DYE-TRACING STUDY REPORT
RADFORD ARMY AMMUNITION PLANT
CONTRACT NO. DAA15-90-D-0008

PREPARED FOR:

U. S. ARMY
ENVIRONMENTAL CENTER

Aberdeen Proving Ground, Maryland

PREPARED BY:

ENGINEERING-SCIENCE, INC.

10521 Rosehaven Street
Fairfax, Virginia 22030

MARCH 1994

AEC Form 45, Feb 93 replaces THAMA Form 45 which is obselete

ENGINEERING-SCIENCE, INC.

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March 9, 1994

Mr. Harry R. Kleiser
Project Manager-Installation Restoration
U.S. Army Environmental Center
Installation Restoration Division
Building E4480
Aberdeen P.G, MD 21010-5401

Re: Radford Army Ammunition Plant, Dye-Tracing Study Report

Dear Mr. Kleiser:

Engineering-Science, Inc. (ES) is pleased to submit the draft report for the Dye-Tracing Study conducted in the vicinity of Solid Waste Management Units 17 and 40 at the Radford Army Ammunition Plant. As required in our statement of work, four copies are provided.

Please call Jeff Titus (703/934-2394) or me (703/934-2388) with any comments or questions.

Sincerely,

ENGINEERING-SCIENCE, INC.

Alexis L. Fricke, P.E.
Project Manager

JT:jt
HAZ/722843.15/FJT0614D.LTR

Attachments

cc: Jeff Titus - ES-Fairfax
Dave Jenkins - ES-Oak Ridge
Charlie Spiers - ES-Atlanta
File 722843

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Prepared For:

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FAIRFAX, VIRGINIA

MARCH 1994

HAZ/722843.15/DYE.TLE

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EXECUTIVE SUMMARY

The Radford Army Ammunition Plant (RAAP) was issued a Permit for Corrective Action and Incinerator Operation by the U.S. Environmental Protection Agency (USEPA) requiring RAAP to conduct Verification Investigations (VIs) at sites of suspected contamination, RCRA Facility Investigations (RFIs) at sites of known contamination, and Corrective Measures Studies (CMSs) at sites requiring remediation.

In 1992, RAAP completed several VIs and RFIs at selected solid waste management units (SWMUs) throughout the installation. Specifically, in the south-central section of the Main Manufacturing Area, VIs were conducted at the Sanitary Landfill (NG Area) (SWMU 40), the Flash Burn Parts Area (SWMU 71), and the Waste Oil Underground Storage Tank Area (UST) (South of Oleum Plant) (SWMU 76), and an RFI was conducted at the Contaminated Waste Burning Areas (SWMUs 17A-E). Site hydrogeology could not be fully characterized during these investigations due to the karst geology in this area of the facility. Groundwater flow determination in the vicinity of SWMUs 17 and 40 has been complicated by abundant solution features and numerous zones of intense weathering and fracturing in the limestone and dolostone bedrock.

A dye-trace test was conducted between September 23, 1993 and December 23, 1993 in an effort to better identify groundwater flow paths through the karst limestone in the south-central section of the Main Manufacturing Area at RAAP. On September 23, 1993 two fluorescent dyes, Fluorescein and Direct Yellow 96, were injected into upland sinkholes in which SWMUs 17A and 17B-E occupy, respectively. A total of 35 locations, including on-site and off-site streams, springs, monitoring wells, and locations along the New River were monitored for the appearance of dye for a three month period. Once hydraulic connections were made between the recharge areas at SWMU 17 and their respective discharge areas in and around the facility, the locations were identified for later groundwater, surface water, and sediment sampling activities.

Based on the results of this investigation, one spring (SPG 3), located along the northwest shoreline of the New River, was identified as being hydraulically connected to the sinkhole which SWMU 17A occupies. The flow path identified by the dye trace closely parallels a west-northwest to east-southeast trending fracture trace which can be extended to connect both the dye injection point and the dye resurgence point. This leads to the conclusion that a direