaminant infiltration. The core logs of the two wells identified well-developed solution cavities or conduits in the Beech Creek. Well WES 3-C3-P2 was favorably situated near the center of the ABG and, although there were no solution cavities present, solution-widened discontinuities were logged that permitted good access (rapid flow) into the aquifer.

48. The quantity of dye to be injected was estimated from consideration of the distance from the injection point to the most distant recovery point, which was approximately 1-1/2 miles. Injection quantity was also a factor of the type of dye being used. Quinlan (1986), suggested 1 lb per mile for fluorescein, 2 lb per mile for DY 96, and 1 gal per mile for Phorwite AR (optical brightener). Dye quantities chosen for this test were conservative to prevent visibly coloring the water of Little Sulphur Creek, which exits the arsenal boundary about 1-1/2 miles south of the ABG. Results of the test indicate that subsequent injections can be made at higher dye concentrations and still be below visible quantities.

49. Logistical considerations included timely access to the injection wells and sampling points, delivery of adequate volume of approved flush water to the injection wells, and potential problems in getting to the sampling points quickly in remote areas in bad weather and over unimproved roads and trails. Laboratory facilities on-site were required to analyze the daily collections of detector samples and to prepare the dyes for injection. Pretest preparations included purchase of and transport to the site of test supplies and materials, especially those difficult to obtain in the field. The tracer tests required injection into existing monitoring wells. Therefore, permission had to be obtained, in writing, from the UIC Section of Region V US EPA, Chicago, Illinois. US EPA also reviewed the entire dye trace proposal prior to granting permission to run the tests.

Preparation of Test Materials

50. Test materials were purchased, prepared, or fabricated at WES prior to the start of field work. Dye specifications, dye analysis methods and

equipment, and dye collector fabrication methods were obtained from the work by Quinlan (1986). Several national laboratories and supply companies were contacted by telephone to locate sources for purchasing the dyes. Dyes were obtained from three different companies. One 10-lb can of sodium fluorescein dye powder (CI Acid yellow 73, 75 percent solution was purchased from Chem Central, 13395 Huron River Drive, Romulus, Michigan 48174 ((313)941-4800). Ten pounds of Direct Yellow 96 dye (Diphenyl Brilliant Flavine) was purchased from Pylam Products Co. Inc., 1001 Stewart Avenue, Garden City, New York 11530 ((516)222-1750). Two cans (total 80 lb) of Phorwite AR solution, liquid, were purchased from Burlington Chemical Co., Inc., PO Box 111, Burlington, North Carolina 27216 ((919)584-0111.

51. Three 1-lb containers of activated carbon (coconut charcoal), 6 to 14 mesh, were obtained from Fisher Scientific, 900 Stewart Avenue, PO Box 4060, Plano, Texas 75074 ((214)578-0666). A Chromatoview Fluorescence Examination Cabinet, a Model UVL-21 longwave UV lamp (compatible with the examination cabinet), and vinyl powder-free work cleanroom gloves for handling the dye were obtained from Baxter Scientific Products, 155 Brookhollow, Harahan, Louisiana 70123 ((504)733-7571). A 2.5-kg container of Potassium Hydroxide (KOH) in flake form, required for eluting the fluorescein dye from the charcoal, was obtained from Thomas Scientific, 99 High Road, PO Box 99, Swedesboro, New Jersey 08085-0099. Other laboratory field items were obtained locally or from existing inventory. Other materials needed for the test were distilled water for rinsing and cleaning of equipment; pliers, wire cutters, and other tools for setting out and recovering dye collectors; wire for attaching collectors to the anchors, premixed concrete for anchor fabrication; chaining pins; and assorted laboratory equipment for analyzing the dye collectors and preparing the dyes for injection.

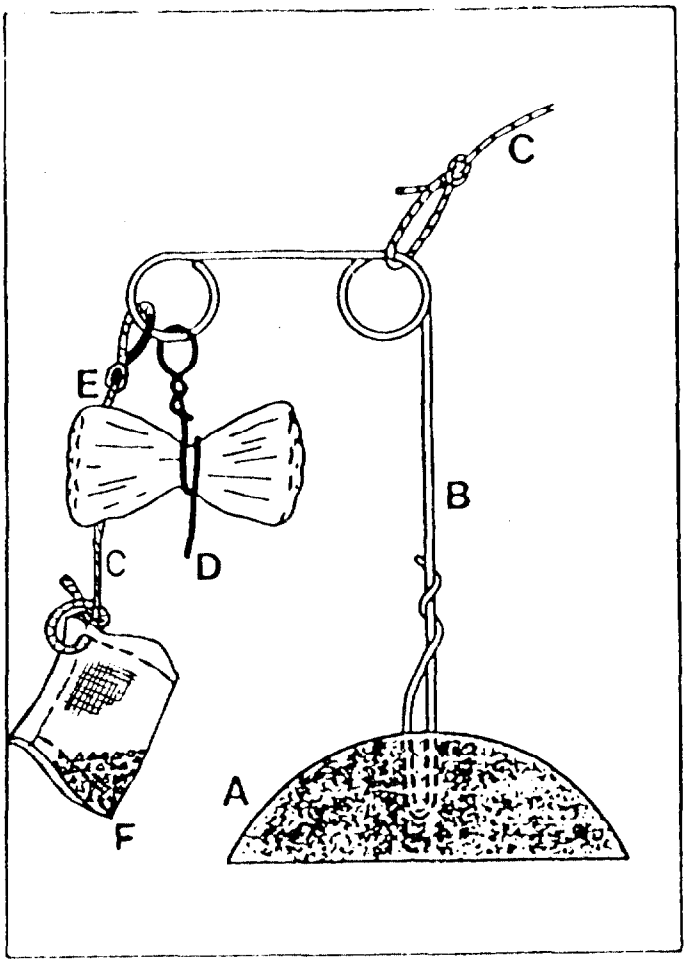
52. The dye collectors, or "bugs" were of two types, cotton and charcoal. The cotton bug is simply a piece of surgical cotton approximately 1-1/2 in. square. The cotton should be free of optical brighteners. Quinlan (1986) tested several brands and forms of cotton for suitability as dye collectors. He found that several brands were treated with optical brightener during manufacture and were unsuitable as detectors of optical brightener tracers. He recommended Johnson and Johnson Red Cross brand surgical cotton. Other suggested products were Swiss Beauty Pads and certain brands of feminine hygiene napkins. A 1-lb package of the Johnson and Johnson cotton was

purchased for the ABG tracer test and tested in the laboratory under UV light. The cotton generally showed no coloration except for an occasional tiny spot of blue, which was considered not to be a problem in recognizing the presence of optical brightener tracer, which would be expected to permeate and be distributed throughout the cotton sample. Indications of optical brightener tracers in samples collected during the test, however, were so faint that it is considered necessary to investigate other, "purer" sources of cotton for subsequent tests using optical brighteners as tracers.

53. The charcoal bugs each consisted of a tablespoon of activated coconut charcoal in a packet of aluminum screening approximately 2-1/2 in. square. The screening allows water to flow freely through the charcoal and effectively retains the charcoal. The empty packets were prepared in the office prior to field work by folding 6-in. square pieces of screen wire into small envelopes and stapling them shut, leaving one side open to receive the charcoal. The charcoal was not sealed in the packets until the field work commenced in order to preserve the freshness of the charcoal and to prevent potential contamination during transport. The final seal was by stapling.

54. Anchors to keep the bugs in place at the sampling point were of two kinds: concrete and wire "gumdrops" and steel chaining pins. The "gumdrop" was adopted from Quinlan's work. It consisted of an inverted bowl-shaped concrete weight approximately 5 in. in diameter supporting a galvanized steel wire to which was attached a nylon cord tie-down and a copper wire holding the cotton or charcoal bug. Figure 19 illustrates the gumdrop anchor. The tie-down cord secured the detector to a tree or other stable object near the stream or spring sampling point. The bowl shape of the gumdrop made it relatively stable when it was placed in moving water such as a stream. The chaining pins were obtained from a surveying supply-house. The pins were 3/16 in., 12-in. long, pointed steel pins each with a loop at one end. The cotton and charcoal bugs were attached to the loop with nylon cord. The pins were pushed into the stream or spring bottom where the bottom was soft enough and secured with cord to a nearby tree or other object. Both types of anchors were used during the tests.

55. Devices for sampling the water in selected wells south of the ABG were constructed. The samplers consisted of approximately 1-ft lengths of 1-1/2-in. PVC pipe open at one end and enclosed with aluminum wire screening on the other end. Cotton and charcoal bugs were placed in the samplers at



A Concrete weight
B Galvanized steel wire
C Tie-down cord
D Copper wire
E Cotton "bug"
F Charcoal packet

Figure 19. "Gumdrop" used to suspend dye detectors (bugs) above stream or spring beds, height about 12 in. (Quinlan 1987)

sampling time and water bailed from the well was poured through the pipe and over the bugs.

Pretest Laboratory Evaluation of Dyes

56. Laboratory tests were conducted at WES prior to commencement of field work to familiarize test personnel with the appearance of dilute dye and to practice the dye elution process. One gram of the fluorescein powder was first dissolved in 1000 ml of distilled water (approximately a 1 part per thousand (ppt) solution). The mixture was then diluted to solutions of approximately 1, 0.1, 0.01 and 0.002 parts per million (ppm). Both bare solution and solution adsorbed on charcoal were examined in small glass beakers under room light and under focused light. Five hundred mls of each solution was poured slowly over screened packets of activated coconut charcoal. The charcoal was then rinsed in distilled water and eluted. Elution was by a mixture of flake potassium hydroxide (KOH) dissolved in alcohol (the procedure for preparing the eluent is described in a later section). Similar dilute solutions were prepared for the DY 96 powder. The optical brightener (Phorwite AR) was in aqueous solution, concentration unknown. The liquid phorwite was observed undiluted and in dilutions of 10(-3), 10(-4), 10(-5), and 10(-6) of full strength by volume. The DY 96 was observed in bare solution and adsorbed on cotton. The cotton-adsorbed dyes were observed under UV light.

57. The Phorwite was observed adsorbed on cotton. Table 1 summarizes the laboratory observations. Fluorescein was detectable down to about 2 ppb (0.002 ppm) under focused light after elution from the charcoal. The DY 96 was distinctive only in concentrations of 0.1 ppm and higher after adsorption on cotton. Phorwite AR was distinctive on cotton (brilliant, blue-white fluorescence) in dilutions of 0.0001 times full strength but weak to very weak in greater dilutions.

Field Procedures

Preinjection preparations

58. Preparations prior to dye injection included monitoring of detection points for background, preparation of dye solutions, measurement of water levels in Beech Creek aquifer wells, placement of bugs in detection points,

coordination of ABG personnel, and arranging for a water truck. Background samples from all monitoring sites had been collected and analyzed in the spring of 1989. All samples tested negative for dye at that time. Background was tested again just prior to the test. Bugs were placed in Springs D, E, and F and Mountain Spring in the afternoon of 18 January 1990. Background bugs were placed in all other detection points in the morning of 19 January. All background bugs were collected in the afternoon of the 19th. Background samples were also collected from wells WES 3-B10, 3-C24, -C25, and -C37 by pouring bailed water over cotton and charcoal detectors placed in the PVC well samplers. The second background test yielded slight indications of blue and yellow fluorescence, and, after 48 hr, very weakly positive response for green color (not necessarily dye) in the water. Background indications were considered low enough to proceed with the test. Fresh bugs for the dye tracer test were placed at all detection points during collection of the background bugs. In all cases, bugs consisted of packets of charcoal and wads of cotton tied to the anchors with nylon cord.

59. Dye mixes were prepared in the WES trailer at Crane on the morning of 20 January (the day of the injection). The fluorescein solution was prepared in a plastic 1-gal water jug by mixing approximately 500 grams (a little over 1 lb Avoirdupois (Av)) of fluorescein powder and tap water to make 1 gal. The DY 96 solution consisted of 800 grams powder in 1 gal of water and 400 grams powder in 1 gal of water for a total weight of dye of roughly 2-1/2-lb Av. The fluorescein powder dissolved readily in the water with agitation. The DY powder was much harder to mix, presumably because too much of the powder was added at one time. Mixing of dyes for future tests should be done in smaller quantities or in larger containers and the mix then transferred to smaller containers for transport to the injection point. Phorwite AR was poured full strength from its container into two plastic water jugs.

Dye injection

60. One gallon of fluorescein solution was injected into well WES 3-C2-P2 at 1035 on the morning of 20 January by pouring the solution into the PVC casing using a dedicated plastic funnel. The hose from the water truck was immediately placed in the well casing and the tank's tap opened. Approximately 1,200 gal of water was added to the well by gravity feed in 60 min, or 20 gpm. The well accepted the water at full flow from the water tank without

overflowing. Flow into the aquifer probably was restricted only by the size of the slots on the well screen and not by the transmissivity of the aquifer.

61. Injection of well WES 3-C3-P2 began at 1225 hr. Two gallons of DY 96 mixture were poured into the well casing. The containers of mix had to be agitated several times to keep the dye in solution. Some undissolved clots of dye were injected into the well in spite of attempts to keep it in solution. It is likely that some of the DY 96 dye remained undissolved in the bottom of the well for several hours and perhaps days after the injection, and that the full 2-1/2 lb did not disperse into the aquifer. The injection was followed immediately by about 500 gal of water from the tank truck. The gravity flow from the tank had to be reduced to about 7 gpm to prevent overflowing the casing, an indication of the relatively lower transmissivity of the Beech Creek aquifer at the position of well WES 3-C3-P2 compared to that of well 3 C2-P2. Two gallons of Phorwite AR was then added to the well at 1345 hr and flushed with another 700 gal of water. Flushing ceased at about 1530 hr.

62. The weather on the day of injection was light to moderate rain with a temperature of about 45° F. There was a steady rain from the morning of the 19th to the middle of the afternoon on the 20th. The springs and Little Sulphur Creek south of the ABG were observed during the dye injection. The creek was flowing just below bank full and the springs' flow had increased substantially over the previous day's flow in response to the rain. The rainfall was considered beneficial to the test by helping to flush the dyes through the aquifer and by providing a high hydrography stage for flow assessment.

63. Water levels in the Beech Creek aquifer were measured on 28-29 December 1989. Table 2 presents measured water levels for Beech Creek wells in the ABG area for three periods. Beech Creek levels change little (less than 1 ft) throughout the year but probably respond dramatically and recover quickly following heavy or prolonged rains. There was not time to measure the water levels during the period of rain on the 19th and 20th of January. The water levels for 28-29 December 1989 (Table 2) are accepted as representative of the aquifer just prior to the rains that occurred during the tracer test. Subsequent tests should incorporate means of spot checking the aquifer level in the study area in selected wells during the test period. The general trend of the Beech Creek piezometric surface is shown by the groundwater contour map of Figure 15.

Data collection

64. Field data including locations and times and dates of detector placement and retrieval were recorded on "Bug Placement Data Sheets." Dye injection data were recorded on "Dye Injection Data Sheets." Data from laboratory analysis of bugs collected for the tracer test area were recorded on "Tracer Analysis Data Sheets". Copies of the original sheets are presented in Appendix E. Bugs were numbered consecutively from 1-84 with a suffix "A" (cotton) or "B" (charcoal) attached. The same numbering system was retained for the laboratory analysis for consistency.

65. A cotton and a charcoal bug were placed at each detection point following the procedure described in paragraphs 52-54. Detection points south of the ABG site received a daily bug and a "long-term" bug. Detection points north of the ABG received only long-term bugs. The long-term bugs were left in place for 7 days and collected on the last day of field work. Their purpose was to permit an accumulation of dye over an extended time for detection points suspected of receiving only small concentrations of dye. Daily bugs were collected, replaced, and analyzed daily.

66. Bugs were placed in the spring or stream to be completely submerged and were secured to the anchor with nylon cord. A pair of neoprene gloves was dedicated to each sampling site to prevent cross-contamination of sites. The bugs were placed in the main stream of moving water and as close to the mouth of a spring as possible. Bugs were collected by approaching the position from downstream to avoid potential contamination of the position by dyes adhering to boots and clothing. The bugs were removed from the anchors, rinsed and squeezed dry (cotton bugs), and sealed in plastic "Zip-loc" sandwich bags. The bags were labeled with indelible markers and placed in a cooler for safekeeping. Fresh bugs were then attached to the anchors. The bug placement, anchoring, and collection procedures worked satisfactorily for this tracer test.

67. The method used to sample selected wells was unsatisfactory. Problems encountered and suggested improvements are discussed below in Part V (para 96).

Laboratory Procedures

General procedures

68. Each day's collection of bugs was returned to the field laboratory immediately following collection. Precautions were taken to minimize potential contamination of collected samples. Disposable latex "surgeon's" gloves were used to handle the bugs for examination. Gloves were discarded after the examination of each sample. Beakers used to elute the charcoal bugs were rinsed thoroughly after each use and examined under UV light for signs of contamination before reuse. Examination of bugs for dyes was done either on the afternoon of the collection day or on the morning of the next day before new bugs were collected. A complete discussion of the Quality Assurance/ Quality Control (QA/QC) procedures is presented in a later section.

Examination of cotton and charcoal packets

69. Cotton bugs were removed from the collection bags in the laboratory and halved. One half was placed in a glass jar for safekeeping (duplication). The other half was examined in the examination box under UV light. Telltale indications of dye were yellow glow for presence of DY 96 and a blue glow for Phorwite AR. A faint yellow glow was present in all of the background samples tested. Occasional specks of bright blue, usually about a millimeter in diameter and isolated, were observed in background samples and in the fresh dry cotton (straight from the box). The blue specks were presumed to be isolated hits of optical brightener from the cotton processing and were considered acceptable for test purposes. The yellow glow is possibly a result of background levels of yellow fluorescence in the groundwater, source unknown. Examination of postinjection cotton bugs produced some positive results in blue fluorescence, as discussed below in Part IV. The background presence of yellow fluorescence, however, prevented confident determination of the presence of DY 96.

70. Examination of the charcoal packets required elution of adsorbed dye from the charcoal. The screen-wire packet for a sample was cut open and the charcoal halved, one half placed in a canning jar for safekeeping. The other half of the charcoal was placed in a small beaker for eluting. The eluent was prepared by dissolving about 10 grams of flake potassium hydroxide (KOH) in 100 ml of 70 percent isopropyl alcohol. The mixture separated into a supersaturated and a lighter saturated solution. The saturated solution was

poured over the charcoal to cover it about 1/4 in. deep. The beaker and its contents were examined under room light and, if necessary, by shining an intense, focused beam of light from a microscope lamp through the beaker. The eluting charcoal was allowed to stand until a positive indication or no indication of dye was obtained. Stand time for the eluting charcoal was as little as a few seconds to several hours to obtain positive indication. For positive indications, a qualitative assessment of the intensity of the dye presence was made.

71. A classification scheme developed by Aley and Fletcher (1976) for fluorescein dye indications was followed in general during the laboratory analysis. The classification scheme is shown in Figure 20. The classifications range from "very strongly positive" to "very weakly positive" to "negative" (no indication of dye presence after standing several hours). It was noted during the analysis of the charcoal bugs for this test that a finer resolution of "positiveness" could be implemented. For example, some of the samples reacted very strongly to elution with an intense green cloud of dye forming immediately upon addition of the eluent to the charcoal. A distinction could easily be made between such a reaction and the "very strongly positive" classification (Figure 20), which requires up to 15 min to obtain a positive indication. Subsequent tracer tests should consider using a finer subdivision of positive indications. The authors found it necessary to add qualifying phrases to the descriptive terms of Figure 20 to describe the analytical results sufficiently.

Quality Assurance/Quality Control Procedures

72. A rigorous Quality Assurance/Quality Control (QA/QC) program was implemented to ensure that an adequate amount of quality data was collected throughout the dye trace test of the Beech Creek aquifer. The QA was a planned system of activities whose purpose was to provide assurance of reliability and defensibility of the data. The QC was a routine application of procedures for controlling the monitoring process. The QC was the responsibility of those performing the hands-on operations in the field and in the laboratory. The following is a description of the dye trace test's QA/QC procedures.

1. Very strongly positive (VSP): Dye can be seen distinctly with the naked eye in sunlight or in an artificially lighted room within 15 minutes of the time that KOH and alcohol are added to the charcoal.

2. Strongly positive (SP): Same as above, but after 15 minutes and before 3 hours.

3. Moderately positive (MP): Dye can be seen with the naked eye in sunlight or in an artificially lighted room, but not until 3 to 24 hours after adding KOH and alcohol. The dye is indistinct, and the observer feels it is necessary to verify the results by beaming a light into the sample jar.

4. Weakly positive (WP): Dye cannot be detected by the naked eye in sunlight or in an artificially lighted room until more than 24 hours after adding KOH and alcohol. Dye can be distinctly seen by the naked eye when a light is beamed through the sample jar.

5. Very weakly positive (VWP): The appearance of the dye is similar to weakly positive tests, but the dye cannot be seen until more than one but less than 10 days after adding KOH and alcohol. The dye can be distinctly seen by the naked eye when a light is beamed through the sample jar.

After Aley, T. and M.W. Fletcher, 1976. The Water Tracer's Cookbook. Missouri Speleology, Vol 16, no. 3, p 16.

Figure 20. Classification of fluorescein dye indications

Sampling procedures

73. The three dyes used in this investigation (Fluorescein, DY96, and Phorwite AR) were capable of adhering to skin, clothing, and sampling equipment. In order to prevent cross-contamination of the dyes, or any other contamination which may have been present at the springs and wells, utmost care was exercised. The dyes were prepared and handled only during the day of injection (see Analytical Procedures, below). All detectors were prefabricated in a dedicated portion of the field laboratory away from the dye storage area.

74. Pairs of long sleeve rubber gloves were dedicated to each of the fourteen sampling sites. The gloves were stored in labelled, dedicated zip-lock bags. The gloves remained in their storage bags until arrival at each sampling site. Sample collection and replacement was performed by only one of the investigators at each site to reduce cross contamination. The second investigator was responsible for logging in the chain-of-custody forms and maintaining the field notebook. At the springs, the bugs were removed from the field apparatus and immediately placed in prelabelled dedicated plastic zip-lock bags. The gloves were then returned to their respective storage bag. Samples were preserved in a chilled cooler to await laboratory analysis. The field QC implemented at the sampling sites in Little Sulphur Creek were the same as those described above for the springs. Care was taken not to walk upstream of the detectors in case dyes may have been adsorbed onto the field rubber boots. This action prevented washing of potentially adsorbed dye into the vicinity of the detectors.

75. Additional procedures were included for the collection of representative groundwater samples from the monitoring wells. A review of historical groundwater data from the monitoring wells (03B10, 03C37, 03C24, 03C25) revealed no significant levels of contamination. Nonetheless, extreme care was taken to prevent cross contamination of the sampling equipment. Prior to each use, the bailer was decontaminated with a distilled water rinse. The dedicated 1-ft lengths of 1-1/2-in. PVC pipe, which housed the bugs, were also rinsed with distilled water. Dedicated lengths of nylon rope were used to lower the bailer into the well and were replaced every other day. The wells were bailed until the groundwater was sediment free. (Table 3 summarizes the bailing activities.) The final bailer was then poured slowly into the

1-1/2-in. PVC pipe to maximize the contact time between the groundwater and bug (i.e. more time for the dye to adsorb onto the detector). As with the springs, the detectors were then placed in dedicated sample bags and the gloves were returned to their dedicated plastic bags.

76. Field log books recorded pertinent information during the dye trace test. Information in the field books was sufficient to reconstruct field tasks without reliance on the authors memory. The field books were standard engineering, water resistant books.

77. The field personnel wore Level D protective clothing. Gloves were added to the Level D clothing when the detectors were collected.

Analytical procedures

78. The QA plan ensured that quality data was generated from the analysis of the dye detectors. The Principal Investigator was trained in conducting dye tracer tests through a short course presented by James F. Quinlan, National Park Service, Ralph O. Ewers, Eastern Kentucky University, and Thomas J. Aley, Ozark Underground Laboratory through the National Water Well Association. The investigators performed laboratory tests to familiarize themselves with characteristics of particular dyes and also to recognize weakly positive concentrations of dyes.

79. The dyes were handled only during the day of the dye injection, 20 January 1990. The dye solutions were premixed in an isolated section of the field laboratory. The premixed dye solutions were stored in plastic jugs and transported to the injection site in a sturdy box. The unused factory dyes remained in storage in a separate room from the detectors and sampling equipment and subsequently were returned to the WES for possible future use. The detectors were returned daily to the laboratory in a chilled cooler. The zip-lock plastic bags were not reused after the sample was removed for analysis.

80. As stated in paragraph 70, fluorescein must be eluted from the coconut charcoal detector in an alcohol solution and inspected visually for a yellow-green color. Preparation of the fluorescein eluent was described earlier. The eluent was prepared daily due to the limited shelf life of the KOH solution (per Quinlan 1987).

81. Prior to the first lab analysis, a matrix spike sample was prepared to check the precision of the eluting method for fluorescein. An aliquot (1 tsp) of coconut charcoal was spiked with approximately 3 ppm of

fluorescein. (The 3-ppm solution of fluorescein was prepared by dissolving approximately 3 grams of fluorescein in 1ℓ of tap water and then diluting to 3 ppm). The charcoal was rinsed with tap water and split into two beakers. The eluent was poured into one beaker and tap water into the other. The beaker eluted with KOH had a strong kelly green eluate under normal (low intensity) light; the beaker filled with tap water showed no signs of elution and remained clear. A second matrix spike was also prepared to measure the KOH efficiency for very low concentrations of fluorescein (e.g. 0.003 ppm). Under identical procedures, no kelly green elution was observed in the KOH beaker. But with the aid of a high intensity light the charcoal eluted kelly green. The beaker with tap water was negative. The investigators were convinced that given the presence of fluorescein in coconut charcoal the saturated KOH being prepared was capable of eluting the fluorescein for detection under either normal or high intensity lighting.

82. The detectors (bugs) were handled with vinyl powder-free gloves which were disposed of after each sample analysis. The scissors used to cut the cotton detectors were decontaminated with a distilled water rinse. The cotton was placed with tweezers inside a UV light box. The beakers used for fluorescein detection had to be reused throughout the lab analysis. The beakers were flushed thoroughly with tap water and rinsed with distilled water. A little KOH eluent was then introduced into the beaker to check for residual fluorescein contamination. These procedures assured the investigators the beakers were free from dye contamination before the charcoal sample was introduced. At no time throughout the lab analysis did a beaker rinsate show evidence of contamination.

83. The fraction of the collected samples which did not undergo lab analysis were transported under chilled preservation to the WES, where they remain in storage.

PART V: Analysis of Dye Trace Results

Summary of Results

84. Three dyes were injected into two Ammunition Burning Ground wells in the Beech Creek aquifer. Dye detectors (bugs) were placed in ten sampling locations south and north of the ABG. Sampling locations were checked for the presence of dyes before and after injection of the dyes. All of the dye detection sites south of the ABG were weakly to moderately positive for the presence of fluorescein (green) dye within a few hours after injection, but bugs analyzed subsequently (daily) were strongly positive for fluorescein only in Springs A and A', two closely spaced sampling points. Spring B, located about 1,000 ft south of Spring A and on the same side of the valley of Little Sulphur Creek, was only weakly positive for fluorescein several days after injection. Spring C and a tributary to Little Sulphur Creek fed by Spring C, located closer to the ABG north of Spring A but on the opposite side of the valley, were negative or only weakly positive for the period of bug collection and analysis. All of the sampled wells were negative, but results for the wells are considered inconclusive because of the method used to sample the wells. Phorwite AR (optical brightener) and DY 96 results were generally inconclusive; that is, the presence of those dyes on the collectors was difficult to distinguish from the weak background fluorescence. Positive indications of Phorwite (blue fluorescence) were obtained in some instances, but assessments were very subjective.

85. Bugs placed in sampling sites north of the ABG (Mtn Spring and Springs D, E, and F) were left in place for approximately 1 week after injection and then analyzed. All but Spring D were weakly positive for fluorescein in normal light after elution for 24 hr. The positive indication was above the very weak background level of green color observed in the background samples. Subsequent tracer test(s) should inject a greater quantity of fluorescein and collect charcoal bugs daily from the sampling springs north of the ABG to verify the existence of a groundwater path from the ABG to the north.

86. There was no immediate indication of the presence of fluorescein dye (or any green color) in the background samples. However, after standing for over 72 hr, the eluted background samples tested very weakly positive for a light green coloration under focused light (microscope lamp) in a darkened

room. It could not be determined whether the very weak coloration was caused by a weak solution of fluorescein or by another agent such as green algae. The presence of the very weak green color in background samples from the Beech Creek aquifer will impede analysis of late-arriving, dilute solutions of true fluorescein dye tracer in this and subsequent tests.

87. Table 3 presents data on when and where bugs were placed and collected. Table 4 presents the results of laboratory analyses of all of the bugs collected for the tracer test (very strongly positive and strongly positive dye indications are emphasized in bold print). An explanation of the abbreviations used is provided at the end of the table. Sampling sites are identified by name or well number. Sites labeled Little S(ulphur) Cr(ee)k North and South are the sites originally identified in the field notes (Appendix C) as "2nd Green Bridge" and "SE Boundary Gate", respectively.

88. Table 5 summarizes the responses of the sampling sites for which a positive response was obtained (excluding the sites north of the ABG, for which only one, long-term sample was collected). Responses are presented by sampling site and by the date of collection of the sample. Table 5 provides a visualization of the arrival times at each site of the slug, or pulse, of dye that was injected at the ABG on 20 January. The immediate (first-day) weak positive response to fluorescein of all sampling points south of the ABG is interpreted to have been a result of a high hydrography from the rains and excess initial head imposed by the flushing water used to chase the dye injection. The dye pulse presumably was forced to overflow the main conduit system near the injection well briefly by the impulse of the rapidly introduced, 1,200 gal of water from the tank truck. Part of the dye pulse may have entered secondary (overflow) groundwater passages through which it could access the other sampling sites. When the initial impulse deteriorated, the dye pulse drained from the overflow system and traversed the main conduit system under normal gradient.

Results by Sampling Area

Springs A, A′ and Little Sulphur Creek South.

89. Springs A and A′ are approximately 50 ft apart and are prominent springs in an area of many seeps. Hunt originally designated only Spring A as the major spring but Spring A′ had sufficient flow to warrant using it as a

sampling site for the tracer test. Spring A′ also served as a "duplicate" or check on dye-trace results for Spring A. Springs A and A′ produced the highest degree of positive fluorescein dye indications (Very Strongly Positive, or VSP) of all sites sampled (see Tables 3 and 5). Figure 21 is a photo of the eluates for the 21 Jan (second collection period) charcoal analysis. The photo quality is poor but the distinct Kelly green of the strongly positive responses in Springs A/A′ and Little Sulphur Creek South, and the lack of a response in the other samples, are apparent. The sampling site in Little Sulphur Creek South is approximately 1,100 ft due south of Springs A and A′ and receives water entering Little Sulphur Creek from the springs as well as water from upstream. Site Little Sulphur Creek South also produced VSP dye indications. These sites registered only weakly positive to moderately positive on the first day of bug collection, similar to other sites south of the ABG. By the second day's collection, however, all three sites produced unmistakable very strong reactions upon elution, indicating that the dye pulse had traversed the distance from the injection point to Springs A and A′ and then via surface runoff to the Little Sulphur Creek South site.

90. A very rough approximation of seepage velocity through the Beech Creek can be made from the test data. Dye was injected at 1035 on 20 January. The first set of bugs was collected at Springs A and A′ at 1545 on the same day (approximately 5 hours postinjection). The second set of bugs was collected from the springs at 1410 of 21 January (approximately 28 hours postinjection). Travel time for the main dye pulse from the ABG to Springs A and A′ is therefore between 5 and 28 hr. Straight-line distance from well WES 3-C2-P2 (the fluorescein injection well) to the springs area is approximately 6,200 ft. However, if the subsurface conduit passages in the Beech Creek are presumed to have a sinuosity similar to the valley of Little Sulphur Creek, the distance from the well to the springs can be estimated at 8,000 ft. If the mean travel time (16 hr) and sinuous travel distance (8,000 ft) are used for calculation, the seepage velocity is roughly 500 ft/hr, or 12,000 ft/day. The Beech Creek water level in well WES 3-C2-P2 was 36 ft higher than the water level in spring A before the test. Assuming 100 per cent porosity and a hydraulic gradient of (36/8000 =) 0.0045, the equivalent "hydraulic conductivity" (k) for such a flow medium would be on the order of $2.7 \times 10(6)$ ft/day (k= 12,000/0.0045), which is several orders of magnitude greater than the highest conductivities reported for granular (Darcian) media

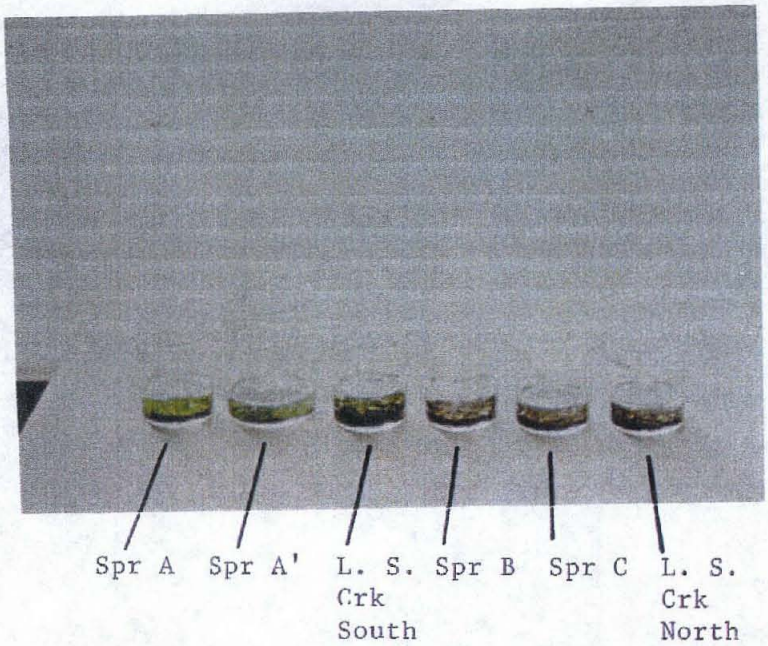


Figure 21. Eluates (elution products) from charcoal for sampling sites south of the ABG for 21 Jan collection

(see Figure 22). While these figures are rough approximations, they indicate that flow in the Beech Creek aquifer in the vicinity of the ABG is characteristic of conduit flow.

91. Table 5 shows that the dye pulse traversing the Springs A and A' area and thence to Little Sulphur Creek South remained very strongly positive for 4 days before weakening somewhat on the last day of the test (25 Jan). The 21 January analysis for these sites was the strongest positive indication obtained for the tracer test (Table 4). A conclusion is that the dye pulse dispersed through the conduit system from the vicinity of the injection well with the pulse front arriving at the Spring A, A' area in 5 - 28 hr. The dispersal of the dye in the groundwater of the conduit system was sufficient to maintain a relatively high concentration of dye passing through the springs for at least 5 days. Dispersal of the dye pulse within the flow system might be caused by soil partially filling the passages or by tortuous conduit channels which would cause turbulence in the groundwater stream.

92. A similar dispersed pulse through Springs A, A', Little Sulphur Creek South and also the other sites south of the ABG was noted for the tracer Phorwite AR (Table 5).

Spring C and Little Sulphur Creek North

93. Spring C issues from the eastern side of the valley wall and produces a small stream which feeds Little Sulphur Creek. Dye detectors were placed in Spring C and in Little Sulphur Creek about 1,000 ft south of the spring. Prior to the tracer test, it was assumed that Spring C would produce the earliest and most pronounced positive response to dye injected at the ABG because of its proximity to the injection site. The actual response, however, was only weakly to very weakly positive (Tables 4, 5). The Little Sulphur Creek North sampling site, which receives flow from Spring C, was correspondingly weakly responsive. The interpretation of the responses in these sites is that groundwater in the Beech Creek at the ABG is drawn south into the valley of Little Sulphur Creek through well-developed conduits at a rate sufficient to prevent feeding of springs on the east bank. The Spring C area possibly drains and receives recharge from Beech Creek of the eastern valley wall with only a small input received from the western and northwestern side, and then only perhaps at a high hydrography resulting from substantial rainfall.

Hydraulic conductivity, meters/day									
10^4	10^3	10^2	10^1	1	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}
Relative hydraulic conductivity									
Very high		High		Moderate			Low		Very low
REPRESENTATIVE MATERIALS									
Unconsolidated deposits									
Clean gravel	–	Clean sand and sand and gravel	–	Fine sand	–	Silt, clay, and mixtures of sand, silt, and clay		–	Massive clay
Consolidated Rocks									
Vesicular and scoriaceous basalt and cavernous limestone and dolomite		–	Clean sandstone and fractured igneous and metamorphic rocks		–	Laminated sandstone, shale, mudstone		–	Massive igneous and metamorphic rocks

Figure 22. Hydraulic conductivities for various classes of geologic materials (Todd 1980)

Spring B

94. Spring B was expected to produce results similar to those of the Springs A, A′ area because of its proximity to them. Spring B's response to fluorescein, however, was only very weakly to weakly positive and was delayed 2 days relative to the response in Springs A and A′ (Tables 4 and 5). After the initial first day's weak response common to all sampling sites, Spring B was negative for fluorescein until the fourth day of sampling, and then was only weakly positive. Its response to Phorwite AR was, subjectively, somewhat stronger (more positive) than the response in springs A and A′ (see the "distinctly positive" response recorded in Table 5 for Phorwite AR). Spring B's unique responses to the two dyes implies that it is fed by ground waters from a subsurface flow system separate from that feeding Springs A and A′. The hydrographic response of Spring B during the rains early in the test period is further evidence of its separation from the system of Springs A,A′, as discussed earlier in paragraph 27 (under Hydrology of the ABG). Subsequent tracer tests should be designed to resolve the question of source of waters feeding the Spring B outlet, perhaps by more efficient sampling of wells in Johnson Hollow, by more careful observation of the surface flow in Johnson Hollow, and by timely measurement of water levels in the Beech Creek wells south of the ABG.

Springs north of the ABG

95. Mountain Springs and the other springs north of the ABG were sampled only once in addition to the background samples. Three of the four sampling sites were only very weakly to weakly positive for fluorescein after 24-hr elution of the charcoal bugs that had been left in place for 6 days (see last page of Table 4). All were negative for the other dyes. The weak response indicates there may be some hydraulic connection in the Beech Creek aquifer between the ABG and the Mountain Springs area. Subsequent tracer testing should resample these stations daily to clarify the inconclusive results of the first test.

Monitoring wells

96. The method used to sample the wells for dye in the tracer test; whereby, water bailed from a well was poured over a cotton swab and a charcoal packet contained in a short section of PVC pipe was considered at the end of the field work to have been unsatisfactory. Field personnel were not confident that sufficient water nor sufficient contact time was available with this

procedure to permit dye accumulation in the bugs. No positive indications of dye were recorded for the well samplers. A better method must be devised to sample wells for dye presence during subsequent dye tracer tests. An improved method now under consideration consists of suspending the bugs in a mesh container from the inside surface of the well casing cap. The mesh container would hang submerged beneath the water surface in the well and be continuously exposed to water flowing through the aquifer and into the well, increasing the probability of accumulating detectable concentrations of dye. The mesh container must be constructed of stainless steel or Teflon to safeguard monitoring well quality.

PART VI: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

97. Hydraulic connection between the Beech Creek aquifer at the Ammunition Burning Ground and springs in Little Sulphur Creek was confirmed by the dye trace. Fluorescein dye was an effective tracer of groundwater flow at the ABG. Springs A/A' and subsequently Little Sulphur Creek were prime outlets for the aquifer at the ABG (see Plate 2). Spring B and C are likely outlets only at high flow conditions. Contamination at the ABG could have a ubiquitous dispersion south of the ABG at high flow.

98. The dyes were injected at the conclusion of a 24 hr, 2-in. rainfall. The springs and streams had nearly two times the mean flow during injection. The water levels in the springs and streams receded to mean flow quickly (within 24 hr), except for Spring B, which flowed at an above-normal rate for 2 days after the rain ceased. Lab detection of preinjection (background) spring and creek samples revealed trace levels of dye-like colors. Postinjection samples north of the ABG remained at background levels. Dye presence was ubiquitous south of the ABG within 5 hr after injection. Only Springs A/A' and Little Sulphur Creek at the boundary gate remained positive throughout the test. The monitoring wells showed only background levels, but sampling methods used for the wells were suspect.

99. Heavy rainfalls at the ABG will rapidly discharge off-base via south springs and subsequently Little Sulphur Creek. The scope of the test did not include off-base sites. Therefore, potential flow from the ABG to outlet springs in Big Sulphur Creek off-post cannot be assessed from present data.

100. Results of analysis of samples collected north of the ABG were generally inconclusive.

Recommendations

101. Another dye tracer test should be conducted in the ABG aquifer to characterize groundwater flow. Detection sites should be increased to include off-post springs in the Little and Big Sulphur Creek valleys. Selected

off-post springs should be considered for quarterly groundwater quality monitoring.

102. Dyes should be injected in greater quantities during subsequent tracer tests to increase the probability of detection at distant sampling points.

103. An improved method of sampling monitoring wells for dyes should be developed before running subsequent tracer tests at the ABG.

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Table 1

Laboratory Observations of Dye Solutions

Dye Solution	Observations	
Fluorescein Solution	Bare	Eluted
1 ppm	Easily visible in room light	Faint in room light, v. strong in focused light
0.1	Faintly vis, room lt	Not visible in room light, faint but pos. in focused light.
0.01	V. positive in focused light, not visible w/ naked eye	Weakly positive after standing for four hours.
0.002	Positive in dark room in focused light, not visible w/ naked eye	Same as 0.01 ppm.
DY 96 Solution	Bare	On Cotton
1 ppm	Positive	Positive
0.1	Positive	Weakly positive
0.01	Negative	Negative
0.001	Negative	Negative
Phorwite AR Solution	Bare	On Cotton
100% × 10(-3)		V. positive, strong blue-white fluorescence
100% × 10(-4)		V. positive, strong blue-white fluorescence
100% × 10(-5)		Weak
100% × 10(-6)		Weak if at all

(100% = full strength from container)

Table 2

Water Levels in Beech Creek Wells, Ammunition Burning Ground

(elevation in ft NGVD)*

Well Number	Date Measured 10/12/87	12/14/87	12/28-29/89
03C1P2	557.06	557.23	557.11
03C2P2	545.79	546.33	546.12
03C3P2	558.49	558.59	558.45
03C4	548.36	548.60	548.45
03C5	547.09	547.26	NOT CHECKED
03C6	546.71	546.92	546.95
03C7	557.96	557.92	557.92
03C8P2	555.26	555.62	555.26
03C9P2	558.47	558.84	558.84
03C10	558.16	558.33	558.14
03C11	548.28	548.58	548.21
03C12	545.69	546.04	545.60
03C13	559.31	558.65	558.40
03C14	557.91	558.13	558.10
03C15	556.50	556.81	556.71
03C16	558.13	558.50	558.12
03C17	558.03	558.57	557.40
03C19	558.42	558.57	558.20
03C20	557.59	557.92	557.70
03C21	557.40	557.74	557.65
03C24	531.55	532.15	531.70
03C25	550.47	551.17	550.71
03C26	558.25	558.56	NOT CHECKED
03C27	543.39	543.50	543.67
03C28	537.05	537.81	537.08
03C29	564.00	564.70	563.47
03C30	563.98	564.82	563.92
03C31	NO WELL	563.41	562.52
03C32	NO WELL	558.19	557.83
03C33	NO WELL	559.23	NOT CHECKED
03C34	NO WELL	NO WELL	556.22
03C35	NO WELL	NO WELL	521.20
03C36	NO WELL	NO WELL	538.60
03C37	NO WELL	NO WELL	518.70
03C38	NO WELL	NO WELL	524.20
03B10	NO WELL	512.45	512.20

* Elevations are approximate: to be confirmed.

Table 3

Bug Placement Data*

Bug Identifier	Date Placed	Date Collected	Comments
Mtn Spr. #1A,B	18 Jan 1990	19 Jan 1990	Background bugs
Spring D #2A,B	18 Jan	19 Jan	"
Spring E #3A,B	18 Jan	19 Jan	"
Spring F #4A,B	18 Jan	19 Jan	"
Spring C #5A,B	19 Jan	19 Jan	"
Little S. Crk North #6A,B	19 Jan	19 Jan	"
Spr. A' #7A,B	19 Jan	19 Jan	"
Spring A #8A,B	19 Jan	19 Jan	"
Spring B #9A,B	19 Jan	19 Jan	"
Little S. Crk South #10A,B	19 Jan	19 Jan	"
Mtn. Spr #11A,B	19 Jan	25 Jan	Long Term (one week)
Spring D #12A,B	19 Jan	25 Jan	" "
Spring E #13A,B	19 Jan	25 Jan	" "
Spring F #14A,B	19 Jan	25 Jan	" "
Spring C #15A,B	19 Jan	20 Jan	
Spring C #16A,B	19 Jan	25 Jan	Long Term (one week)
Little S. Crk North #17A,B	19 Jan	20 Jan	
Little S. Crk North #18A,B	19 Jan	25 Jan	Long Term (one week)
Spring A #19A,B	19 Jan	20 Jan	
Spring A #20A,B	19 Jan	25 Jan	Long Term (one week)
Spr. A' #21A,B	19 Jan	20 Jan	
Spr. A' #22A,B	19 Jan	25 Jan	Long Term (one week)
Spring B #23A,B	19 Jan	20 Jan	
Spring B #24A,B	19 Jan	25 Jan	Long Term (one week)
Little S. Crk South #25A,B	19 Jan	20 Jan	
Little S. Crk South #26A,B	19 Jan	25 Jan	Long Term (one week)
03B10 #27A,B	19 Jan	19 Jan	Background sample bailed
03C24 #28A,B	19 Jan	19 Jan	Background sample bailed
03C25 #29A,B	19 Jan	19 Jan	Background sample bailed
03C37 #30A,B	19 Jan	19 Jan	Background sample bailed
Spring C #31A,B	20 Jan	21 Jan	
Little S. Crk North #32A,B	20 Jan	21 Jan	
Spring A #33A,B	20 Jan	21 Jan	
Spr. A' #34A,B	20 Jan	21 Jan	
Little S. Crk South #35A,B	20 Jan	21 Jan	
Spring B #36A,B	20 Jan	21 Jan	

Note: Dye injection occurred on 20 January 1990.

Table 3 (Continued)

Bug Identifier	Date Placed	Date Collected	Comments
Spring C #37A,B	21 Jan 1990	22 Jan 1990	
Little S. Crk North #38A,B			
Spring A #39A,B	21 Jan	22 Jan	
Spr. A' #40A,B	21 Jan	22 Jan	
03B10 #41A,B	21 Jan		4 bailers of water from well
03C24 #42A,B		21 Jan	5 bailers of water from well
03C25 #43A,B		21 Jan	6 bailers of water from well
Spring B #44A,B	21 Jan	22 Jan	
Little S. Crk South #45A,B	21 Jan	22 Jan	
03C37 #46A,B		21 Jan	5 bailers of water from well
Spring C #47A,B	22 Jan	23 Jan	
Little S. Crk North #48A,B	22 Jan	23 Jan	
Spring A #49A,B	22 Jan	23 Jan	
Spr. A' #50A,B	22 Jan	23 Jan	
Little S. Crk South #51A,B	22 Jan	23 Jan	
Spring B #52A,B	22 Jan	23 Jan	
03B10 #53A,B		22 Jan	6 bailers of water from well
03C37 #54A,B		22 Jan	5 bailers of water from well
Spring C #55A,B	23 Jan	24 Jan	
Little S. Crk North #56A,B	23 Jan	24 Jan	
Spring A #57A,B	23 Jan	24 Jan	
Spr. A' #58A,B	23 Jan	24 Jan	
Little S. Crk South #59A,B	23 Jan	24 Jan	
Spring B #60A,B	23 Jan	24 Jan	
03B10 #61A,B		23 Jan	6 bailers of water from well
03C37 #62A,B		23 Jan	5 bailers of water from well
Spring C #63A,B	24 Jan	25 Jan	
Little S. Crk North #64A,B	24 Jan	25 Jan	
Spring A #65A,B	24 Jan	25 Jan	
Spr. A' #66A,B	24 Jan	25 Jan	
Spring B #67A,B	24 Jan	25 Jan	
03B10 #68A,B		24 Jan	4 bailers of water from well
03C24 #69A,B		24 Jan	4 bailers of water from well
03C25 #70A,B		24 Jan	4 bailers of water from well
Little S. Crk South #71A,B	24 Jan	25 Jan	
03C37 #72A,B		24 Jan	5 bailers of water from well
Mtn Spr #73A,B	25 Jan		To be collected
Spring D #74A,B	25 Jan		To be collected
Spring E #75A,B	25 Jan		To be collected

Table 3 (Concluded)

Bug Identifier	Date Placed	Date Collected	Comments
Spring F #76A,B	25 Jan 1990		To be collected
Spring C #77A,B	25 Jan		To be collected
Little S. Crk North #78A,B	25 Jan		To be collected
Spr. A' #79A,B	25 Jan		To be collected
Spring A #80A,B	25 Jan		To be collected
Little S. Crk South #81A,B	25 Jan		To be collected
03B10 #82A,B		25 Jan	5 bailers of water from well
03C37 #83A,B			5 bailers of water from well
Spring B #84A,B	25 Jan		To be collected

(Sheet 3 of 3)

Table 4

Results of Laboratory Analyses of Dye Detectors

Date Collected/ Analyzed (1990)	Bug Identifier		Bug Type	Results*
19 Jan/21 Jan	Mtn. Spr.	#1A	Cotton	Blue spots, faint yel fluor
		#1B	Charcoal	VWP after 48 hr
	Spring D	#2A	Cotton	Faint yel fluor
		#2B	Charcoal	VWP after 48 hr
	Spring E	#3A	Cotton	Spots of yel, faint yel glow
		#3B	Charcoal	VWP after 48 hr
	Spring F	#4A	Cotton	Spots of yel. fluor, lt yel glow
		#4B	Charcoal	VWP after 48 hr
	Spring C,	#5A	Cotton	Spots of yel fluor, faint yel glow
		#5B	Charcoal	VWP after 48 hr
	Little S. Crk North	#6A	Cotton	Faint yel glow
		#6B	Charcoal	VWP after 48 hr
	Spring A'	#7A	Cotton	Blue spots, faint yel fluor
		#7B	Charcoal	VWP after 48 hr
	Spring A	#8A	Cotton	Blue streak, faint yel fluor
		#8B	Charcoal	VWP after 48 hr
	Spring B	#9A	Cotton	Faint yel fluor
		#9B	Charcoal	VWP after 48 hr
	Little S. Crk South	#10A	Cotton	Faint yel fluor
		#10B	Charcoal	VWP after 48 hr
	03B10	#27A	Cotton	Blue, yel spots, faint yel fluor
		#27B	Charcoal	VWP after 48 hr
	03C24	#28A	Cotton	Blue spots, faint yel fluor
		#28B	Charcoal	VWP after 48 hr
	03C25	#29A	Cotton	Faint yel fluor
		#29B	Charcoal	VWP after 48 hr
	03C37	#30A	Cotton	Blue spots, faint yel fluor
		#30B	Charcoal	VWP after 48 hr
********** All of the above are BACKGROUND samples **********				
20 Jan/21 Jan	Spring C	#15A	Cotton	Mod blue fluor, faint yel fluor
		#15B	Charcoal	WP (w/ focused light after 24 hr)
	Little S. Crk North	#17A	Cotton	Faint yel fluor
		#17B	Charcoal	WP (w/ focused light after 24 hr)

* See end of Table 4 for key to abbreviations.

(Continued)

Table 4 (Continued)

Date Collected/ Analyzed (1990)	Bug Identifier	Bug Type	Results
	Spring A #19A	Cotton	Mod blue fluor, faint yel fluor
	#19B	Charcoal	MP (w/ focused light after 7 hr)
	Spring A' #21A	Cotton	Faint yel fluor
	#21B	Charcoal	WP (w/ focused light after 24 hr)
	Spring B #23A	Cotton	Mod blue fluor, faint yel fluor
	#23B	Charcoal	WP (w/ focused light after 24 hr)
	Little S. Crk South #25A	Cotton	Faint yel fluor
	#25B	Charcoal	WP (w/ focused light after 24 hr)
21 Jan/22 Jan	Spring C #31A	Cotton	Weakly pos for light blue fluor
	#31B	Charcoal	VWP
	Little S. Crk North #32A	Cotton	Weakly pos for light blue fluor
	#32B	Charcoal	Negative
	Spring A #33A	Cotton	Weakly pos for light blue fluor
	#33B	Charcoal	VSP (Strongest positive of test)
	Spring A' #34A	Cotton	Positive for blue fluor
	#34B	Charcoal	VSP (response immediate)
	Little S. Crk South #35A	Cotton	Positive, pronounced blue fluor
	#35B	Charcoal	VSP (response immediate)
	Spring B #36A	Cotton	Very weakly pos for light blue fluor
	#36B	Charcoal	Negative
22 Jan/22 Jan	Spring C #37A	Cotton	Negative
	#37B	Charcoal	VWP after 36 hr
	Little S. Crk North #38A	Cotton	Negative
	#38B	Charcoal	Negative
	Spring A #39A	Cotton	Mod pos for blue and yel fluor
	#39B	Charcoal	VSP (somewhat slower than #33B)
	Spring A' #40A	Cotton	Mod pos for blue and yel fluor
	#40B	Charcoal	VSP (same as #39B)

Table 4 (Continued)

Date Collected/ Analyzed (1990)	Bug Identifier		Bug Type	Results
21 Jan/22 Jan	03B10	#41A	Cotton	Very weak for blue fluor
		#41B	Charcoal	Negative
	03C24	#42A	Cotton	Very weak for blue fluor
		#42B	Charcoal	Negative
	03C25	#43A	Cotton	Negative
		#43B	Charcoal	Negative
22 Jan/22 Jan	Spring B	#44A	Cotton	Positive, distinct blue fluor
		#44B	Charcoal	Negative
	Little S. Crk South	#45A	Cotton	Positive for light blue fluor
		#45B	Charcoal	VSP (less intense than #35B)
21 Jan/22 Jan	03C37	#46A	Cotton	Negative
		#46B	Charcoal	Negative
22 Jan/22 Jan	03B10	#53A	Cotton	Weak for blue fluor
		#53B	Charcoal	Negative
	03C37	#54A	Cotton	Negative
		#54B	Charcoal	Negative
23 Jan/24 Jan	Spring C	#47A	Cotton	Negative
		#47B	Charcoal	Negative? (after 20 hr water was too cloudy to read)
	Little S. Crk North	#48A	Cotton	Negative
		#48B	Charcoal	VWP to WP after 20 hr
	Spring A	#49A	Cotton	Weak for blue fluor
		#49B	Charcoal	VSP after 5 to 10 min
23 Jan/24 Jan	Spring A'	#50A	Cotton	Positive for blue fluor
		#50B	Charcoal	VSP after 5 min
	Little S. Crk South	#51A	Cotton	Very weak for blue fluor
		#51B	Charcoal	VSP after 5 min (less than #45B)
	Spring B	#52A	Cotton	Very weak for blue fluor
		#52B	Charcoal	WP after 20 hr in focused light
22 Jan/24 Jan	03B10	#53A	Cotton	Sample lost.
		#53B	Charcoal	Negative
	03C37	#54A	Cotton	Negative
		#54B	Charcoal	Negative (cloudy after 20 hr)
24 Jan/24 Jan	Spring C	#55A	Cotton	Negative
		#55B	Charcoal	WP after 19 hr
	Little S. Crk North	#56A	Cotton	Negative
		#56B	Charcoal	WP after 20 hr
	Spring A	#57A	Cotton	Weak for blue fluor
		#57B	Charcoal	VSP after 5 min

Table 4 (Continued)

Date Collected/ Analyzed (1990)	Bug Identifier		Bug Type	Results
	Spring A'	#58A	Cotton	Weak for blue fluor
		#58B	Charcoal	VSP after a few min
	Little S. Crk South	#59A	Cotton	Negative
		#59B	Charcoal	VSP after 10 min in focused light
	Spring B	#60A	Cotton	Negative
		#60B	Charcoal	VWP after 20 hr
	03B10	#68A	Cotton	Very weak for blue fluor
		#68B	Charcoal	After 24 hrs, trace grn < background
	03C24	#69A	Cotton	Negative
		#69B	Charcoal	Negative
	03C25	#70A	Cotton	Very weak blue fluor
		#70B	Charcoal	Negative
	03C37	#72A	Cotton	Negative
		#72B	Charcoal	Negative
25 Jan/25 Jan	Spring C	#63A	Cotton	Negative
		#63B	Charcoal	VWP after 24 hr
	Little S. Crk North	#64A	Cotton	Negative
		#64B	Charcoal	VWP after 24 hr
	Spring A	#65A	Cotton	Negative
		#65B	Charcoal	SP in focused light beam after 5 min
	Spring A'	#66A	Cotton	Weak for blue fluor
		#66B	Charcoal	SP in focused light beam after 5 min
	Spring B	#67A	Cotton	Negative
		#67B	Charcoal	Negative
	Little S. Crk South	#71A	Cotton	Negative
		#71B	Charcoal	VSP (immediate response)
25 Jan/25 Jan	03B10	#82A	Cotton	Negative
		#82B	Charcoal	Negative
	03C37	#83A	Cotton	Negative
		#83B	Charcoal	Negative
Following are long-term bugs (left at sample site about one week):				
25 Jan/25 Jan	Mtn Spr	#11A	Cotton	Negative, very dirty
		#11B	Charcoal	VWP after 24 hr (> background)
	Spring D	#12A	Cotton	Negative
		#12B	Charcoal	Negative

Table 4 (Concluded)

Date Collected/ Analyzed (1990)	Bug Identifier	Bug Type	Results
	Spring E #13A	Cotton	Negative
	#13B	Charcoal	WP after 24 hr in room light
	Spring F #14A	Cotton	Negative, very dirty
	#14B	Charcoal	WP after 24 hr in room light
	Spring C #16A	Cotton	Negative
	#16B	Charcoal	WP after 45 min in focused light
	Little S. Crk North #18A	Cotton	Negative, very dirty
	#18B	Charcoal	WP after 24 hr in focused light
	Spring A #20A	Cotton	Negative, very dirty
	#20B	Charcoal	VSP, immediate response
	Spring A' #22A	Cotton	Negative, very dirty
	#22B	Charcoal	VSP, immediate response
	Spring B #24A	Cotton	Very weak for blue fluor
	#24B	Charcoal	WP after 24 hr
	Little S. Crk South #26A	Cotton	Negative, very dirty
	#26B	Charcoal	VSP, immediate response

Key to abbreviations in Table 4

Pos = positive WP = weakly positive VWP = very weakly positive
MP = moderately positive SP = strongly positive
VSP = very strongly positive mod = moderate lt = light
fluor = fluorescence yel = yellow min = minute(s) hr = hours
Little S. Crk = Little Sulphur Creek

Table 5

Positive Response Sequences for Fluorescein and Phorwite AR at Sampling Sites South of ABG*

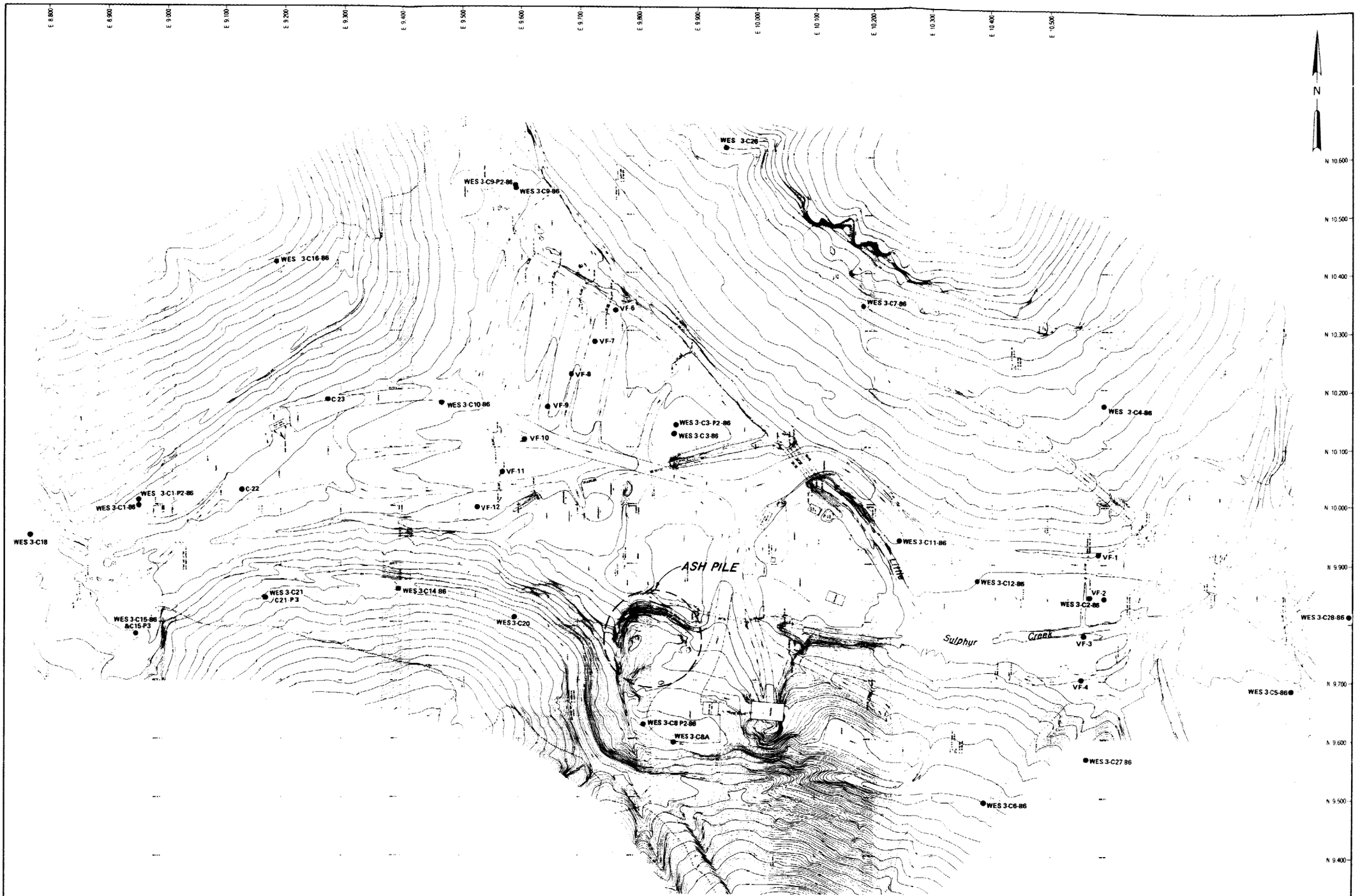
Fluorescein -- Positive responses only

Sampling Site	Date Collected					
	Jan 20	Jan 21	Jan 22	Jan 23	Jan 24	Jan 25
Spring C	WP	VWP	VWP	Neg?	WP	VWP
Bug #	15	31	37	47	55	63
Little S. Crk	WP	Negative	Negative	VWP	WP	VWP
North, #	17	32	38	48	56	64
Spring A	MP	VSP	VSP	VSP	VSP	SP
Bug #	19	33	39	49	57	65
Spring A'	WP	VSP	VSP	VSP	VSP	SP
Bug #	21	34	40	50	58	66
Spring B	WP	Negative	Negative	WP	VWP	Neg.
Bug #	23	36	44	52	60	67
Little S. Crk	WP	VSP	VSP	VSP	VSP	VSP
South, #	25	35	45	51	59	71

Phorwite AR -- Positive responses only

Sampling Site	Date Collected					
	Jan 20	Jan 21	Jan 22	Jan 23	Jan 24	Jan 25
Spring C	Mod	Weak	Negative	Negative	Negative	Neg
Bug #	15	31	37	47	55	63
Little S. Crk	Negative	Weak	Negative	Negative	Negative	Neg
North, #	17	32	38	48	56	64
Spring A	Mod	Weak	Mod	Weak	Weak	Neg
Bug #	19	33	39	49	57	65
Spring A'	Negative	Positive	Mod	Positive	Weak	Weak
Bug #	21	34	40	50	58	66
Spring B	Mod	Weak	Pos, distinct	Weak	Negative	Neg
Bug #	23	36	44	52	60	67
Little S. Crk	Negative	Pos, distinct	Pos	Weak	Negative	Neg
South, #	25	35	45	51	59	71

* See Figure 20 and Table 4 for key to abbreviations.



NOTE: CONTOUR INTERVAL 1 FT.

DEPARTMENT OF THE NAVY — NAVAL FACILITIES ENGINEERING COMMAND

NAVAL WEAPONS SUPPORT CENTER
CRANE, INDIANA

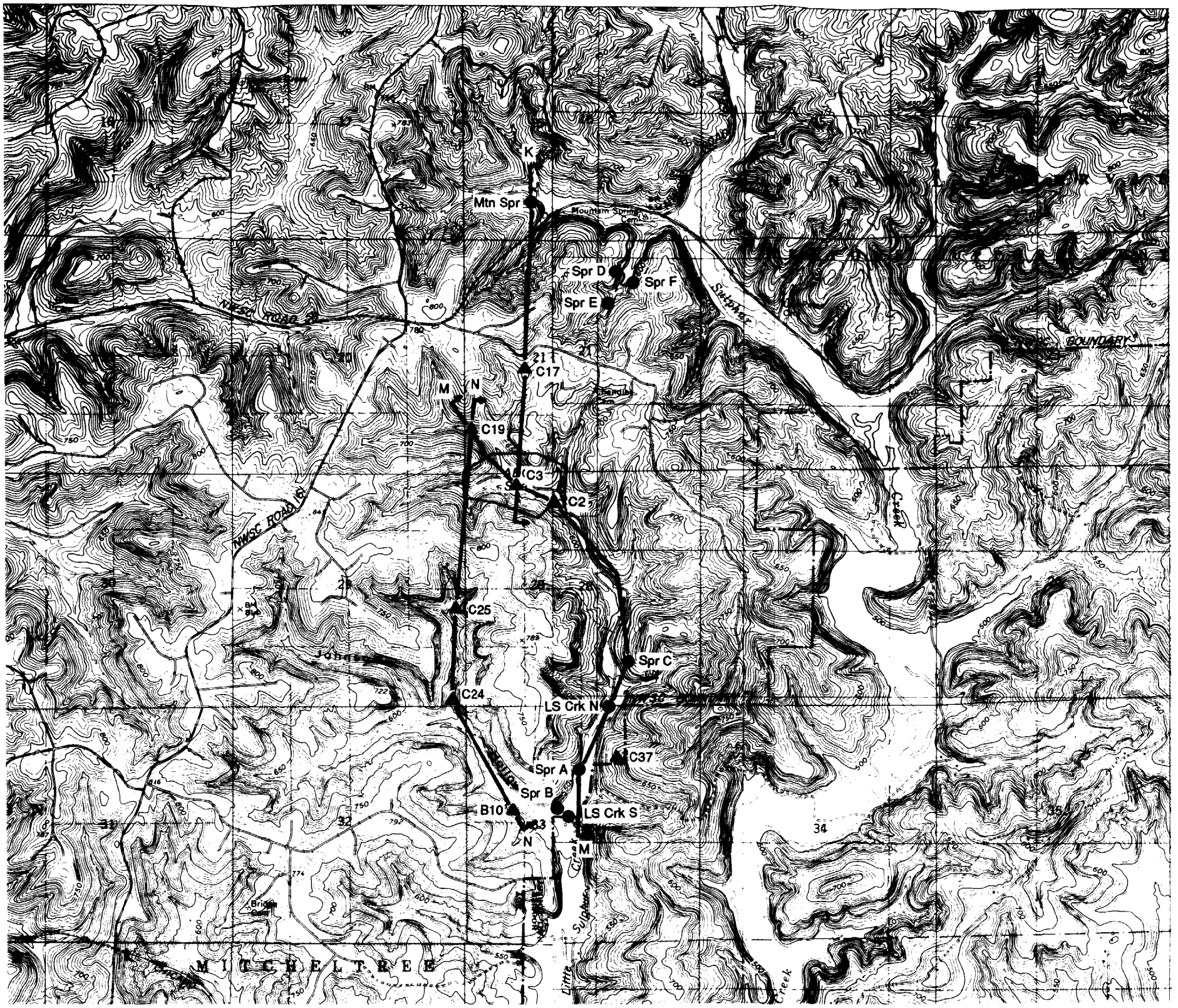
PREPARED BY
U.S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION
VICKSBURG, MISSISSIPPI

DRAWN BY: R. Hunt
CHECKED BY: W. Murphy

AMMUNITION BURNING GROUND
Site Topography and Boring/Well Locations

60 0 60 FT

PLATE 1



NOTE: CONTOUR INTERVAL 10 FT.
(SEE TEXT FOR MAP SOURCE)

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NAVAL WEAPONS SUPPORT CENTER
CRANE, INDIANA

PREPARED BY
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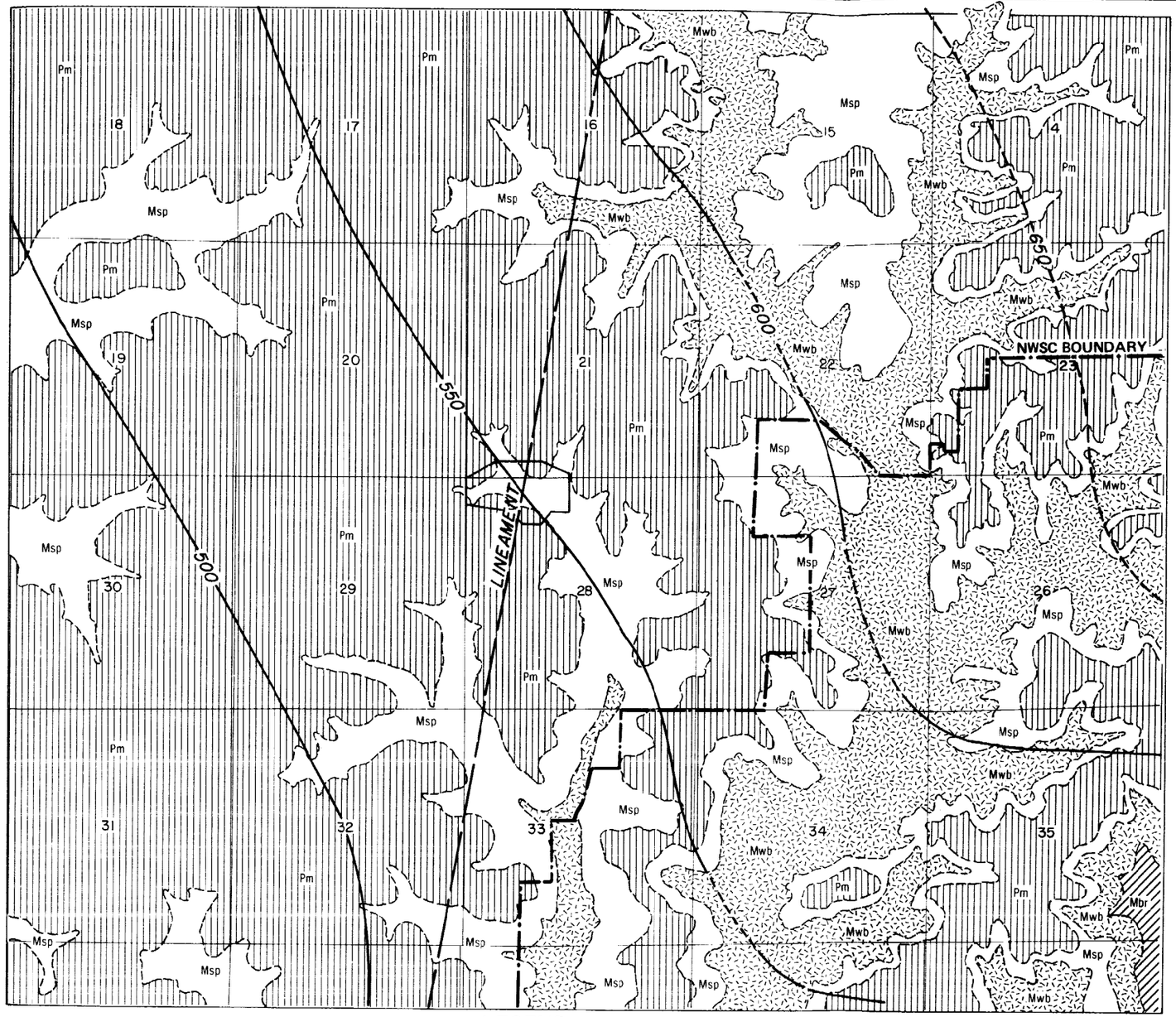
VICKSBURG, MISSISSIPPI

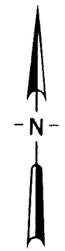
DRAWN BY: R. Hunt
CHECKED BY: W. Murphy

TOPOGRAPHIC MAP
ABG Study Area

1000 0 1000 FT

PLATE 2





NOTE: CONTOUR INTERVAL 10 FT.
ELEVATIONS IN FT MSL

LEGEND

600 — Structure Contours on Top of Beech Creek Limestone (Lower Formation of Stephensport Group)

Contacts Between Groups

	GROUP	PERIOD
Pm	Raccoon Creek	— Pennsylvanian
Msp	Stephensport	— Mississippian
Mwb	West Baden	
Mbr	Blue River	

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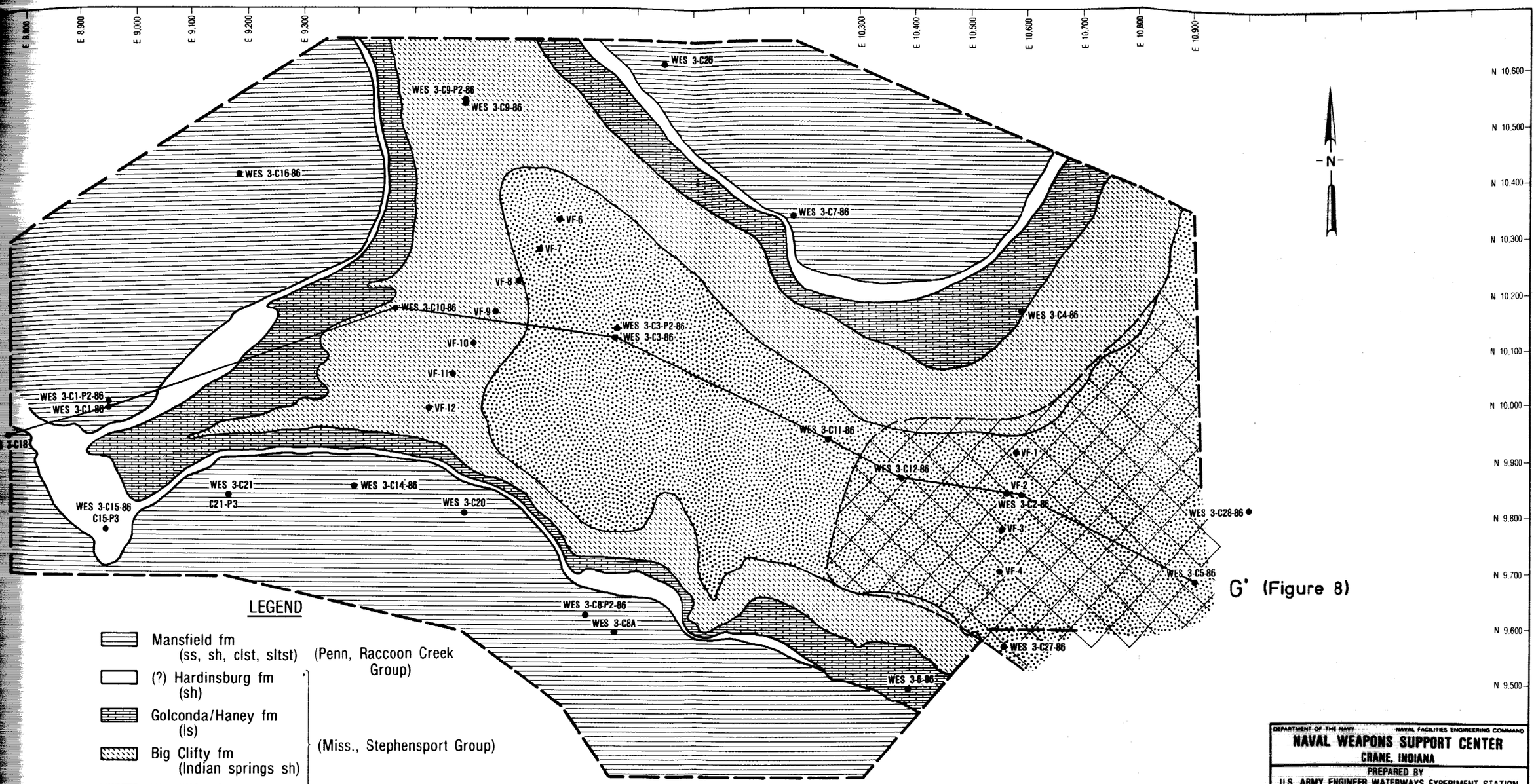
VICKSBURG, MISSISSIPPI

DRAWN BY R. Hunt
CHECKED BY W. Murphy

GEOLOGIC MAP
ABG Study Area

1000 0 1000 FT

PLATE 3



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NAVAL WEAPONS SUPPORT CENTER
CRANE, INDIANA

PREPARED BY
U.S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION
VICKSBURG, MISSISSIPPI

DRAWN BY: R. Hunt
CHECKED BY: W. Murphy

AMMUNITION BURNING GROUND
Site Geologic Map, with Approximate Area of Beech Creek LS Solution Caverns

60 0 60 FT

PLATE 4

APPENDIX A: ACRONYMS USED IN THE REPORT

ABG	Ammunition Burning Ground
CAP	Corrective Actions Program
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFR	Code of Federal Regulations
CMS	Corrective Measures Study
EPA	Environmental Protection Agency
HMTC	Hazardous Material Technical Center
HSWA	Hazardous and Solid Waste Amendments
IAS	Initial Assessment Study
IRP	Installation Restoration Program
NACIP	Navy Assessment and Control of Installation Pollutants
NAVCOMPT	Navy Comptroller
NAVFAC	Naval Facilities Engineering Command
NCP	National Oil and Hazardous Substances Contingency Plan
NEESA	Naval Energy and Environmental Support Agency
NORTHDIV	Northern Division
NWSC	Naval Weapons Support Center
PEP	Propellants
QA/QC	Quality Assurance/Quality Control
RCRA	Resource Conservation and Recovery Act
RD/RA	Remedial Design/Remedial Action
RFA	RCRA Facility Assessment
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
SARA	Superfund Amendments and Reauthorization Act
SWMU	Solid Waste Management Unit
TSD	Treatment, Storage or Disposal
UIC	Underground Injection Control
USAE	United States Army Engineer
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
USN	United States Navy
WES	Waterways Experiment Station

APPENDIX B: EPA REVIEW COMMENTS, ABG REPORT AND PROPOSAL

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 5
230 SOUTH DEARBORN ST.
CHICAGO, ILLINOIS 60604

REPLY TO THE ATTENTION OF:

22 JUN 1989

5HR-JCK-13

Captain C.E. Johnson
Commanding Officer
Department of the Navy
Naval Weapons Support Center
Crane, Indiana 47522-5000

RE: Technical Review
Geologic Reports and Activities
Naval Weapons Support Center
Crane, Indiana
IN5 170 023 498

Dear Captain Johnson:

The United States Environmental Protection Agency (U.S. EPA) has completed a technical review of the following documents submitted by the above referenced facility:

1. Geology and Hydrogeology of the Ammunition Burning Grounds, Crane Naval Weapons Support Center, Final Technical Report (October 1988),

2. Ground Water Assessment Plan for the Ammunition Burning Grounds (January 24, 1989); and

3. Proposed Dye Tracer Tests in the Beech Creek Aquifer at the Ammunition Burning Grounds (April 3, 1989).

Enclosed is a copy of our review comments, requirements, and support information. The additional requirements or changes in workplans must be incorporated into the corrective action work being done at the Ammunition Burning Grounds (ABG). The monitoring program that will be developed shall incorporate the individual monitoring requirements of closure, permitting, and corrective action into one main program for the entire ABG area. We feel that the programs can not and should not be broken into repetitive requirements, but should be comprehensive for this area.

Please submit a revised tracer test proposal as soon as possible, so that the approved plan can be incorporated into the corrective action portion of the draft container storage permit for the facility. Soil characterization for the ABG will also be incorporated into the draft permit. The Navy may want to consider doing some public affairs activities, notifying the people living near the area of the ABG that the tracer test will be taking place, to assure no future problems with the testing activities on-site.

If you have any questions regarding this matter, please contact Carol Witt of my staff, at (312) 886-6146, for assistance.

Sincerely,

Karl E. Bremer

Karl E. Bremer, Chief
RCRA Permitting Branch

cc: J. Hunsicker, USNC
T. Linson, IDEM
T. Miller, IDEM
B. Muno, REB

ATTACHMENT I
Technical Review of NWSC-CAAA's Geologic Reports and Activities
Crane, Indiana
IN5 170 023 498

DOCUMENT: Geology and Hydrogeology of the Ammunition Burning Grounds, Crane Naval Weapons Support Center, Final Technical Report GL-88-27 (October 1988)

1. Regional Geology

In order to distinguish soil types that may be present at the Ammunition Burning Grounds (ABG) and their distribution throughout the facility, the following factors, not included in the general description of the geologic report, should be kept in consideration:

Although the Wisconsinan and Illinoian Glaciations of the Pleistocene Epoch never produced glaciers that reached or surpassed the area now occupied by NWSC; they did significantly influence the overall drainage and landscape form. The very weight of the ice mass depressed the earths crust and probably crushed many of the limestone caves in the area, or glacial drift may have filled some caves or sinkholes (north of the NWSC). As the glacial ice moved forward, it produced end moraines as well as transporting large amounts of till.

As the ice began to ablate, tremendous meltwater streams flowed out to cut deep valleys as the streams flowed towards the Ohio River. These meltwaters transported large quantities of sediment downstream, sorting and depositing the material along the way. Periglacial winds would have deposited loess over the area as well. During the Wisconsinan Glaciation, many preglacial and glacial stream segments became integrated along their lengths. Several of these streams in the Crawford Upland (where the NWSC is located) became entrenched. These entrenched streams are a definite controlling factor on the local ground water flow conditions.

2. Site Soils

The soils in the area of the ABG should be classified using the Unified Soil Classification System (USCS). Also, the constituents released must be identified in order to determine the leachability and pathways of constituents within the soil horizon.

3. Regional Ground Water Trends

Although the geologic report stresses on the ABG, the overall Corrective Action program for the facility should carefully look at regional trends throughout the facility. This is especially true when you have situations like the Dye Burial Grounds investigation going on next to the ABG. This is brought out a little in the report, but the "big picture" must be kept in mind.

a. Aquicludes

Although the shales at the site are effective barriers, especially with the artesian conditions evident at the site, the investigation should be cautious in the fact that some areas may be more highly fractured and constituents may not follow the ground water flow, therefore there is a potential of migration through the shales. The shales are aquicludes not aquitards.

b. Flow Patterns

The fact that regional ground water flows to the southwest is purely coincidental with the stratigraphic dip. The ground water is flowing from areas of high hydrostatic head to areas of low hydrostatic head. Stratigraphic dip probably locally controls various aspects of the ground water flow (as reported on page 15 of the report), but not regional flow trends. Contaminants that are dense will flow down the stratigraphic dip regardless of the hydraulic gradient. These comments must be kept in mind during the investigation.

4. Solution Cavern Passages

An understanding of the subsurface conduits is esstential if the extent to which the subsurface has been contaminated is to be established and a corrective measure formulated. Nearly all drainage, subsidence, and collapse are triggered by the development of underlying caves. Thus an understanding of caves is essential to the hydrologic and geomorphic interpretation of such a region, as well as assessing aquifer yield, constituent migration, and soil and bedrock conditions. The geologic report stresses on the karst conditions and identifies a major solution zone at the site, but more details must be developed. The following information researched by Malcolm Field, U.S. EPA Headquarters, should be used in developing the investigation of karst flow conditions.

Type of Cave Likely to Occur at the NWSC

Typical caves formed in this area may be classed as network caves which consist of angular grids on intersecting fissure-like passages formed by the solutional widening of nearly all major fractures within given areas of soluable rock. Closed loops are common, and the straight, relatively narrow passages for a pattern like that of city streets. This type of cave is restricted to rocks containing prominent, nearly vertical fractures. Some rudimentary network caves do not contain closed loops but consist of an angular array of dead-end fissures.

Several caves have been mapped at the NWSC. These include Granny's Cave, Aunt Liz Cave, Fisher's Folly, Pleasant Cave, Sargent's Cave, Blume Cave, and Goldsberry Pit Cave. Others likely exist at the facility. A copy of the map of Tow Cave (Figure 1) is enclosed. Although not within the NWSC property boundary, it is nearby. The good quality of this map and its relation to the regional jointing pattern (see rose diagram on the map) make it useful by depicting how jointing controls cave formation in the Crawford Upland.

General Aspects of Cave Development in the Area

Cave formation requires the flow of underground water that is of sufficiently aggressive nature to solutionally remove the bedrock and to keep the solutionally aggressive water in contact with the cave walls. This requires that the initial water movement follow a system of joints and/or bedding plane partings prior to cave development. Solutionally enlarged joints tend to produce fissure-like passages which can determine the pattern of nearly every passage in a cave. Intergranular pores are relatively unimportant in regard to cave development, but are significant in regard to permeability.

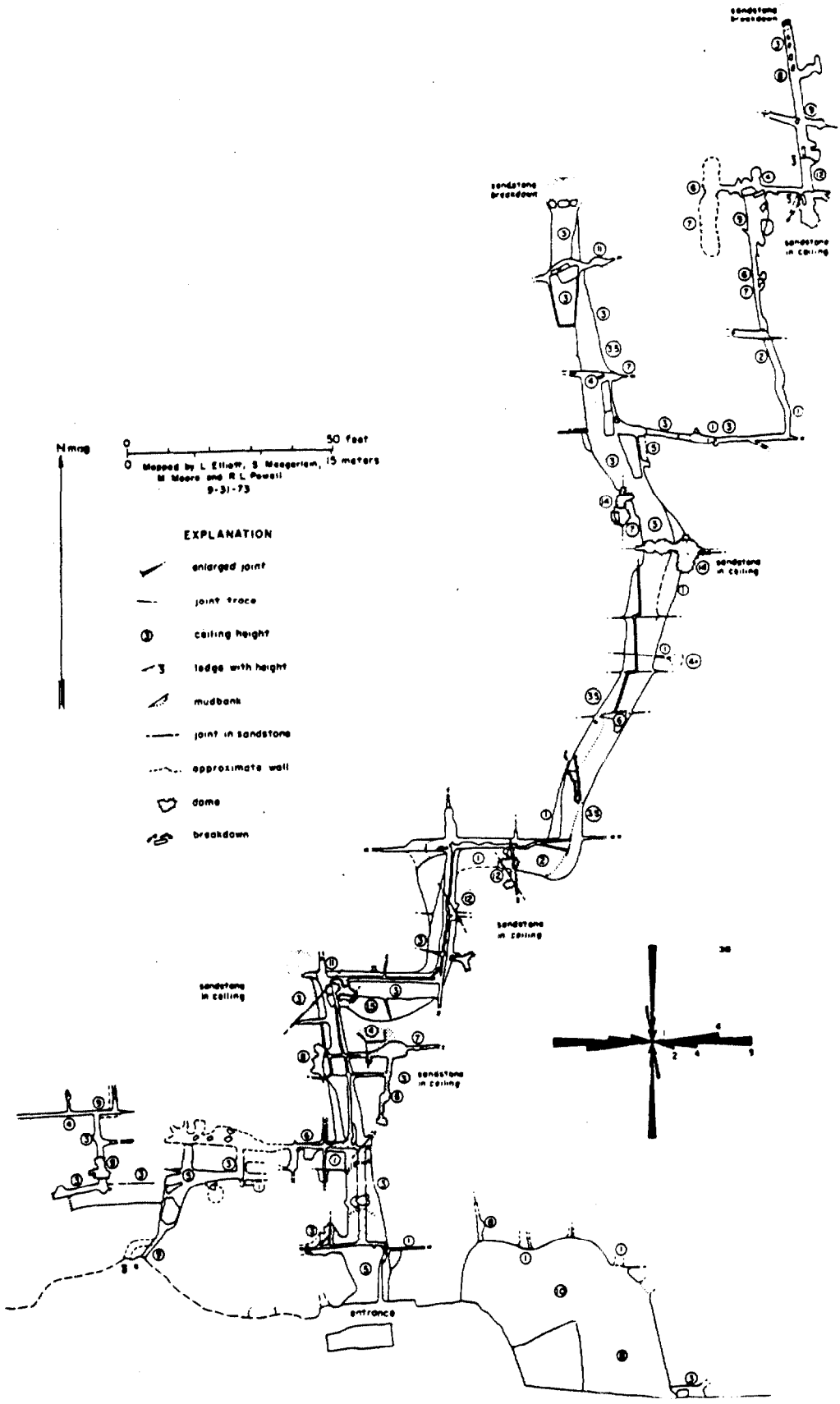

Figure B1. Tow Cave, Martin County, Indiana

Caves are well adjusted to the present pattern of recharge from the land surface indicating that the upper part of the caves is formed in the vadose zone at the same time that the underlying parts are formed in the phreatic zone. The water table in a karst region is highly irregular and discontinuous because of the great variations in the size and distribution of subsurface openings and in the amount of water they transmit. It is crucial to note that water level records are only measures of the hydrostatic head in the diffuse-flow portion of the aquifer (see Attachment II), because it is highly unlikely that any wells actually intercept a cave. Infiltrating water concentrates along narrow paths within a given fracture, thus creating discrete conduits no more than a few feet or tens of feet in diameter rather than a myriad of amorphous interconnected openings. Flow through caves is therefore best described in terms of pipe hyraulics instead of by a continuous potential field.

Water movement in the vadose zone is governed mainly by gravity and capillarity with gravity being the most important in regard to those openings wide enough to enlarge caves. Therefore, vadose passages trend downward in the direction of flow, having been formed by water descending vertically along the steepest available openings. Vadose water descending vertically along a fracture or a cluster of intersecting fractures may eventually form a shaft which may range in size from a few inches in diameter and depth to tens of feet in diameter and hundreds of feet deep. Recharge occurs through surface pits, through an inclined vadose passage, or less commonly, through fractures in overlying insoluable rock. Passages at the bottom of a shaft (or shaft complex) drain the water.

Water in the phreatic zone forms a continuous medium, and its tendency to be drawn downward by gravity is offset to varying degrees by the downward increase in hydrostatic pressure. Phreatic water flow is greatest along the routes affording the greatest efficiency (least expenditure of hyraulic head per unit discharge). Caves form along these preferred routes, extending from where the incoming vadose water reaches the water table to where it emerges at a surface outlet at a lower elevation. A phreatic passage enlarges solutionally over its entire perimeter thus acquiring a smooth rounded cross section with an arched ceiling. Tubular passages and fissures with lenticular cross sections are most common. Only a small amount of solutional enlargement is needed for phreatic passages to become so efficient in transmitting water that the hydraulic gradients within them become very low (almost flat). Those that form entirely along the water table have barely measurable gradients.

Recharge Through Permeable Insoluable Rock

In upland areas where the limestone is capped by thin permeable sandstone, aggressive diffuse recharge is readily transmitted to the underlying limestone. Every major fracture in the limestone, regardless of width, receives comparable amounts of recharge of the same chemical character, allowing all fractures to grow at comparable rates in the initial stages. Fracture enlargement probably begins while the sandstone-limestone contact is still below the fluvial base level. At first, the sandstone has the higher permeability of the two rock types and most of the ground water flows through it. However, the small amount of water entering the limestone gradually widens the fractures until the limestone has the higher permeability. Much or most of the water then flows through the limestone, as the overall resistance to flow is less than through the sandstone alone. Uniform recharge continues to take place after the water table drops below the level of the cave.

A permeable caprock is not enough to ensure an equal distribution of recharge to all major fractures in the underlying limestone. Solutionally widened fractures must extend upward to the sandstone contact, and aggressive water must continue to enter through the caprock after the cave has become exposed above the water table.

In many sandstone-capped network caves, the water is channeled through joints in the caprock that are co-planar with those in the limestone. In this case the soil governs the flow to each joint. If diffuse flow encounters poorly jointed limestone, interstratal solution and complex systems of shafts and narrow canyons are formed. Small caves of this type typically occur in the predominantly bedded Girkin Formation (which contains the Beech Creek Limestone) where a sandstone cap of the Big Clifty Formation is particularly thin along plateau margins (such as the Crawford Upland).

Cave Formation in the Crawford Uplands

The Beech Creek Limestone being overlain by the jointed, permeable sandstone of the Big Clifty Formation and underlain by the relatively impermeable shale of the Elwren Formation has resulted in significant joint dissolution in the Beech Creek Limestone. Initially, ground water flow was induced by infiltration of surface water into the overlying sandstone. This infiltrating water was perched within the sandstone except where underlain by permeable joints in the underlying limestone unit, which accepts water from the sandstone. The release of ground water from the sandstone is regulated by transmissivity, amount of hydrostatic head within the sandstone, and the location and size of the open joints in the limestone.

Water infiltrating into the limestone through joints descends to unite with a perched ground water body within open joints in the limestone. This perched water body generally does not flow through the underlying shale; rather, the ground water will tend to flow on top of the shale layer. Discharge is via outcrop springs or seeps that are perched above the Elwren Formation which is dependent upon the amount of available ground water and joint solution development. It is important to note here that the United States is in the midst of a three (3) year drought, the worst of which occurred last year. Many of the springs and seeps identified at the ABG are probably flowing well below their potential or may not be flowing at all.

As ground water slowly seeps from the overlying sandstone into the limestone, a steeply sloping water table may develop in the limestone. Ground water flowing in open master joints tends to develop lower solution channels within the limestone more readily than do cross joints that do not extend through more than one bed without offsets from joints in lower beds. Although some solution channels will develop in the upper beds, ultimate control is by the position of the outlet.

Reports indicate that most cave streams in the Beech Creek Limestone have not dissolved or eroded through the lowermost beds of limestone which are commonly a very fine grained sparitic to micritic limestone, or rarely a calcareous sandstone. The stream progressively grades higher stratigraphically upstream from the spring outlet. It is also apparent that the caves developed in the Beech Creek Limestone appear to have initially developed a large solution conduit or cave passage above the basal unit.

Discharge of ground water from the sandstone is apparently most rapid and greatest into those joints in the limestone which are widest and provide the easiest release of water to the outlet. Most caves in the Beech Creek Limestone fed by ground water perched in the overlying Big Clifty Formation appear to closely parallel the outcrop of the limestone unit.

Cave entrances and solution-subsidence features in the area are associated with the top of the Beech Creek Limestone and the base of the overlying sandstone of the Big Clifty Formation, which illustrates the effectiveness of solution removal of the limestone where the water first contacts the carbonate rock. Several caves in the Beech Creek Limestone contain domes or shafts where continued seepage of water from the overlying sandstone has dissolved a vertical passage along a joint through the limestone. Collapse of the overlying sandstone into a pinnacled and channeled Beech Creek Limestone is thus a common occurrence (as indicated in the ABG geologic report).

Hydrogeology of the ABG Study Area

Overall, this section, especially the Middle Ground-Water Zone description, was exceptionally detailed and representative of actual site conditions at the ABG. Although the geologic report makes a strong case against possible interconnections in this section, the investigation should confirm the possiblity of, or lack of, interconnections.

The section on the Beech Creek Aquifer is consistent with literature on the aquifer and typical karst hydrological principles, but certain facts should be emphasized. All the available literature (published and unpublished), as well as the site geologic conditions would indicate that the Beech Creek Aquifer is in fact the one most likely to be transporting constituents away from the ABG site. The section on the local hydrological situation closely parallels the literature and includes a very good description regarding the recharge mechanisms operating at the site. In addition, several points are brought out. Page 38 of the geologic report explains that flow is primarily down the Little Sulfur Creek drainage way and secondarily down through the Johnson Hollow drainage way with a low ground-water divide separating the two discharge areas. This is probably accurate unless the three (3) year long drought has created an abnormal condition which is probably unlikely.

The next important fact is that surface water infiltrates the sandstone of the Big Clifty Formation which the geologic report claims is "...highly permeable and is capable of taking most of the water that comes in contact with its surface." Clayey alluvium in the area is said to retard the infiltrating water, but not too significantly. Therefore, rapid infiltration is to be expected.

A third important point is that surface runoff occurs from seepage out of the Gloconda/Haney Aquifer into the ABG valley and continues to flow over the Indian Springs Shale until reaching the sandstone of the Big Clifty Formation. This flow of water is to the east of the ground water divide and is therefore likely to flow towards Little Sulfur Creek.

The fourth and most important point is that surface runoff and two creek branches flow into the ABG site from the west and northwest to form the headwaters of Little Sulfur Creek. These branches join at the ABG, but sink into the ground a short distance from the ABG.

Fifth, Little Sulfur Creek remains dry (except under certain rainfall conditions) until Springs A, B, and C produce moderate amounts of water by discharge from the Beech Creek Limestone. The geologic report claims that these springs are outlets for solution conduits within the Beech Creek Limestone. Evidence for this statement occurs in paragraph 68 of the report, where observations of two of the springs after rainfall events showed greatly increased discharge and high turbidity. This is absolutely correct. The only thing this does not tell us is that no evidence yet proves that any connection exists between these springs and the ABG site. It is very possible that flow from the ABG discharges into Johnson Hollow although little evidence exists for this scenario (at least at present).

The final point made in the hydrogeology section of the report occurs in paragraph 66, which states that several springs "...issue from the Beech Creek along the Little Sulfur Creek Valley flanks south of the NWSC boundary." NWSC must identify potential outlets for contaminated ground water off-site, and assure appropriate corrective measures for any "plume" migrating off-site. This must be done through the tracer test proposed.

A generalized model for the area is shown in Figure 2. Condition A in the figure could be representative of the Golconda/Haney Limestone while B and C are indicative of probable conditions in the Beech Creek Limestone. Condition C is very common and is depicted on several of the cross sections contained in the ABG geologic report. Condition B, however has not been shown to exist in any of the cross sections. Although less common than condition C, condition B does occur with some frequency and should be assumed to exist beneath the ABG site. This would mean that it is quite possible that not all of the karst hydrological problems have been established yet.

5. Recommendations and Additional Work

Most of the work conducted to date was of a general geological and hydrological nature, but is still considered essential to the design of more focused studies. The exceptional quality of work conducted and the report describing such has provided the appropriate level of information necessary for designing studies leading to the definintion of the true ground water flow paths underneath the ABG site. The following items of additional work must be incorporated into the overall corrective action program.

a. Additional Borings and Wells

Additional cored borings and wells should be installed, as described in Recommendation C of the ABG geologic report, for the same reasons described in the report. These wells will also provide additional water quality monitoring data prior to any ground water exiting the NWSC facility. The addition of three wells, as discussed in the meeting betweeen USNC and U.S. EPA in May 1989, will determine the potential for any off-site migration towards the eastern boundary.

b. Soil Characterization

Both surface and subsurface soil must be characterized using the USCS and evaluated for hazardous constituent content. The extent of soil contamination must be defined, and will be used to determine fate and transport of any surface water and ground water contamination. This investigation shall be incorporated into the Corrective Action Plan (CAP).

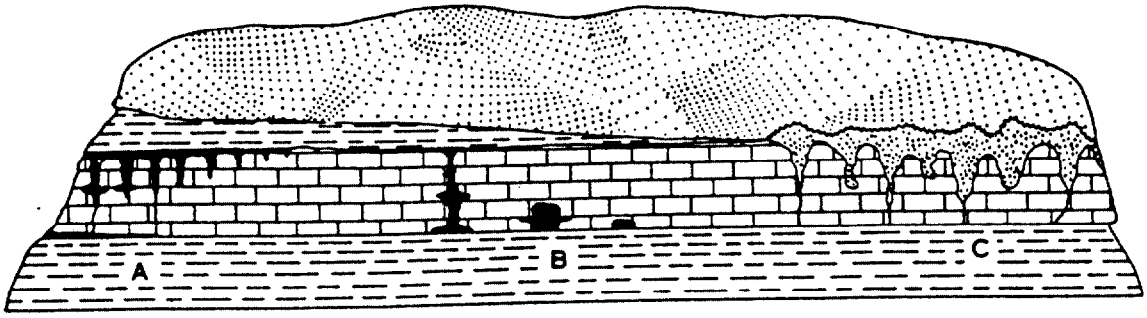

Figure B2. Three-types of solution in limestone. A, limited solution near outcrop; B, deep-seated individual joint enlargement; C, general solution beneath sandstone collecting bed

DOCUMENT: Ground Water Assessment Plan for the Ammunition Burning Grounds (January 24, 1989)

1. Overall Review

A typical assessment plan for the ABG virtually can not be completed. At this stage in the study, USNC began with a simple monitoring well system and has expanded the amount of wells to define the extent of contamination at the site. Due to the karst conditions in the downgradient directions, a tracer test to determine the flow paths was proposed (see review of the tracer test below). A staged approach of investigation is necessary, as discussed in the assessment plan. Once the flow is defined, wells may be selected for continued monitoring. After the plume is characterized, USNC will be required to do a Corrective Measures Study to determine what to do with the plume. Further studies at this point will be incorporated into the Corrective Action work being done under permitting.

DOCUMENT: Proposed Dye Tracer Tests in the Beech Creek Aquifer at the Ammunition Burning Grounds (April 3, 1989)

1. Other Permits Required

NWSC must submit a written request to the U.S. EPA Water Division to seek permission to conduct the dye tracer test, which involves injection of materials into the ground. The request must include the following:

a. The purpose of the survey;
b. A description of the type of facility, and ABG operations;
c. The general geology of the area; and
d. A detailed description of the procedures of the tracer test, including which wells will be used, construction oe the wells, springs monitored, emplacement areas identified, tracers to be used, and the schedule of the project.

As long as the dye tracer test is a short term event required by RCRA in order to define the ground water flow in the karst conditions at the site, and will not harm human health or the environment, the Water Division may be able to authorize the event under their injection rules for Class V wells. The request must be submitted to:

Mr. Edward P. Watters, Section Chief
UIC Section, Water Division
U.S. EPA Region V 5-WQS-TUB-8
111 West Jackson
Chicago, IL 60604

If you have any questions regarding the information to be submitted, contact Jessie Chiu, at (312) 886-1499, for assistance.

3. Method of Dye Injection

The proposed method of dye injection is satisfactory. USNC must make sure that sufficient quantities of water are used to flush the dye into the aquifer, and they must record the quality of water injected to assure that other hazardous constituents are not being added to the system.

4. Location of Dye Detectors

The proposed dye detector locations are adequate, but NWSC must place more detectors, if possible, in the Johnson Hollow well locations in order to assure that all possible discharge points are monitored.

5. Dye Detector Material

Dye detectors must consist of surgical cotton (tampons are a possible substitute) and activated charcoal. Most cotton is already treated with optical brighteners, but surgical cotton generally is not. All cotton detectors must be examined under a fluorescent light prior to use to ensure that treatment with optical brighteners has not occurred. Activated charcoal is necessary for the proper adsorption of fluorescent dyes. Any other charcoal will be incapable of adsorbing the dyes.

6. Detail of the Report

NWSC must expand on the details concerning the length of time necessary for a proper analysis of background fluorescence; and how the water withdrawn from downgradient wells for dye analysis will be managed and disposed of. Any water withdrawn from wells must be contained and disposed of properly if the ground water was previously found to contain hazardous constituents at that well.

APPENDIX C: BORING LOGS, LEGEND, AND WELL INSTALLATION DIAGRAMS

Boring Log Legends

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
			ROCK CORE BORING LOGS			
		ROCK SYMBOLS				
			SANDSTONE			
			LIMESTONE			
			SHALE OR CLAYSHALE			
			SHALE W/ CLAYEY LIMESTONE			
			CALCAREOUS SANDSTONE, SANDY LIMESTONE			
			SHALE W/ SANDSTONE LENSES			
			COAL			
			CLAYSTONE			
		SOIL SYMBOLS				
			CRUSHED LIMESTONE ROAD FILL			
			SILT (ML)			
			CLAY (CL OR CH) OR CLAYEY SILT (ML-CL)			
			CLAY (CL) WITH ROCK FRAGMENTS			
			CLAYEY SAND (SC)			
			SILT (ML) WITH ROCK FRAGMENTS			
		JOINT SYMBOLS				
			CLOSED HORIZONTAL JOINT			
		10	CLOSED JOINT DIPPING 10°			
		10	OPEN JOINT DIPPING 10°			
		80	CLOSED OR INCIPIENT JOINT DIPPING 80°			
		35 60	INTERSECTING JOINTS W/ DIPS AS SHOWN			
			STYLOLITES			
			ROUGH, IRREGULAR JOINT			
			CORE LOSS ZONE			

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PROJECT

HOLE NO.

DRILLING LOG	DIVISION	INSTALLATION	SHEET OF SHEETS
1. PROJECT: WELL INSTALLATION (ABG		10. SIZE AND TYPE OF BIT	
2. LOCATION (Coordinates or Station)		11. DATUM FOR ELEVATION SHOWN (TBM or MSL)	
3. DRILLING AGENCY		12. MANUFACTURER'S DESIGNATION OF DRILL	
4. HOLE NO. (As shown on drawing title and file number): 03C3P2		13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED / UNDISTURBED	
5. NAME OF DRILLER		14. TOTAL NUMBER CORE BOXES	
6. DIRECTION OF HOLE: ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.		15. ELEVATION GROUND WATER	
		16. DATE HOLE: STARTED / COMPLETED: 10/23/86	
7. THICKNESS OF OVERBURDEN		17. ELEVATION TOP OF HOLE	
8. DEPTH DRILLED INTO ROCK		18. TOTAL CORE RECOVERY FOR BORING %	
9. TOTAL DEPTH OF HOLE		19. SIGNATURE OF INSPECTOR	

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
			Well No.: WES-3-C3P2-86 (Beech Creek Ls)			Date well screen was set: 10/23/86
600.2			+2.5'			
597.7			0.0' Ground surface			
			Grout mixture			Water level just Prior to setting screen – 39.0'
			18.0'			
			Bentonite Pellets			
			20.0'			Teflon pipe between 35.8 – 66.8'
			Filter Pack			
541.9			55.8			
			Well Screen			
531.9			65.8			Lost all drill water near Base of Ls
			Trap			
			66.8			
			67.0 Boring Depth			

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Hole No.

DRILLING LOG	DIVISION	INSTALLATION	SHEET OF SHEETS

1. PROJECT: ABG Monitoring Wells	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station): Summary Log	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number): 03C3	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
	15. ELEVATION GROUND WATER
6. DIRECTION OF HOLE: ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	16. DATE HOLE — STARTED — COMPLETED
7. THICKNESS OF OVERBURDEN	17. ELEVATION TOP OF HOLE
8. DEPTH DRILLED INTO ROCK	18. TOTAL CORE RECOVERY FOR BORING %
9. TOTAL DEPTH OF HOLE	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0		SILT (ML)			
			Silty CLAY (CL)			
	10		CLAY (CL)			
			Clayey SAND (SC) - residual soil			
			TOP OF ROCK			
	20					
			SANDSTONE (Big Clifty Fm)			
	30					
	40				▼	Water level 12/14/87
	50		LIMESTONE (Beech Creek Fm)			
	60					Well screen for 03C3P2
			SHALE (Elwren)			
	70					

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PROJECT | HOLE NO.

Hole No. WES-C3-86

DRILLING LOG	DIVISION U S Navy	INSTALLATION Grove, In	SHEET 1 OF 5 SHEETS

1. PROJECT NWSC Groundwater Study	10. SIZE AND TYPE OF BIT HQ wirline Core Bbl
2. LOCATION (Coordinates or Station) (ABG) (Burning Grounds), Geologic Study	11. DATUM FOR ELEVATION SHOWN (TBM or MSL) MSL
3. DRILLING AGENCY WES	12. MANUFACTURER'S DESIGNATION OF DRILL Failing 1500
4. HOLE NO. (As shown on drawing title and file number) WES-C3-86	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED / UNDISTURBED
5. NAME OF DRILLER Dan Taylor	14. TOTAL NUMBER CORE BOXES 11
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
	16. DATE HOLE: STARTED 9/5/86 COMPLETED 9/13/86
7. THICKNESS OF OVERBURDEN 14.0'	17. ELEVATION TOP OF HOLE ~ 598.5 (Topo map)
8. DEPTH DRILLED INTO ROCK	18. TOTAL CORE RECOVERY FOR BORING %
9. TOTAL DEPTH OF HOLE 150.7'	19. SIGNATURE OF INSPECTOR Geologist Richard W. Hunt

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0		Clayey Silt (MSL), Tan w/small to large rk frags, v firm, moist			Drilled from 0.0 to ~8.0' w/ 8" folding auger; 8.0 to 17.2 w/ pitcher sampler using water; 17.2 to 18.5 w/ 6" RR bit; + 18.5 to Bot. w/ HQ wire line core bbl using water. (Bot Depth 150.7')
	1					
	2					
	3		Silty Clay (CL) olive Br - Br, w/rk frags, v firm, moist			
	4					
	5					
	6					
	7		Silty Clay (CL), rBr, v firm, moist			
	8		Clay (CL) rusty Br, w/ abundant rk frags (mostly sub-rounded to angular wea SS frags), v firm, moist.			
	9					
	10					

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PROJECT | HOLE NO.

Hole No. WES-C3-86

DRILLING LOG	DIVISION	INSTALLATION	SHEET 2 OF 15 SHEETS

1. PROJECT
2. LOCATION (Coordinates or Station)
3. DRILLING AGENCY
4. HOLE NO. (As shown on drawing title and file number)
5. NAME OF DRILLER
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED _____ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE
10. SIZE AND TYPE OF BIT
11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
12. MANUFACTURER'S DESIGNATION OF DRILL
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN | DISTURBED | UNDISTURBED
14. TOTAL NUMBER CORE BOXES
15. ELEVATION GROUND WATER
16. DATE HOLE | STARTED | COMPLETED
17. ELEVATION TOP OF HOLE
18. TOTAL CORE RECOVERY FOR BORING %
19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	10		Clay w/rk frags (cont.)			
			← Base of stream cut			
	11		Clayey Sand (SC) rusty Br & lGr (mottled) mass, firm, moist, highly wea SS frags occur w/depth. (Zone is wea residual on top of Big clifty sandstone)			
	12					
	13					
	14		Sand to soft sandstone, (highly wea SS) w/ mod hd SS frags, oxidized, vf-f, moist, yBr			
	15		Big clifty SS			
	16					
	17		✓ Top of Trun Rk (17.2')			
			Sandstone, lyBr, vf-f, uniform grained rounded qtz sd, thin bd, hard, friable, oxidized, shallow cross bedding + ripples.			
	18					Set 6" dia PVC surface casing to 18.5'.
			(weak sandstone)	Run 1		9/8/86 started coring w/ HQ wire line 661, using water.
	19		Big clifty SS			
	20					

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PROJECT | HOLE NO.

Hole No. WES-C3-86

DRILLING LOG	DIVISION	INSTALLATION	SHEET 3 OF 15 SHEETS

1. PROJECT	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED / UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
7. THICKNESS OF OVERBURDEN	16. DATE HOLE: STARTED / COMPLETED
8. DEPTH DRILLED INTO ROCK	17. ELEVATION TOP OF HOLE
9. TOTAL DEPTH OF HOLE	18. TOTAL CORE RECOVERY FOR BORING %
	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	20		SS (cont.)			
	21					
	22					
		40 / 45		9.5 / 9.5	Rec. / Run	
	23					
		20 / 20	Sts are tight, lightly stn sli rough, planar			
	24	15 / 20				
	25					
	26					
	27					
	28			28.0 / Run 2		
	29		rBr, highly oxidized + lim stn, occ Fe nodules, softer than above & below			← Zone should correlate w/ 18.2-19.3' in WES-C2-86
	30					

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PROJECT | HOLE NO.

Hole No. WES-C3-86

DRILLING LOG	DIVISION	INSTALLATION	SHEET 4 OF 15 SHEETS

1. PROJECT	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
	15. ELEVATION GROUND WATER
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	16. DATE HOLE — STARTED — COMPLETED
	17. ELEVATION TOP OF HOLE
7. THICKNESS OF OVERBURDEN	18. TOTAL CORE RECOVERY FOR BORING %
8. DEPTH DRILLED INTO ROCK	19. SIGNATURE OF INSPECTOR
9. TOTAL DEPTH OF HOLE	

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	30		SS (cont)			
	31					
	32	15 20 30				good water return
	33			33.2 Runs		
	34	15 15 30				
	35					
	36		35.7' probable high ground water level in zone confined above the Elwren Shale fm.			
	37		(35.7-42.5') SS is pale Br + less oxidized than above	10.2 / 10.2		
	38					
	39					
	40					

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PROJECT | HOLE NO.

Hole No. WES-C3-86

DRILLING LOG	DIVISION	INSTALLATION	SHEET 5 OF 15 SHEETS

1. PROJECT	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
7. THICKNESS OF OVERBURDEN	16. DATE HOLE — STARTED — COMPLETED
8. DEPTH DRILLED INTO ROCK	17. ELEVATION TOP OF HOLE
9. TOTAL DEPTH OF HOLE	18. TOTAL CORE RECOVERY FOR BORING %
	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	40		SS (Cont.)			
	41	0				
	42	0				
	43	0				Flange
	44	60	dBr, coarser grained oxidized num small oxidized Fe grains (Base of Big Cliffy SS) 45.1'	Run 1		
	45	5	dGr shale lens			Top of Beech Creek Ls – 45.1'
	46		slight solutioning at Ls contact. (open jt)			
	47	0	Limestone (Beech Cr) 1-m grBr m-coarse crystalline, mass, fossiliferous, v hard. v dense, Brittle,			
		3	Open jts along bedding have tan-yBr clay coating or stainin (oxidized)	10.0 / 10.0		Loosing slight amount of drill water
	48	70	Tight			
		5 / 70	Tight			
	49					
	50					

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Hole No. WES-13-86

DRILLING LOG	DIVISION	INSTALLATION	SHEET 6 OF 15 SHEETS

1. PROJECT	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
	16. DATE HOLE — STARTED — COMPLETED
7. THICKNESS OF OVERBURDEN	17. ELEVATION TOP OF HOLE
8. DEPTH DRILLED INTO ROCK	18. TOTAL CORE RECOVERY FOR BORING %
9. TOTAL DEPTH OF HOLE	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	50		Ls (cont.)			
	51	o	Tan clay stn			
	52					
	53	o	Tan clay along jt.			
		o	53.4' – probable low ground water level (?) in zone above the Elwren shale fm. No oxidation along jts below 54.4'	53.4 Run 5		good water Return
	54					
		s	Limestone Below 53.1' is dkr, fm crystalline, mass, fossiliferous w/ occ to num blk wavey shaley pts and or poorly to well formed stylolites (similar to above otherwise)			
	55					
	56			9.9/10.0		
	57					
	58					
	59					
	60					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. PROJECT HOLE NO.

Hole No. WES-03-86

DRILLING LOG	DIVISION	INSTALLATION	SHEET 7 OF 15 SHEETS

1. PROJECT	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
7. THICKNESS OF OVERBURDEN	16. DATE HOLE — STARTED — COMPLETED
8. DEPTH DRILLED INTO ROCK	17. ELEVATION TOP OF HOLE
9. TOTAL DEPTH OF HOLE	18. TOTAL CORE RECOVERY FOR BORING %
	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	60	0	Ls (cont.)			
		3				
	61					
	62					
		6				
	63			63.3 / 65.4		Pull Depth
				Run 6		
	64					
		5				Good water Return
	65		Num dgrGn sh inclus in bot 0.5'.			
			Base Beech Creek Ls (65.5') Elwren Fm (Top)			Top Elwren fm - 65.5'
	66		Shale dgrGn, thbd, mod hd, highly frac. (random) w/ s'sides.			
	67			10.1 / 10.6		
	68		drBr + grGn mottled			
	69					
	70		Shale or Claystone drBr mass, hard			

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. PROJECT HOLE NO.

Hole No. WES-C3-86

DRILLING LOG	DIVISION	INSTALLATION	SHEET 8 OF 15 SHEETS

1. PROJECT	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED / UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
7. THICKNESS OF OVERBURDEN	16. DATE HOLE: STARTED / COMPLETED
8. DEPTH DRILLED INTO ROCK	17. ELEVATION TOP OF HOLE
9. TOTAL DEPTH OF HOLE	18. TOTAL CORE RECOVERY FOR BORING %
	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	70		Blocky - flaky, num random frac. w/ sides			
			Shale (cont)			
	71					Reamed hole w/6" RR Bit to 71.5' + set 4" PVC Casing Grouted the Casing w/ seal set 6' into the Elwren Sh.
	72					
	73					
				73.4 Run 7		Flange 9/11/86
	74					
	75					Good water Return
	76					
	77		Shale, dgrGn, mass at top w/ occ sub-rounded to sub-angular Gr Ls (?) inclus ranging From 3/4" to >2" in size. Grades into th bd w/ depth, mod hard - hard,	9.7 / 10.0		
	78					
	79		Thinly laminated w/ silty sand pts + lens below ~79', shallow cross bd + ripples.			
	80					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT | HOLE NO.

Hole No. WES-C3-86

DRILLING LOG	DIVISION	INSTALLATION	SHEET 9 OF 15 SHEETS

1. PROJECT	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
7. THICKNESS OF OVERBURDEN	16. DATE HOLE — STARTED — COMPLETED
8. DEPTH DRILLED INTO ROCK	17. ELEVATION TOP OF HOLE
9. TOTAL DEPTH OF HOLE	18. TOTAL CORE RECOVERY FOR BORING %
	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	80		Shale (cont)			
	81		Sandstone, mgr Br, vf grained, w/gr Gn shaley pts, hard, cross bd, shallow ripples.			
	82		Base of Elwren			Top of Reeksville - 82.3'
			Top Reeksville fm 82.3' Limestone, lgr Br, sdy, f granular - crystalline, v hard, brittle, cross bd (?)	83.2' / 83.4 Run 8		Full depth
	83					
	84		num wavey Gn shaley pts.			
	85		conglomeratic - fossiliferous (?)			good water return.
	86		Shale, vd gnGr, mass th bd, blocky - flakey, occ Ls inclus up to ~3/4" size, num random frac w/ss sides, hd - mod hd.	10.2 / 10.0		Note from 85.4' to 85.9' frac's are coated w/ Blk Crude oil.
	87		laminated w/lt - ss lens.			
	88		Laminated w/lGr ss lens			
	89					
	90		Sandstone, mGr, vf grained, w/num dGr			

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. PROJECT HOLE NO.

Hole No. WES-C3-86

DRILLING LOG	DIVISION	INSTALLATION	SHEET 10 OF 15 SHEETS

1. PROJECT	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED / UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
7. THICKNESS OF OVERBURDEN	16. DATE HOLE: STARTED / COMPLETED
8. DEPTH DRILLED INTO ROCK	17. ELEVATION TOP OF HOLE
9. TOTAL DEPTH OF HOLE	18. TOTAL CORE RECOVERY FOR BORING %
	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	90		wavey shale pts shallow cross bd, hard, brittle			
	91		Base of Reelsville			
			Top Sample Fm (91.4')			Top of Sample fm - 91.4'
	92		Shale, vdGr-Blk, th bd, w/occ to num thin lGr ss lens and pts (from 91.4 to 99.0'), hard platey-blocky, occ pyrite inclus			
	93			93.4 / Run 9		
	94		- Ls len			
						Good water Return
	95					
	96			9.7 / 10.0		
	97			10.3		
	98					
	99		From 99.0' to 110.2' occ thin ss lens,			
	100					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT | HOLE NO.

Hole No. WES-C3-86

DRILLING LOG	DIVISION	INSTALLATION	SHEET 11 OF 15 SHEETS

1. PROJECT	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
7. THICKNESS OF OVERBURDEN	16. DATE HOLE — STARTED — COMPLETED
8. DEPTH DRILLED INTO ROCK	17. ELEVATION TOP OF HOLE
9. TOTAL DEPTH OF HOLE	18. TOTAL CORE RECOVERY FOR BORING %
	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	100		Shale (Cont.)			
	101					
	102					
	103			103.1		Full depth
				103.4		
				Run 10		9/12/86
	104					
						Good water Return
	105					
	106					
	107			10.3 / 10.0		
				+0.3		
	108					
	109					
	110					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT | HOLE NO.

Hole No. WES-C3-86

DRILLING LOG	DIVISION	INSTALLATION	SHEET 12 OF 15 SHEETS

1. PROJECT	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
	15. ELEVATION GROUND WATER
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	16. DATE HOLE — STARTED — COMPLETED
7. THICKNESS OF OVERBURDEN	17. ELEVATION TOP OF HOLE
8. DEPTH DRILLED INTO ROCK	18. TOTAL CORE RECOVERY FOR BORING %
9. TOTAL DEPTH OF HOLE	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Descriptions) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	110		Sh (cont)			
			(110.2 to 111.3) - num SS/Ls lens			
			Ls lens			
	111					
	112					
	113			113.4 / Run 11		
	114		(113.5 to 120.5') num 1Gr SS lens + pts.			
	115					
	116					
	117			10.2 / 10.2		
	118					
	119					
	120					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT | HOLE NO.

Hole No. WES-C3-86

DRILLING LOG	DIVISION	INSTALLATION	SHEET 13 OF 15 SHEETS

1. PROJECT	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
7. THICKNESS OF OVERBURDEN	16. DATE HOLE — STARTED — COMPLETED
8. DEPTH DRILLED INTO ROCK	17. ELEVATION TOP OF HOLE
9. TOTAL DEPTH OF HOLE	18. TOTAL CORE RECOVERY FOR BORING %
	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	120		Shale (Cont.)			
			Sandstone, l-m grBr, vf-f grained, w/num vdGr wavey shaley pts, cross bd, hd sli friable - brittle.			
	121					
	122					
			Calc ss/sdy Ls, v hd, brittle, occ fossils, lgrBr			
	123			123.6 Run 12		
	124					
	125					
	126					
			Shale, Blk, th bd w/lGr ss lens + pts, occ pyrite inclus, hd, platey - flakey			
	127			9.7 / 10.0		
	128					
				~~0.0~~ 0.1		0.1' Core ground away in shale
	129					
	130		See Next sheet			

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. PROJECT HOLE NO.

Hole No. WES-C3-86

DRILLING LOG	DIVISION	INSTALLATION	SHEET 14 OF 15 SHEETS

1. PROJECT	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED / UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
	16. DATE HOLE: STARTED / COMPLETED
7. THICKNESS OF OVERBURDEN	17. ELEVATION TOP OF HOLE
8. DEPTH DRILLED INTO ROCK	18. TOTAL CORE RECOVERY FOR BORING %
9. TOTAL DEPTH OF HOLE	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	130		Sandstone, 1-mgrBr, (as above)			
	131					
	132					
	133		Shale, dGr-Blk, th bd, hd, platey, flakey	133.4 / 133.6		Full Depth
	134					
	135					water return left a Blk "earthy", "flat" film on water in mud pan, noticed in lower zone of shale; possibly near top of Ls.
	136			10.2 / 10.0		
	137		Base of Sample fm			Top of Beaver Bend Ls – 137.2'
	138		Limestone (Beaver Bend fm), mgrBr, f-m granular-crystalline, fossiliferous, occ stylolites v hard, v dense, Brittle, Joints along bding as shown are most probably open.	+0.2		loosing ~25% of drill water.
	139					Lost all drill water at ~139.5'
	140					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. PROJECT HOLE NO.

Hole No. WES-23-86

DRILLING LOG	DIVISION	INSTALLATION	SHEET 15 OF 15 SHEETS

1. PROJECT	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
	15. ELEVATION GROUND WATER
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	16. DATE HOLE — STARTED — COMPLETED
7. THICKNESS OF OVERBURDEN	17. ELEVATION TOP OF HOLE
8. DEPTH DRILLED INTO ROCK	18. TOTAL CORE RECOVERY FOR BORING %
9. TOTAL DEPTH OF HOLE	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	140		Limestone (Cont.)			
	141					
	142	o				
		o				
	143	o		143.6 Run 14		
	144					
	145			3.7/3.7		
	146					
	147		Ls has num shaley pts/or num. stylolites containing insoluble residue (blk)	147.3 Run 15		Blocked
	148	o		1.7/1.7		
	149		Bot of Beaver Bend. / 1Gr soft clay	149.0 Run 16		Blocked Top of Bethel Fm - 149.0'
	150		Shale, vdgnGr, sdy in top 0.5', mass, num random frac, hd, blocky-flakey.	1.7/1.7 150.7		Bot. Depth - 150.7'

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. PROJECT HOLE NO.

DRILLING LOG	DIVISION	INSTALLATION	SHEET OF SHEETS

1. PROJECT: WELL INSTALLATION (ABG)
2. LOCATION (Coordinates or Station)
3. DRILLING AGENCY
4. HOLE NO. (As shown on drawing title and file number): 03C2P2
5. NAME OF DRILLER
6. DIRECTION OF HOLE: ☐ VERTICAL ☐ INCLINED _____ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE
10. SIZE AND TYPE OF BIT
11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
12. MANUFACTURER'S DESIGNATION OF DRILL
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED / UNDISTURBED
14. TOTAL NUMBER CORE BOXES
15. ELEVATION GROUND WATER
16. DATE HOLE: STARTED / COMPLETED 10/29/86
17. ELEVATION TOP OF HOLE
18. TOTAL CORE RECOVERY FOR BORING %
19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
			Well No: WES-3-C2P2-86 (Beech Creek Ls)			Date well screen was set: 10/29/86
583.6			+2.5			
581.1			0.0' Ground surface			
			Grout mixture			Water level just Prior to setting Screen – 36.0'
			14.0'			
			Bentonite Pellets			Teflon Pipe between 27.3 to 49.0'
			17.0'			
			Filter Pack			
543.1			38.0'			
			Well Screen			
533.1			48.0'			
			Trap			
			49.0'			
			49.0' Boring Depth			

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT) PROJECT HOLE NO.

Hole No.

DRILLING LOG	DIVISION	INSTALLATION	SHEET OF SHEETS

1. PROJECT: ABG Monitoring Wells
2. LOCATION (Coordinates or Station): Summary Log
3. DRILLING AGENCY
4. HOLE NO. (As shown on drawing title and file number): 03C2
5. NAME OF DRILLER
6. DIRECTION OF HOLE: ☐ VERTICAL ☐ INCLINED _____ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE
10. SIZE AND TYPE OF BIT
11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
12. MANUFACTURER'S DESIGNATION OF DRILL
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED / UNDISTURBED
14. TOTAL NUMBER CORE BOXES
15. ELEVATION GROUND WATER
16. DATE HOLE: STARTED / COMPLETED
17. ELEVATION TOP OF HOLE
18. TOTAL CORE RECOVERY FOR BORING %
19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0		SILT (ML)			
	10		Silty SAND (SM) TOP OF ROCK			
	20		SANDSTONE (Big Clifty Fm)			
	30		Open or clay-filled			
	40		LIMESTONE (Beech Creek Fm) Open			water level 12/14/87 Well screen for 03C2P2
	50		SHALE (Elwren Fm)			
	60					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT | HOLE NO.

Hole No. WES-C2-86

DRILLING LOG	DIVISION US Navy	INSTALLATION Crane In.	SHEET 1 OF 14 SHEETS

1. PROJECT: NWSC Groundwater Study
2. LOCATION (Coordinates or Station): (ABC/Burning Grounds), Geologic Study
3. DRILLING AGENCY: WES
4. HOLE NO. (As shown on drawing title and file number): WES-C2-86
5. NAME OF DRILLER: Don Taylor
6. DIRECTION OF HOLE: ☑ VERTICAL ☐ INCLINED _____ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN: 8.5'
8. DEPTH DRILLED INTO ROCK:
9. TOTAL DEPTH OF HOLE: 132.7'
10. SIZE AND TYPE OF BIT: HQ wireline
11. DATUM FOR ELEVATION SHOWN (TBM or MSL):
12. MANUFACTURER'S DESIGNATION OF DRILL: Failing 1500
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED: ; UNDISTURBED:
14. TOTAL NUMBER CORE BOXES: 10
15. ELEVATION GROUND WATER:
16. DATE HOLE: STARTED Aug 28, 1986; COMPLETED Sept 4, 1986
17. ELEVATION TOP OF HOLE: ~ 581.5'
18. TOTAL CORE RECOVERY FOR BORING: %
19. SIGNATURE OF INSPECTOR: Geologist Richard W. Hunt

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0		Silt (ML) dBr, clayey, w/ small ss frags, becomes sdy w/ depth, firm, moist in upper 1½' becoming sli-moist w/ depth			Drilled from 0.0 to 10.2' with an 8" dia. folding auger
	5		Silt (ML), drBr + yBr, sdy, num ss frags w/ Fe crusting (rounded + angular), firm, sli-moist - dry.			
	9		Silty Sand, (soft ss) (Big silty ss), lyTan, vf, firm, oxidized weathered			
	10					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT | HOLE NO.

Hole No. CJES C2-86

DRILLING LOG	DIVISION	INSTALLATION	SHEET 2 OF 14 SHEETS

1. PROJECT	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED / UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
	15. ELEVATION GROUND WATER
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	16. DATE HOLE: STARTED / COMPLETED
7. THICKNESS OF OVERBURDEN	17. ELEVATION TOP OF HOLE
8. DEPTH DRILLED INTO ROCK	18. TOTAL CORE RECOVERY FOR BORING %
9. TOTAL DEPTH OF HOLE	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	10		Grades to SS	Run 1		Set Temporary Surface Casing to ~10.0'.
		20	Sandstone, ly Tan w/lGr lens, vf uniform grain, th bd w/shallow cross bding + ripples, (bed dip 8-10°), oxidized, mod hard, friable; blk min stain + Limonite along jts.			Started coring w/ HQ wireline bbl at 10.2' w/clear water.
	11	45				Lost all water return at ~11.5'
	12			4.8 / 5.3	Rel. / Run	
	13	45		(~0.5)		
	14					
	15	45		15.5		
		70		Run 2		
		30 / 45				
	16					
	17	80	Concentration of Blk Fe grains.			
		30		8.2 / 8.9		
	18	20	Thin clay lens			
		10				
		10	drBr. highly oxidized zone (Limonite concentration) soft rk.	(~0.7)		
	19	11				
		45				
	20	30				

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (PROJECT) (HOLE NO.)

Hole No. WES-CC-86

DRILLING LOG	DIVISION	INSTALLATION	SHEET 3 OF 14 SHEETS

1. PROJECT	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
7. THICKNESS OF OVERBURDEN	16. DATE HOLE — STARTED — COMPLETED
8. DEPTH DRILLED INTO ROCK	17. ELEVATION TOP OF HOLE
9. TOTAL DEPTH OF HOLE	18. TOTAL CORE RECOVERY FOR BORING %
	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	20		SS, (Cont)			
			(20.3 - 22.2') slightly coarser, 1-Br oxidized num Fe grains. (vf-m)			
	21					
			Joints have Blk min stain + limonite coating, generally rough + planar to sli irregular.			
	22					
			Color becomes 1 ton-Gr below 22.2 - 25.0'			
	23					
	24			24.4 Run 3		
	25		(25.0 - 26.4') slightly coaser (vf m), 1-d Br num oxidized Fe grains, 1Br + dEr			
	26					
	27			8.1/9.1'		
	28		Color 1 Ton-Gr below 26.4' to ~32.5'	(~1.0')		~27 to 28' (Projected Top of Beech Creek Ls prior to Solutioning processes. Big Cliff SS below ~28' has settled into Solution Cavities in upper Beech Creek Ls
	29					
	30					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT | HOLE NO.

Hole No. WES-RZ-86

DRILLING LOG	DIVISION	INSTALLATION	SHEET 4 OF 14 SHEETS

1. PROJECT	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
7. THICKNESS OF OVERBURDEN	16. DATE HOLE — STARTED — COMPLETED
8. DEPTH DRILLED INTO ROCK	17. ELEVATION TOP OF HOLE
9. TOTAL DEPTH OF HOLE	18. TOTAL CORE RECOVERY FOR BORING %
	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	30		SS, (cont) (Big cliffy)			
	31		Blk min stn along Jts.			
	32					
	33		open (clay filled)			
			(33.5-36.5') SS is dBr + lBr, vf m grain w/ minor coarse grains mum oxidized Fe grains + small Fe nodules up to ~1/4" size. Lim + Blk min stn along Jts.	33.5' / Run 4		
	34					
	35					
	36					
	37		Note: The core loss zone represents solutioning in the upper Beech creek Ls. The overlying Big Cliffy SS has dropped down, or settled into the cavities created by the solutioning. Joints and bedding planes in the lower Big Cliffy SS have opened in proportion to the degree of settlement.	3.0 / 8.0' (-5.0)		
	38					
	39					
	40					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT) PROJECT HOLE NO.

Hole No. WES-CZ-86

DRILLING LOG	DIVISION	INSTALLATION	SHEET 5 OF 14 SHEETS

1. PROJECT	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
	16. DATE HOLE — STARTED — COMPLETED
7. THICKNESS OF OVERBURDEN	17. ELEVATION TOP OF HOLE
8. DEPTH DRILLED INTO ROCK	18. TOTAL CORE RECOVERY FOR BORING %
9. TOTAL DEPTH OF HOLE	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	40					
	41			41.5 Run 5		8/29/86 water level – 36.0'
	42					
	43					
	44		Solution surface ?	3.0 / 6.0'		
	45		Limestone (Beech Cr. – Lower zone) m br Gr + wea in top 1½', vdGr + unwea in bot 1½', f-m crystalline, v hard, fossiliferous, slightly shaley w/ pyrite inclus at contact w/ underlying Elwren shale. Joints are coated w/ white calcareous + fim stn.	(3.0')		– Beech Creek Ls. (Lower Zone)
	46					
	47		Pyrite crystals at contact ?	47.5 Run 6		Top Elwren fm 47.5'
	48		Shale (Elwren fm) dgr Gn, mass-th bd, mod hard, crumbly-flakey, occ s'sides			
	49			3.1 / 4.7 (1.6)		
	50					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (PROJECT) (HOLE NO.)

Hole No. WES-CZ-86

DRILLING LOG	DIVISION	INSTALLATION	SHEET 6 OF 19 SHEETS

1. PROJECT	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
	16. DATE HOLE — STARTED — COMPLETED
7. THICKNESS OF OVERBURDEN	17. ELEVATION TOP OF HOLE
8. DEPTH DRILLED INTO ROCK	18. TOTAL CORE RECOVERY FOR BORING %
9. TOTAL DEPTH OF HOLE	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	50		Shale (cont.)			In an effort to set 4" casing ran a 5 3/4" RR Bit to ~ 45.0'. Rods broke off at top of 10' Guide above bit. Retrived tools from hole and went back in with a 6 3/4" RR Bit. Bit was "grabbing" so bad in cavity zone that the possibility of breaking off in hole over-shadowed continuing w/RR Bit. Using a diamond shoe on end of 6" casing - reamed hole to 54.8' and set 4" PVC casing to 54.8'. Sealed casing in the Elpuren Sh w/ Grout. 9/3/86 - started back coring w/HQ wireline bbl. Getting most of water return thr. 4" casing.
	51					
	52		Shale, dgrGn w/alter drBr layering, tin bd, platey, hard	52.2' Run 7		
	53			2.1/2.6		
	54			-0.5		
			num drBr veinlets (like healed frac's) in Gn Sh.	54.8' Run 8		
	55		claystone drBr, mass, hd, blocky, s'sides dip ~5°.			
			Shale, dgrGn, mass, highly frac w/ occ angular GnGr Ls(?) and drBr claystone inclus, hard, blocky, (zone has somewhat of a breciated appearance)			
	56					
	57		mottled w/ drBr clst.	7.9/8.3		
	58			-0.4		
	59					
	60		See next sheet			

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT | HOLE NO.

Hole No. OVES-C2-86

DRILLING LOG	DIVISION	INSTALLATION	SHEET 7 OF 14 SHEETS

1. PROJECT	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
	16. DATE HOLE — STARTED — COMPLETED
7. THICKNESS OF OVERBURDEN	17. ELEVATION TOP OF HOLE
8. DEPTH DRILLED INTO ROCK	18. TOTAL CORE RECOVERY FOR BORING %
9. TOTAL DEPTH OF HOLE	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	60		Shale dGnGr, w/lter lens & partings of mGr, vf silty sandstone (v thnly laminated sh & SS), hard			
	61					
	62			62.7		Pull depth
	63			63.1		
				Run 9		
			↙ Top Reelsville fm 63.8'			Top Reelsville fm 63.8'
	64		Limestone, v hard, brittle — olive grBr, sdy, ferruginous — lGr, vf granular-crystalline sdy(?)			
	65		alter olive grBr & lGr Ls (as above), cross bedding (Breaks appear fresh)			
	66		lGr Ls (as above)	10.4 / 10.0		
	67		(66.4-70.0) Shale dGr laminated w/mGr silty SS/Ls. (Similar to above), small angular Ls frags are included in the top 0.3'.	+0.4		
	68					
	69					
	70					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT | HOLE NO.

Hole No. WES-CZ-B6

DRILLING LOG	DIVISION	INSTALLATION	SHEET 8 OF 11 SHEETS

1. PROJECT	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED / UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
7. THICKNESS OF OVERBURDEN	16. DATE HOLE: STARTED / COMPLETED
8. DEPTH DRILLED INTO ROCK	17. ELEVATION TOP OF HOLE
9. TOTAL DEPTH OF HOLE	18. TOTAL CORE RECOVERY FOR BORING %
	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	70		(70.0 - 73.1) Sandstone, mgr Br, fine grained, mass w/num gr Gn shale partings + Flattened inclusions, v hard, brittle (Jt's are rgh, irreg, part) filled w/Gr clay			
	71		Ls, lGr, w/acc Gn sh pts, v hard, brittle			
	72		Ls (as above)			
	73		← Top of Sample fm	73.1		Top of Sample fm 73.1
			Shale, dGr, th bd w/ num to acc lGr, v fine thin SS / Ls lens, hard, Platey - flakey	Run 10		
	74					
	75					
	76			10.0 / 10.0		
	77					
	78					
	79		Ls, lGr, v fine, granular, brittle, v hard, acc Sh pts.			
	80					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. PROJECT HOLE NO.

Hole No. WES-C2-86

DRILLING LOG	DIVISION	INSTALLATION	SHEET 9 OF 14 SHEETS

1. PROJECT	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED / UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
7. THICKNESS OF OVERBURDEN	16. DATE HOLE: STARTED / COMPLETED
8. DEPTH DRILLED INTO ROCK	17. ELEVATION TOP OF HOLE
9. TOTAL DEPTH OF HOLE	18. TOTAL CORE RECOVERY FOR BORING %
	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	80		Shale (cont.)			
	81					
	82					
	83			83.1 Run 11		Pull 9/4/86
	84					
	85		Ls, olive Gr, v hd, v Fine.			
	86					
	87			8.8'/10.0		
	88			100%		
	89					
	90					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. PROJECT HOLE NO.

Hole No. WES-C2-86

DRILLING LOG	DIVISION	INSTALLATION	SHEET -10 OF 14 SHEETS

1. PROJECT	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
	15. ELEVATION GROUND WATER
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	16. DATE HOLE — STARTED — COMPLETED
7. THICKNESS OF OVERBURDEN	17. ELEVATION TOP OF HOLE
8. DEPTH DRILLED INTO ROCK	18. TOTAL CORE RECOVERY FOR BORING %
9. TOTAL DEPTH OF HOLE	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	90		Shale (Cont.)			
	91					
				91.9		Pull depth
	92					
	93			93.1		
				Run 12		
	94					
	95			100%		
	96			10.1 / 9.4		
				(+0.7		
	97			+0.5		
				(+1.2)		
	98					
	99					
	100					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. PROJECT HOLE NO.

Hole No. WES-C2-86

DRILLING LOG	DIVISION	INSTALLATION	SHEET 11 OF 14 SHEETS

1. PROJECT	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED / UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
	16. DATE HOLE: STARTED / COMPLETED
7. THICKNESS OF OVERBURDEN	17. ELEVATION TOP OF HOLE
8. DEPTH DRILLED INTO ROCK	18. TOTAL CORE RECOVERY FOR BORING %
9. TOTAL DEPTH OF HOLE	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	100		Shale (cont)			
	101		Sandstone, m Gr, fine grained (uniform rounded qtz sd grains), mm vdGr-Blk wavey shale partings, hard, sli friable. (101.0-114.5')			
	102			102.0		Pull depth
				102.5 / Run 13		
	103	S				
		S				Good water Ret.
	104	60	It's rough, irregular, Fresh (v tight insitu)			
				100%		
	105	80				
	106		lighter Gr + less friable SS than above and below, Calcareous (sd, Ls?)	10.4 / 10.3		
				(+0.1) +0.4 (+0.5)		
	107					
	108					
	109	70				
	110					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT | HOLE NO.

Hole No. WES-C2-86

DRILLING LOG	DIVISION	INSTALLATION	SHEET 12 OF 14 SHEETS

1. PROJECT	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
7. THICKNESS OF OVERBURDEN	16. DATE HOLE — STARTED — COMPLETED
8. DEPTH DRILLED INTO ROCK	17. ELEVATION TOP OF HOLE
9. TOTAL DEPTH OF HOLE	18. TOTAL CORE RECOVERY FOR BORING %
	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	110		Sandstone (Cont.)			
	111	4	Fresh			
	112			112.4		Pull depth
				112.8		
				Run 14		
	113	85	Fresh			
	114					
			Shale, dGr, thbd, mod hard, earthy			
	115					
				100%		
	116			10.4 / 10.0		
			Alter. Ls lens up to 1" thick			
			Clay, vlGr, soft	+0.4		
	117		Limestone, lt-m gr-Br, Coarse grained oolitic(?) v hard, brittle.			Top of Beaver Creek Ls - 117.0'
	118					
			dGr Sh lens			
			Limestone, Gr-brGr, fine-med grained-crystalline, oolitic (?), v hard, brittle, occ well developed stylolites			
	119					
	120					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT | HOLE NO.

Hole No. CWES-C2-26

DRILLING LOG	DIVISION	INSTALLATION	SHEET 13 OF 14 SHEETS

1. PROJECT	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED / UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
7. THICKNESS OF OVERBURDEN	16. DATE HOLE: STARTED / COMPLETED
8. DEPTH DRILLED INTO ROCK	17. ELEVATION TOP OF HOLE
9. TOTAL DEPTH OF HOLE	18. TOTAL CORE RECOVERY FOR BORING %
	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	120		LS (cont.)			
	121					Loosing 50% of drill water
	122	90 / 80	partially open, light stn along jts.			
				122.8' Run 15		Flange
	123					
	124					
	125	5°	- Lost all drilling water that was remaining at this depth			— Lost all drill water.
	126					
	127	15				
	128					
	129		Top of Bethel Fm			Top of Bethel Fm. 129.5'
	130		Shale, dGr, th bd w/ num vf ss pts + thin			

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT | HOLE NO.

Hole No. WES-LZ-86

DRILLING LOG	DIVISION	INSTALLATION	SHEET 14 OF 14 SHEETS

1. PROJECT	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED / UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
7. THICKNESS OF OVERBURDEN	16. DATE HOLE: STARTED / COMPLETED 9/4/86
8. DEPTH DRILLED INTO ROCK	17. ELEVATION TOP OF HOLE
9. TOTAL DEPTH OF HOLE	18. TOTAL CORE RECOVERY FOR BORING %
	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	130		disc shaped lens, hard, platey.			
	131					
	136					
	133		Bottom of hole 132.7'			water level 9/5/86 68.7' (water in Beaver Bend Ls)
	134					
	135					
	136					
	137					
	138					
	139					
	140					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT | HOLE NO.

APPENDIX D: SAFETY DATA SHEETS FOR DYES

MATERIAL SAFETY DATA SHEET

15174 Uranine Conc.

SECTION I - IDENTIFICATION

MANUFACTURER/DISTRIBUTOR. CHEMCENTRAL/Detroit
EMERGENCY PHONE NUMBER... (313) 941-4800
EFFECTIVE DATE..... 11-05-85

CHEMICAL NAME..... Acid Yellow 73 (Color Index name)
TRADE NAME..... 15174 Uranine Conc.
CHEMICAL FAMILY..... Xanthene
CHEMICAL FORMULA..... 45350 (Color Index formula)

SECTION II - HAZARDOUS INGREDIENTS

HAZARDOUS COMPONENTS	HAZARDOUS %	TLV (Units)	PROD. CAS #
None as per part 29 CFR 1910.1200			

SECTION III - PHYSICAL DATA

BOILING Point(F)..... N/A
FREEZING POINT (F)..... N/A
VOLATILITY/VOL(%)..... N/A
MELTING POINT..... N/A
VAPOR PRESSURE (mm Hg)... N/A
VAPOR DENSITY (Air=1).... N/A
SOLUBILITY IN H20..... Moderate
APPEARANCE/ODOR..... Orange powder, no characteristic odor
SPECIFIC GRAVITY (H20=1). Approximately 1
EVAPORATION RATE..... N/A
PH..... N/A

SECTION IV - FIRE AND EXPLOSION HAZARD DATA

FLASH POINT..... N/A
LOWER FLAME LIMIT..... N/A
HIGHER FLAME LIMIT..... N/A
EXTINGUISH MEDIA..... Water fog, CO_2, or Dry chemical.
FOR FIRE..... Fire fighters should be equipped with self contained breathing apparatus and turnout gear.
UNUSUAL FIRE HAZARD..... Adequate ventilation and clean up must be maintained to minimize dust accumulation. May form explosive dust/air mixture.

SECTION V - HEALTH HAZARD DATA

MATERIAL SAFETY DATA SHEET

15174 Uranine Conc.

THRESHOLD LIMIT VALUE.... Ingestion in rats LD 50>6,800 mg/kg
OVER EXPOSURE EFFECTS.... Contact with eyes may result in severe irritation. Contact with skin may result in irritation. Ingestion may result in gastric disturbances. Inhalation of dust may irritate respiratory tract.
FIRST AID PROCEDURES..... Flush eyes with flowing water at least 15 minutes. If irritation develops, consult a physician. Wash affected skin areas thoroughly with soap and water. If irritation develops, consult a physician. Remove and launder contaminated clothing before reuse. If swallowed, dilute with water and induce vomiting. Get immediate medical attention. If inhaled, move to fresh air. Aid in breathing, if necessary, and get medical attention.
NEVER GIVE FLUIDS OR INDUCE VOMITING IF PATIENT IS UNCONSCIOUS OR HAS CONVULSIONS.

SECTION VI - REACTIVITY DATA

CHEMICAL STABILITY..... Stable
CONDITIONS TO AVOID..... N/A
INCOMPATIBLE MATERIALS... Unknown
DECOMPOSITION PRODUCTS... Carbon monoxide,Carbon dioxide,and oxides of Nitrogen.

HAZARDOUS POLYMERIZATION. Does not occur
POLYMERIZATION AVOID..... N/A

SECTION VII - SPILL OR LEAK PROCEDURE

FOR SPILL ..... Spills should be contained and placed in suitable containers.
WASTE DISPOSAL METHOD.... Do not discharge into sewers or waterways. Dispose of in accordance with local regulations.

SECTION VIII - SPECIAL PROTECTION

RESPIRATORY PROTECTION... NIOSH/OSHA approved dust respirator as necessary.
VENTILATION..... Local exhaust to control dusts.
PROTECTIVE GLOVES..... To prevent skin contact.
EYE PROTECTION..... Goggles.
PROTECTIVE EQUIPMENT..... Eye wash fountains should be easily accessible.
HANDLING AND STORAGE..... Keep away from excessive heat and moisture. Keep containers closed.

SECTION IX - SPECIAL PRECAUTIONS

HAZARD CLASS..... N/A
DOT SHIPPING NAME..... Coal Tar Dyestuff

MATERIAL SAFETY DATA SHEET

15174 Uranine Conc.

REPORTABLE QUANTITY (RQ) . N/A
SN NUMBER..... N/A
NA #..... N/A
PACKAGING SIZE..... Various

FOOT NOTES
This information is furnished without warranty, representation, or license of any kind, except that it is accurate to the best of CHEMCENTRAL Corporation's knowledge or obtained from sources believed by CHEMCENTRAL Corporation to be accurate. The CHEMCENTRAL Corporation does not assume any legal responsibility for use or reliance upon same. Customers are encouraged to conduct their own tests. Before using any product, read its label.

N/A - Not applicable

REFERENCES

MATERIAL SAFETY DATA SHEET

MANUFACTURING DIV. ADDRESS

MOBAY CHEMICAL CORPORATION-Dyes and Pigments Division
PO Box 385 Union Metropolitan Park
Union, New Jersey 07083

DATA SHEET NO.
DIVISION
ISSUE DATE Aug 1983
ISSUED BY
SUPERSEDES ISSUE OF Nov 1980

CHEMTREC CHEMICAL TRANSPORTATION EMERGENCY TELEPHONE NO: 800-424-9300; DISTRICT OF COLUMBIA: 202-483-7616	MOBAY NON-TRANSPORTATION EMERGENCY NO.: (803) 553-3155
PRODUCT NAME: PHORWITE AR Solution	PRODUCT CODE NUMBER: 70129, 09
CHEMICAL FAMILY: Stilbene	CHEMICAL NAME & SYNONYMS: Fluorescent whitening agent
CHEMICAL FORMULA: Proprietary	TRADE NAME & SYNONYMS: Same as product name

HAZARDOUS INGREDIENTS

HAZARDOUS MIXTURES OF OTHER LIQUIDS, SOLIDS OR GASES	%	CURRENT TLV
None as per 29 CFR section 1910.1000 subpart Z		

PHYSICAL DATA

APPEARANCE (SOLID, LIQUID, GAS)	MOLECULAR WEIGHT	MELT POINT	SPECIFIC GRAVITY
Liquid	NA	NA	NE
VAPOR DENSITY (AIR=1)	COLOR	BULK DENSITY	BOILING POINT
NE	Yellow	NA	NE
VAPOR PRESSURE	SOLUBILITY (WATER)	ODOR	% VOLATILE BY VOLUME
NE	Soluble	Characteristic	NE

FIRE & EXPLOSION DATA

FLASH POINT °F (METHOD USED)	FLAMMABLE LIMIT	EXTINGUISHING MEDIA
NA	Lel NA Uel NA	Water, dry chemical, CO_2, foa

SPECIAL FIRE FIGHTING PROCEDURES, UNUSUAL FIRE OR EXPLOSION HAZARDS

Firefighters should be equipped with self-contained breathing apparatus to protect against potentially toxic and irritating fumes.

TOXICITY DATA

LD50, ORAL (INGESTION)	LD50, DERMAL (SKIN CONTACT)	INHALATION (LC50)
NE	NE	NE
FISH, LC50 (LETHAL CONCENTRATION)	TLV (UNITS) (THRESHOLD LIMIT VALUE)	SKIN IRRITATION
NE	NE	NE
EFFECTS TO EYE	EFFECTS TO LUNG	OTHER
NE	NE	

EMERGENCY AND FIRST AID PROCEDURES, EFFECTS OF OVER EXPOSURE

For eyes: Flush thoroughly with water. Get prompt medical attention.

For skin: Flush with water.

Effects of overexposure: Prolonged contact may cause irritation.

PYLAM Products Company, Inc.

MATERIAL SAFETY DATA SHEET

I. MATERIAL IDENTIFICATION

NAME: DIRECT YELLOW 96
MANUFACTURER/DISTRIBUTOR: PYLAM PRODUCTS COMPANY INC.
1001 STEWART AVE.
GARDEN CITY, N.Y. 11530

TELEPHONE NUMBER: (516) 222-1750

COLOR INDEX NAME/NUMBER: DIR. YELLOW 96 CAS NUMBER:

DATE PREPARED: 2/89 TYPE: STILBENE

II. HAZARDOUS COMPONENTS NONE AS PER 29CFR PART 1919.1200

III. PHYSICAL DATA

ODOR : NONE
FORM : POWDER
COLOR : YELLOW
SOLUBILITY IN H20: GOOD

IV. HAZARDOUS REACTIVITY

INSTABILITY : STABLE. POLYMERIZATION: NOT OCCUR
INCOMPATIBILITY: OXIDIZING AND REDUCING AGENTS
DECOMPOSITION PRODUCTS: OXIDES OF NITROGEN AND OXYGEN

V. FIRE AND EXPLOSION DATA

DUST MAY FORM EXPLOSIVE MIXTURE WITH AIR.
EXTINGUISHING MEDIA: WATER. DRY CHEMICAL. CO2.
SPECIAL FIRE FIGHTING INSTRUCTIONS: NONE

VI. SPECIAL PROTECTION

GENERALLY APPLICABLE CONTROL MEASURES AND PROCEDURES

USE ONLY WITH ADEQUATE VENTILATION. KEEP CONTAINER TIGHTLY CLOSED. AVOID DUST GENERATION. DO NOT CONSUME FOOD, DRINK OR TOBACCO IN THE AREAS WHERE THEY MAY BECOME CONTAMINATED WITH THIS MATERIAL.

PERSONAL PROTECTIVE EQUIPMENT

EYE/FACE: COVERALL CHEMICAL SPLASH GOGGLES.
PROTECTIVE GLOVES: RUBBER

VII. HEALTH HAZARD DATA

TLV UNITS: ~~NOT ESTABLISHED~~
OVER EXPLOSURE EFFECTS: ~~NOT ESTABLISHED~~
LD50 GREATER THAN - 15,000 MG/KG

EYE - NON-IRRITATING
SKIN " "

VIII. EMERGENCY FIRST AID

INHALATION – IF LARGE AMOUNTS ARE INHALED, REMOVE TO FRESH AIR. IF NOT BREATHING, GIVE ARTIFICIAL RESPIRATION, PREFERABLY MOUTH-TO-MOUTH. IF BREATHING IS DIFFICULT, GIVE OXYGEN, AND CALL A PHYSICIAN.

SKIN CONTACT – FLUSH SKIN WITH WATER AFTER EXCESSIVE CONTACT. WASH THOROUGHLY WITH HANDCREAM OR HANDCLEANER.

EYE CONTACT – FLUSH EYES IMMEDIATELY WITH PLENTY OF WATER FOR AT LEAST 15 MINUTES. CALL A PHYSICIAN.

INGESTION – INDUCE VOMITING IMMEDIATELY BY GIVING TWO GLASSES OF WATER ALSO STICKING FINGER DOWN THROAT. NEVER GIVE FLUIDS TO AN UNCONSCIOUS PERSON. CALL A PHYSICIAN.

IX. DISPOSAL AND LEAK INFORMATION

USE AN ABSORBENT TO PREVENT DUSTING. SWEEP OR SHOVEL INTO A CONTAINER. WASH DOWN THE AREA WITH WATER.

WASTE DISPOSAL METHOD

BURY OR INCINERATE ACCORDING TO FEDERAL, STATE, AND LOCAL REGULATIONS.

DRUM DISPOSAL

CONTAINERS SHOULD BE TRIPLE RINSED WITH WATER BEFORE DISPOSAL.

X. SHIPPING DATA

DOT PROPER SHIP – NOT REGULATED

XI. STORAGE DATA

STORE IN COOL, DRY PLACE.

THE DATA AND INFORMATION GIVEN IN THIS MATERIAL SAFETY DATA SHEET ARE ACCURATE ON THE DATE OF PREPARATION. IT DOES NOT INDICATE ANY WARRANTY OR REPRESENTATION. WE DISCLAIM ALL LIABILITY RELATING TO USE OF THIS MATERIAL SINCE THIS IS BEYOND OUR CONTROL.

APPENDIX E: PHOTOS OF DYE TRACE SAMPLING SITES

Figure E1. Mountain spring

Figure E2. Spring D

Figure E3. Spring E

Figure E4. Solution-widened joints in Beech Creek limestone at Spring E

Figure E5. Spring F

Figure E6. Spring F

Figure E7. Spring A

Figure E8. Spring A

Figure E9. Spring A′ area (also see Figure 9 of main text)

Figure E10. Spring C

Figure E11. Spring C

Figure E12. Little Sulphur Creek north

Figure E13. Little Sulphur Creek south

APPENDIX F: TRACER TEST DATA SHEETS

DYE INJECTION DATA SHEET

TEST SITE: Ammunition Burning Grounds
NAVWPNSUPPCEN, Crane, Ind.

INVESTIGATOR: USAEWES - Murphy
NORTHNAVFACENCOM - Ciocco

DATE INJECTED	INJECTION SITE (Well #)	TRACER(S) USED	COMMENTS
gin Injection 1035 hrs. 20 JAN 90	03-C03P2-86	Flourescein	No primer water - Pour (inject) 1 gallon slug of
ind Fresh Water 1135 hrs			Flourescein into well. Flush slug w/ Fresh
			water from WES water truck at 20 gpm int
			T&C unit 1130 hrs. Total of 1200 gallons
			of Fresh water. (Note - well take max
			flow rate (w/ mod hydraulic head) from WE
			tank. Very cavernous formation)
egin Injection 1235 hrs 20 JAN 90	03-C03P2-86	DYECT Yellow (DY) 96	No primer water - Pour (inject) 2 gallons
ind Fresh Water 1345 hrs			(2-1 gal. jugs) of DY96 into monitoring well. At
			1235 hrs begin pumping fresh water at 20 gpm
			into well. Formation tight & can't take rate capac
			so reduce flow to a "steady state" at ≈ 7 gpm.
			Pump fresh water from WES tank truck unt
			1345 hrs. Total of 68 min x 7 gpm = 476 gallon
egin Injection 1346 hrs 20 JAN 90	03-C03P2-86	Phorwite AR	Immed. follows fresh water for DY96. No prime
ind Fresh Water 1533 hrs			Inject (pour) 2 gallons of Phorwite AR into w
			Flush fresh water into well @ 7 gpm until
			1533 or 107 min x 7 gpm = "749 gallons"

page 1 of 1

BUG PLACEMENT DATA SHEET

TEST SITE: Ammunition Burning Grounds
NAVWPNSUPPCEN, Crane IN

INVESTIGATOR: USAEWES - Murphy
NORTHNAVFACENGCOM - Ciocco

Date Bug Placed	Monitoring Loc.	Bug Type Cotton	Bug Type Charcoal	Date Bug Collected	Jar #	Comments
1530 hrs 18 Jan 90	Mtn Spring	1A	1B	1340 hrs. 19 Jan 90	1A & B	Background bugs
1630 hrs 18 Jan 90	Spring D	2A	2B	1400 19 Jan 90	2A & B	" "
1640 hrs 18 Jan 90	Spring E	3A	3B	1412 19 Jan 90	3A & 3B	" "
1650 hrs 18 Jan 90	Spring F	4A	4B	1420 19 Jan 90	4A & 4B	" "
1010 hrs 19 Jan 90	Spring C	5A	5B	1445 19 Jan 90	5A & 5B	" "
1020 hrs 19 Jan 90	2nd Green Bridge in Little Sulphur Creek	6A	6B	1455 19 Jan 90	6A & 6B	" "
1040 hrs 19 Jan 90	Spring A'	7A	7B	1520 19 Jan 90	7A & 7B	(90 Loaded N of Spring A)
1043 hrs 19 Jan 90	Spring A	8A	8B	1523 19 Jan 90	8A & 8B	" "
1100 hrs 19 Jan 90	Spring B	9A	9B	1535 19 Jan 90	9A & 9B	" "
1130 hrs 19 Jan 90	SE Boundary Gate in Little Sulphur Creek	10A	10B	1550 19 Jan 90	10A & 10B	" "
1340 hrs 19 Jan 90	Mtn. Spring	11A	11B	0890 25 Jan 90	11A & B	will be left for plant tow
1400 hrs 19 Jan 90	Spring D	12A	12B	0900 25 Jan 90	12A & B	" "
1414 hrs. 19 Jan 90	Spring E	13A	13B	0920 25 Jan 90	13A & B	" "
1421 hrs 19 Jan 90	Spring F	14A	14B	0930 25 Jan 90	14A & B	" "
1450 hrs 19 Jan 90	Spring C	15A	15B	150 20 Jan 90	15A & B	collected after injection
1450 hrs 19 Jan 90	Spring C	16A	16B	0940 25 Jan 90	16A & B	One week bug w/ rope
1500 hrs 19 Jan 90	2nd Green Bridge in Little Sulphur Creek	17A	17B	1525 20 Jan 90	17A & B	collected after injection
1500 hrs 19 Jan 90	2nd Green Bridge in Little Sulphur Creek	18A	18B	0950 25 Jan 90	18A & B	One week bug w/ rope
1522 hrs 19 Jan 90	Spring A	19A	19B	1545 20 Jan 90	19A & B	collected after injection
1522 hrs 19 Jan 90	Spring A	20A	20B	0955 25 Jan 90	20A & B	One week bug w/ rope
1523 hrs 19 Jan 90	Spring A'	21A	21B	1545 20 Jan 90	21A & B	collected after injection
1522 hrs 19 Jan 90	Spring A'	22A	22B	1000 25 Jan 90		One week bug w/ rope
1535 hrs 19 Jan 90	Spring B	23A	23B	1610 20 Jan 90	23A & B	collected after injection
1535 hrs 19 Jan 90	Spring B	24A	24B			one week bug w/ rope
1600 hrs 19 Jan 90	SE Boundary Gate in Little Sulphur Creek	25A	25B	1600 20 Jan 90	25A & B	collected after injection
1600 hrs 19 Jan 90	SE Boundary Gate in Little Sulphur Creek	26A	26B	1030 25 Jan 90	26A & B	one week bug w/ rope
1615 hrs 19 Jan 90	MW B 18	27A	27B	1620 19 Jan 90	27A & B	Background Bug & boiler & power bugs
1630 hrs 19 Jan 90	MW C 24	28A	28B	1635 19 Jan 90	28A & B	(Kerosene Petrol vapors in well)
1645 hrs 19 Jan 90	MW C 25	29A	29B	1645 19 Jan 90	29A & B	" " "
1715 hrs 19 Jan 90	MW C 37	30A	30B	1725 19 Jan 90	30A & B	" " "
1510 hrs 20 Jan 90	Spring C	31A	31B	1345 21 Jan 90	31A & B	2nd smpl after injection

BUG PLACEMENT DATA SHEET

TEST SITE: Ammunition Burning Grounds
NAVWPNSUPPCEN, Crane, IN

INVESTIGATOR: USAEWES - Murphy
NORTHNAVFACENGCOM - Ciocco

Date Bug Placed	Monitoring Loc.	Bug Type Cotton	Bug Type Charcoal	Date Bug Collected	Jar #	Comments
1525 hrs 20 Jan 90	2nd Green Bridge in Little Sulphur Creek	32A	32B	1350 hrs 21 Jan 90	32A & B	2nd smpl after injection
1545 hrs 20 Jan 90	Spring A	33A	33B	1405 21 Jan 90	33A & B	" " "
1545 hrs 20 Jan 90	Spring A'	34A	34B	1410 21 Jan 90	34A & B	" " "
1600 hrs 20 Jan 90	SE Boundary Gate in Little Sulphur Creek	35A	35B	1625 21 Jan 90	35A & B	" " "
1610 hrs 20 Jan 90	Spring B	36A	36B	1610 21 Jan 90	36A & B	4 Bad overflow spring flow
1345 hrs 21 Jan 90	Spring C	37A	37B	1340 22 Jan 90	37A & B	3rd Smpl. after inject.
1350 hrs 21 Jan 90	2nd Green Bridge in Little Sulphur Creek	38A	38B	1355 22 Jan 90	38A & B	" " "
1405 hrs 21 Jan 90	Spring A	39A	39B	1420 22 Jan 90	39A & B	" " "
1410 hrs 21 Jan 90	Spring A'	40A	40B	1420 22 Jan 90	40A & B	" " "
1435 hrs 21 Jan 90	MWB10	41A	41B	1435 21 Jan 90	41A & B	4 Bailers, 1 clear 3 cloudy, 1st smpl after inject.
1520 hrs 21 Jan 90	MWC24	42A	42B	1525 21 Jan 90	42A & B	5 bailers, 3 clear 1 cloudy good recovery reported on w/ 1st smpl. after injection
1545 hrs 21 Jan 90	MWC25	43A	43B	1545 21 Jan 90	43A & B	6 bailers - all clear good recovery 1st smpl. after injection
1615 hrs 21 Jan 90	Spring B	44A	44B	1440 22 Jan 90	44A & B	3rd smpl. after injection
1625 hrs 21 Jan 90	SE Boundary Gate in Little Sulphur Creek	45A	45B	1440 22 Jan 90	45A & B	" " "
1650 hrs 21 Jan 90	MWC37	46A	46B	1700 21 Jan 90	46A & B	5 bailer - 3 clear 2 cloudy 1st smpl after injection
1340 hrs 22 Jan 90	Spring C	47A	47B	0930 23 Jan 90	47A & B	4th smpl. after injection
1355 hrs 22 Jan 90	2nd Green Bridge in Little Sulphur Creek	48A	48B	0940 23 Jan 90	48A & B	" "
1420 hrs 22 Jan 90	Spring A	49A	49B	0950 23 Jan 90	49A & B	" "
1420 22 Jan 90	Spring A'	50A	50B	0955 23 Jan 90	50A & B	" "
1440 22 Jan 90	SE Boundary Gate in Little Sulphur Creek	51A	51B	1040 23 Jan 90	51A & B	" "
1450 22 Jan 90	Spring B	52A	52B	1000 23 Jan 90	52A & B	" "
1510 22 Jan 90	MWB10	53A	53B	1510 22 Jan 90	53A & B	6 bailers; 4 clear 2 cloudy 2nd smpl. after inject.
1545 22 Jan 90	MWC37	54A	54B	1550 22 Jan 90	54A & B	5 bailers; 4 clear 1 cloudy 2nd smpl after inject.
0930 23 Jan 90	Spring C	55A	55B	0915 24 Jan 90	55A & B	5th smpl after injection
0940 23 Jan 90	2nd Green Bridge in Little Sulphur Creek	56A	56B	0930 24 Jan 90	56A & B	" " "
0950 23 Jan 90	Spring A	57A	57B	0940 24 Jan 90	57A & B	" " "
0955 23 Jan 90	Spring A'	58A	58B	0945 24 Jan 90	58A & B	" " "
1012 23 Jan 90	SE Boundary Gate in Little Sulphur Creek	59A	59B	1150 24 Jan 90	S	" " "
1020 23 Jan 90	Spring B	60A	60B	0950 24 Jan 90	60A & B	6 Bailer; 2 clear, 5 cl.
1045 23 Jan 90	MWB10	61A	61B	1050 23 Jan 90	61A & B	3rd smpl after inj 5 bailers - all clear
1115 23 Jan 90	MWC37	62A	62B	1130 23 Jan 90	62A & B	3rd smpl after inject

Page 2 of 3

BUG PLACEMENT DATA SHEET

TEST SITE: Ammunition Burning Grounds
NAVWPN SUPPCEN, Crane, IN

INVESTIGATOR: USAEWES - Murphy
NORTHWESTDIVNAVFACENGCOM - Cicco

Date Bug Placed	Monitoring Loc.	Bug Type Cotton	Bug Type Charcoal	Date Bug Collected	Jar #	Comments
0915 hrs 24 Jan90	Spring C	63A	63B	0940 25 Jan90	63A&B	
0930 hrs 24 Jan90	2nd Green Bridge in Little Sulphur Creek	64A	64B	0955 25 Jan90	64A&B	
0945 hrs 24 Jan90	Spring A	65A	65B	1000 25 Jan90	65A&B	
0945 hrs 24 Jan90	Spring A'	66A	66B	1000 25 Jan90	66A&B	
0950 hrs 24 Jan90	Spring B	67A	67B	1005 25 Jan90	67A&B	
1010 hrs 24 Jan90	MW B10	68A	68B	1015 hrs 24 Jan90	68A&B	4 boilers, 1 clean, 3 dirty 4th sample after injection
1040 hrs 24 Jan90	MW C24	69A	69B	1045 hrs 24 Jan90	69A&B	4 boilers, 2 clean, 2 dirty 4th sample after injection
1115 hrs 24 Jan90	MW C25	70A	70B	1120 hrs 24 Jan90	70A&B	4 boiler, 2 clean, 3 dirty 4th sample after injection
1150 hrs 24 Jan90	SE Boundary Gate in Little Sulphur Creek	71A	71B	1030 hrs 25 Jan90	71A&B	
1320 hrs 24 Jan90	MW C37	72A	72B	1320 24 Jan90	72A&B	All 5 boilers, 4 clean 4th sample after injection
2840 hrs 25 Jan90	Mtn. Spring	73A	73B			Pick up 1 month
2900 25 Jan90	Spring D	74A	74B			" "
2920 25 Jan90	Spring E	75A	75B			" "
2930 25 Jan90	Spring F	76A	76B			" "
2945 25 Jan90	Spring C	77A	77B			" "
0955 25 Jan90	2nd Green Bridge in Little Sulphur Creek	78A	78B			" "
1022 25 Jan90	Spring A'	79A	79B			" "
1212 25 Jan90	Spring A	80A	80B			
1030 25 Jan90	SE Bound Gate in Little Sulphur Creek	81A	81B			
1055 25 Jan90	MW B10	82A	82B	1100 25 Jan90	82A&B	5 boilers, 2 clean 3 d. 5th smp after injection
1120 25 Jan90	MW C37	83A	83B	25 Jan90	83A&B	5 Boilers, 4 clean 5th smpl after injection
1020 25 Jan90	Spring B	84A	84B			pick up in 1 month

TRACER ANALYSIS DATA SHEET

TEST SITE: Ammunition Burning Grounds
NAVWPNSUPPCEN, Crane, IN

INVESTIGATOR: USAEWES; Murphy
NORTHDIV/FACENGCOM Doc

DATE ANALYZED	BUG TYPE	ELUTANT	RESULTS*
2940 21 Jan90 for Spring F *	4A Cotton	none	4 spots of yel fluor, tr. lt yel glow
	4B Coc. Charcoal	KOH	negative (for Flourescein)
0943 21 Jan90 for 2nd Green Bridge	6A Cotton	none	faint yel glow
	6B Coc. Charcoal	KOH	negative
2945 hrs, 21 Jan90 for Spring E	3A Cotton	none	3-4 spots of yel fluor, sl yel glow
	3B Coc. Charcoal	KOH	negation
2955 hrs 21 Jan for SE Bound GATE	10A Cotton	none	tr faint yel fluor
	10B Coc Charcoal	KOH	negatitive
1000 hrs 21 Jan90 for Spring D	2A Cotton	none	tr faint yel fluor
	2B Coc. Charcoal	KOH	negative
1010 hrs 21 Jan90 for Spring A	8A cotton	none	1/4 streak of blue fluor, tr faint yel fluor
	8B Coc. Charcoal	KOH	negative
1012 hrs 21 Jan90 for Spring A'	7A cotton	none	3 spec blue fluor, tr. lt yel fluor
	7B Coc Charcoal	KOH	negative
1025 hrs 21 Jan90 for MWC29	29A cotton	none	faint yel fluor
	29B Coc Charcoal	KOH	negative
1036 hrs 21 Jan90 for Spring B	9A cotton	none	faint yel fluor
	9B Coc. Charcoal	KOH	negative
0940 hrs 21 Jan90 for Spring C	5A cotton	none	faint yel fluor, 2 yel bright spots of fluor
	5B Coc. Charcoal	KOH	negative
1030 hrs 21 Jan90 for Mtn. Spring	1A cotton	none	tr blue spots, faint yel fluor, tr br yel fluor
	1B Coc Charcoal	KOH	negative
1055 hrs 21 Jan90 for MWB10	27A cotton	none	faint yel fluor, tr blue & yel bright fluor spots
	27B Coc Charcoal	KOH	negative
1105 hrs 21 Jan90 for MWC29	28A cotton	none	Faint yel fluor, tr. blue spotty fluor
	28B Coc Charcoal	KOH	negative
1110 hrs 21 Jan90 for MWC37	30A cotton	none	faint yel glow, several blue spots of fluor
	30B Coc. Charcoal	KOH	negative

TRACER ANALYSIS DATA SHEET

TEST SITE: Ammunition Burning Grounds
NAVWPNSUPPCEN, Crane, IN

INVESTIGATOR: USAEWES : Murphy
NORTHNAVFACENGCOM : Ciocco

DATE ANALYZED	BUG TYPE	ELUTANT	RESULTS*
1128 hrs 21 Jan 90 for Spring A #19A	cotton	none	mod lt blue well dist. flour., faint yel flour
" " 19B	Coc. Charcoal	KOH	positive w/ intense light after ~7 hrs
1127 hrs 21 Jan 90 for Spring A' 21A	cotton	none	faint yel flour
" " 21B	Coc. Charcoal	KOH	wp
1135 hrs 21 Jan 90 for 2nd Green Bridge 17A	cotton	none	faint yel flour
" " 17B	Coc. Charcoal	KOH	wp
1138 hrs 21 Jan 90 for SE Bound Gate 25A	cotton	none	faint yel flour
" " 25B	Coc. Charcoal	KOH	wp
1145 hrs 21 Jan 90 for Spring C 15A	cotton	none	mod lt blue-purple well dist. flour, faint yel flour
" " 15B	Coc. Charcoal	KOH	wp, after 24 hrs simpl show extem. weak green fl
1155 hrs 21 Jan 90 for Spring B 23A	cotton	none	mod lt blue well dist. flour, tr faint yel flour
" " 23B	Coc. Charcoal	KOH	wp
1235 hrs 22 Jan 90 for SE Bound Gate 35A	cotton	none	positive, ½ simpl has pronounced blue flour
" " 35B	Coc. Charcoal	KOH	VSP, max color intensity immed. after elutration
1040 hrs 22 Jan 90 for MWC25 43A	cotton	none	negative, faint yel background flour
" " 43B	Coc. Charcoal	KOH	negative
1050 hrs 22 Jan 90 for Spring B 36A	cotton	none	very weak lt. blue flourescence ?
" " 36B	Coc. Charcoal	KOH	negative w/ slight immed, let sit
1025 hrs 22 Jan 90 Spring A 33A	cotton	none	sl tr lt blue flourescence
33B	Coc. Charcoal	KOH	★ Most intensely positive Result ★ VSP, run onsite neg, run duplicate VSP (see fn)
1115 hrs 22 Jan 90 Spring C 31A	cotton	none	wp, lt blue flourescence
" " 31B	Coc. Charcoal	KOH	vwp let sit (Rinsate ND)
1050 hrs. 22 Jan 90 2nd Green Bridge 32A	cotton	none	wp, tr lt blue flour.
" " 32B	Coc. Charcoal	KOH	negative, let sit (rinsate ND)
1047 hrs. 22 Jan 90 MWC24 42A	cotton	none	vwp
" " 42B	Coc. Charcoal	KOH	negative (rinsate ND)
1100 hrs 22 Jan 90 Spring A' 34A	cotton	none	positive, g. blue flourescence
" " 34B	Coc. Charcoal	KOH	VSP (rinsate ND)
1110 hrs 22 Jan 90 MWB10 41A	cotton	none	vwp tr lt. blue flourescence

TRACER ANALYSIS DATA SHEET

TEST SITE: Ammunition Burning Grounds
NAVWPNSUPPCEN, Crane IN

INVESTIGATOR: USAEWES - Murphy
NORTHNAVFACENGCOM - Ciocco

DATE ANALYZED	BUG TYPE	ELUTANT	RESULTS*
1120 22 Jan90 MWC37 # 46A	cotton	none	negative
" " " 46B	Coc Charcoal	KOH	negative (rinsate blank, ND)
1650 22 Jan90 Spring C 37A	cotton	none	negative, tr lt yel flour
" " " 37B	Coc Charcoal	KOH	negative, let sit (rinsate ND), vwp after 36
1710 22 Jan90 2nd Green Bridge 38A	cotton	none	negative, tr lt yel flour & lt blue flour
" " " 38B	Coc Charcoal	KOH	negative imed & after 36hrs (rinsate ND)
1720 hrs 22 Jan90 Spring A 39A	cotton	none	positive, mod yel & blue flour
" " " 39B	Coc Charcoal	KOH	VSP, slow w/ naked eye not as immediately intense as 33B (rinsate
1734 hrs 22 Jan90 Spring A' 40A	cotton	none	positive, mod-brt yel & blue flour
" " " 40B	Coc Charcoal	KOH	VSP, same as 39B (rinsate, ND)
1755M 22 Jan90 Spring B 44A	cotton	none	positive, good blue glow / flouresscence
" " 44B	Coc. Charcoal	KOH	negative, immediately nothing, 36hrs neg (rinsate ND)
1740 hrs 22 Jan90 SE Bound Gate 45A	cotton	none	positive, lt blue flour
" " 45B	Coc Charcoal	KOH	VSP, less intense than yesterdays (rinsate
1833 hrs 22 Jan90 MWB10 53A	cotton	none	positive, v lt blue flour (rinsate blanks ND)
" " 53B	Coc Charcoal	KOH	negative immed & after 36 hrs
1[illegible] 22 Jan90 MWC37 54A	cotton	none	negative tr lt-med yel flour (rinsate ND)
" " 54A	Coc. Charcoal	KOH	negative imed & after 36 hrs
1430 hrs 24 Jan90 2nd Green Bridge 48A	cotton	none	negative (rinsate ND)
" " " 48B	Coc Charcoal	KOH	neg. immed., Let sit after 20 hrs. very weakly p
1925 hrs 24 Jan90 Spring C 47A	cotton	none	negative, tr lt. yel. flour background (?) (rinsate ND)
" " " 47B	Coc Charcoal	KOH	neg. immed, let sit 20 hrs too cloudy to classify
1935 hrs 24 Jan90 SE Bound Gate 51A	cotton	none	vwp, tr v lt. blue flour (rinsate ND)
" " " 51B	Coc. Charcoal	KOH	vsp, after 5 min w/ artificial light and intense light
1945 hrs 24 Jan90 Spring A 49A	cotton	none	sl positive, lt blue flour (rinsate ND)
" " " 49B	Coc. Charcoal	KOH	vsp after 5 min to 10 min
1500 24 Jan90 Spring A' 50A	cotton	none	vsp w/ lt blue flour (rinsate ND)
" " " 50B	Coc. Charcoal	KOH	vsp after 5 minutes

TRACER ANALYSIS DATA SHEET

TEST SITE: Ammunition Burning Grounds
NAVWPNSUPPCEN) Crane, IN

INVESTIGATOR: USAEWES - Murphy
NORTHNAVFACENGCOM - Clocc

DATE ANALYZED	BUG TYPE	ELUTANT	RESULTS*
1515 hrs 24 Jan90 Spring B 51A	cotton	none	uwp for lt blue flour, tr lt yel flour (rinsate ND)
" " " 51B	Coc Charcoal	KOH	neg immed, Let sit, after 20 hrs weakly posit
1522 hrs 24 Jan90 MWB10 53A	cotton	none	MIA!
" " " 53B	Coc. Charcoal	KOH	neg immed, Let sit, nothing after 24 hrs (rinsate ND)
1530 hrs 24 Jan90 MW37 54A	cotton	none	negative
" " " 54B	Coc. Charcoal	KOH	neg immed, Let sit, after 20 hrs nothing but clo (rinsate ND)
1540 hrs 24 Jan90 Spring C 55A	cotton	none	negative, tr lt yel flour
" " " 55B	Coc. Charcoal	KOH	neg immed, Let sit 19 hrs & weakly positive (rinsate ND)
1542 hrs 24 Jan90 2nd Green Br. 56A	cotton	none	negative, tr lt yel flour
" " " 56B	Coc. Charcoal	KOH	neg. immed, Let sit, positive after 20 hrs weakly po (rinsate ND)
1545 hrs 24 Jan90 Spring A 57A	cotton	none	sl pos. w/ Lt blue flour
" " " 57B	Coc. Charcoal	KOH	neg immed, Let sit ⇒ usp after 5 min (rinsate ND)
1550 hrs 24 Jan90 Spring A' 58A	cotton	none	weakly pos w/ Lt blue flour
" " " 58B	Coc Charcoal	KOH	usp, though not bright immed (rinsate ND)
1600 24 Jan90 SE Bound Gate 59A	cotton	none	negative, tr lt yel flour
" " " 59B	Coc. Charcoal	KOH	neg. immed, Let sit usp after 10 min w/ intense (rinsate ND)
1605 24 Jan90 Spring B 60A	cotton	none	negative
" " " 60B	Coc Charcoal	KOH	neg. immed, Let sit 20 hrs & very weakly positive (rinsate ND)
1610 24 Jan90 MWB10 68A	cotton	none	vw positive, tr v lt blue flour
" " " 68B	Coc Charcoal	KOH	neg. immed, Let sit after 24 hrs trace greens bg (rinsate ND)
1620 24 Jan90 MWC24 69A	cotton	none	neg. too dirty
" " " 69B	Coc. Charcoal	KOH	neg immed - Let sit (negative ND)
1625 24 Jan90 MWC25 70A	cotton	none	very faint lt blue flour
" " " 70B	Coc. Charcoal	KOH	neg. immed., Let sit, after 20 hrs nothing (rinsate ND)
1630 24 Jan90 MWC37 72A	cotton	none	negative, tr yel BG flour
" " " 72B	Coc. Charcoal	KOH	neg. immed, Let sit, after 24 hrs crystal clear (rinsate ND) Less than BG
-Long Term- 1310 25 Jan90 Spring C 16A	cotton	none	negative, tr bg flour
" " " 16B	Coc. Charcoal	KOH	neg immed, Let sit, after 45 min w/ inter light WP, w/ artifical light after 24 hrs (rinsate ND)

TRACER ANALYSIS DATA SHEET

TEST SITE: Ammunition Burning Grounds NAVWPNSUPPCEN, Crane, IN

INVESTIGATOR: USAEWES - Murphy, NORTHNAVFACENGCOM - Cissell

-Long Term-	DATE ANALYZED	BUG TYPE	ELUTANT	RESULTS*
1320 hrs	25 Jan 90 Spring B *24A	cotton	none	VWP, tr lt blue flour (rinsate ND)
"	" 24B	Coc Charcoal	KOH	neg immed, let sit, weakly pos. after 24 hrs w/ naked
1325	25 Jan 90 Spring E 13A	cotton	none	negative, tr bg yel flour (rinsate ND)
"	" 13B	Coc. Charcoal	KOH	neg. immed., Let sit, WP w/ naked eye after 24 hrs
1330	25 Jan 90 Spring A 20A	cotton	none	negative; too dirty for UV inspection
"	" 20A	Coc. Charcoal	KOH	not as strong as 33B immed. (rinsate N) VSP, good green dye immed w/ art reg light
1340	25 Jan 90 Spring D 12A	cotton	none	negative, v dirty (rinsate N)
"	" 12B	Coc. Charcoal	KOH	neg. immed, let sit, neg. after 24 hrs
1345	25 Jan 90 Spring F 14A	cotton	none	negative, smpl. very dirty, tr yel BG flour (rinsate N)
"	" 14B	Coc. Charcoal	KOH	neg. immed., let sit, WP after 24 hrs w/ naked eye
1350	25 Jan 90 2nd Gr. Br. 18A	cotton	none	negative, too damn dirty! (rinsate N)
"	" 18A	Coc. Charcoal	KOH	neg. immed., let sit, w positive after 24 hrs. w/ art light
1355	25 Jan 90 SE Bound Gate 26A	cotton	none	negative, too dirty (rinsate N)
"	" 26B	Coc. Charcoal	KOH	VSP immed green & lt blue w/ art. reg light
1405	25 Jan 90 Mtn Spring 11A	cotton	none	negative, too dirty
"	" 11B	Coc. Charcoal	KOH	neg immed, let sit, under reg. artif. light above BG VWP after 24 hrs. (rinsate N)
1410	25 Jan 90 Spr. A' 22A	cotton	none	negative, too dirty
	22B	Coc. Charcoal	KOH	VSP, immed green w/ elutant (rinsate ND)
~~-END Long Term-~~				
1418	25 Jan 90 2nd Gr Bridge 64A	cotton	none	negative w/ clean cotton, tr. yel bg flour (rinsate ND)
"	" 64B	Coc Charcoal	KOH	neg. immed, let sit, VWP w/ reg. light after 24 hrs
1425	25 Jan 90 Spring C 63A	cotton	none	negative
"	" 63B	Coc Charcoal	KOH	neg. immed, let sit, VWP w/ reg. art. light after 24 hr (rinsate N)
1435	25 Jan 90 Spring A 65A	cotton	none	negative, tr. yel flour
"	" 65B	Coc Charcoal	KOH	neg immed, let sit 5 min & strongly pos w/ int. liq (rinsate ND)
1440	25 Jan 90 Spring A' 66A	cotton	none	weakly positive w/ lt blue flour
"	" 66B	Coc Charcoal	KOH	strongly positive w/ artificial reg lighting after 5 min (rinsate ND)
1445	25 Jan 90 Spring B 67A	cotton	none	negative, tr. yel flour BG
"	" 67B	Coc Charcoal	KOH	neg. immed. Let sit (rinsate ND)
1448	25 Jan 90 SE Bound Gate 71A	cotton	none	negative, tr yel flour BG
"	" 71B	Coc Charcoal	KOH	VSP imm. after elution (rinsate ND)

*See attached classification scheme.

TRACER ANALYSIS DATA SHEET

TEST SITE: Ammunition Burning Grounds
NAVWPNSUPPCEN! Crane, IN

INVESTIGATOR: USAEWES - Murphy
NORTHWAUFACENGCOM - Ciocco

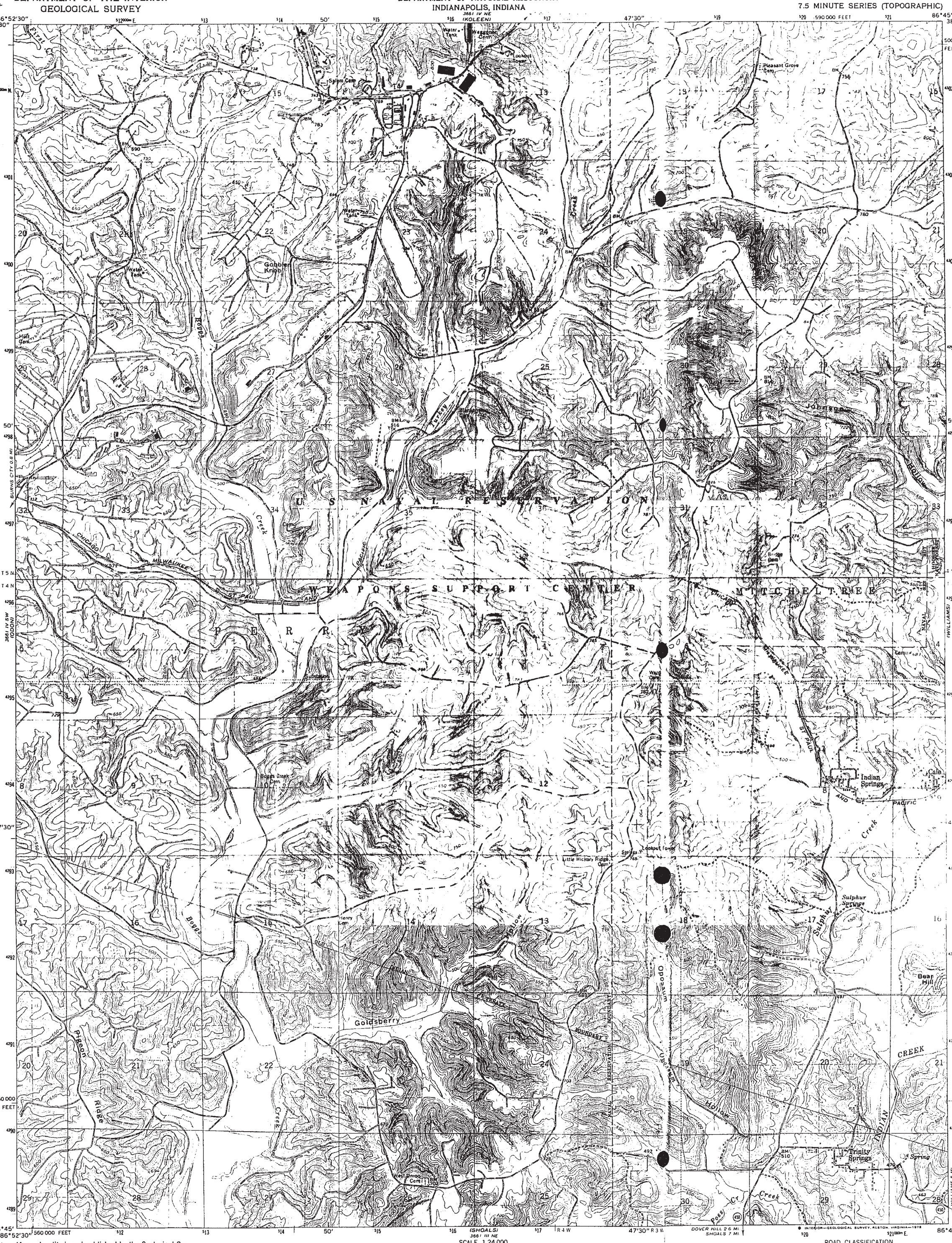
	DATE ANALYZED		BUG TYPE	ELUTANT	RESULTS*
1300 hrs	25 Jan90 MWB10	82A	cotton	none	negative, tr lt yellow BG Flour (rinsate ND)
		82B	Coc. Charcoal	Coc. Charcoal	neg immed, let sit
1505	25 Jan90 MWC37	83A	cotton	none	negative, tr. lt. yellow BG Flour
		83B	Coc. Charcoal	Coc. Charcoal	neg. immed, let sit, neg. after 24 hrs

*See attached ...

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
INDIANAPOLIS, INDIANA

INDIAN SPRINGS QUADRANGLE
INDIANA – MARTIN CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)



Mapped, edited, and published by the Geological Survey

Control by USGS and NOS/NOAA

Topography by photogrammetric methods from aerial photographs taken 1956. Field checked 1956. Revised 1975. Map edited 1978

Polyconic projection. 1927 North American datum
10,000-foot grid ticks based on Indiana coordinate system, west zone
1000-meter Universal Transverse Mercator grid ticks, zone 16, shown in blue

Fine red dashed lines indicate selected fence and field lines where generally visible on aerial photographs. This information is unchecked

There may be private inholdings within the boundaries of the National or State reservations shown on this map

MN
GN
0°07'
2 MILS
½°
9 MILS

1978 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

1 ½ 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, RESTON, VIRGINIA 22092
AND INDIANA DEPARTMENT OF NATURAL RESOURCES, INDIANAPOLIS, INDIANA 46204
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

INDIANA
QUADRANGLE LOCATION

ROAD CLASSIFICATION

Primary highway, hard surface — Light-duty road, hard or improved surface

Secondary highway, hard surface — Unimproved road

Interstate Route — U. S. Route — State Route

INDIAN SPRINGS, IND.
N3845—W8645/7.5

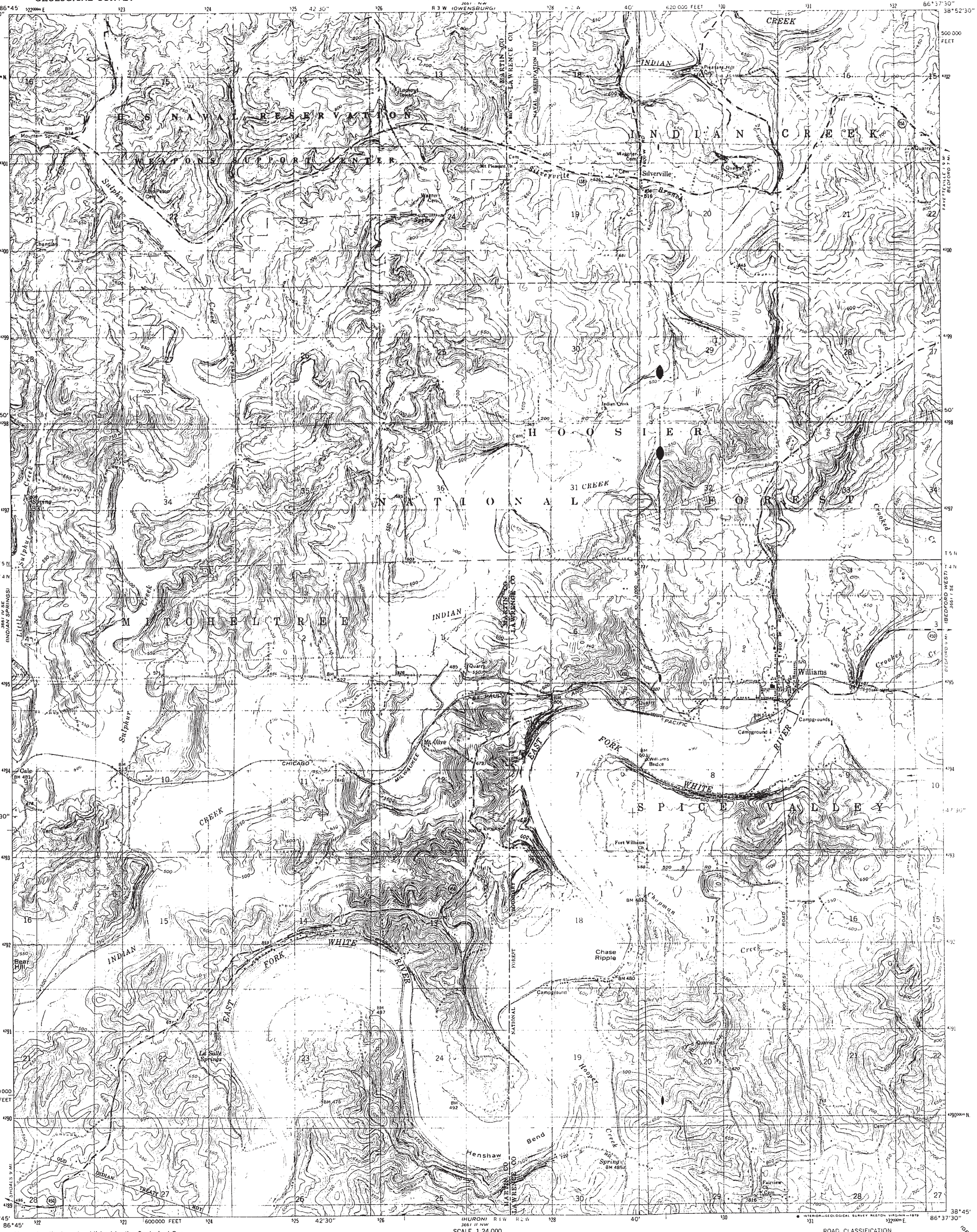
1978

AMS 3661 IV SE—SERIES V851

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
INDIANAPOLIS, INDIANA

WILLIAMS QUADRANGLE
INDIANA
7.5 MINUTE SERIES (TOPOGRAPHIC)
SW/4 OOLITIC 15' QUADRANGLE



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10,000-foot grid ticks based on Indiana coordinate system, west zone
1000-meter Universal Transverse Mercator grid, zone 16

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UTM GRID AND 1978 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

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WILLIAMS, IND.
SW/4 OOLITIC 15' QUADRANGLE
N3845—W8637.5/7.5

1978

AMS 3661 I SW—SERIES V851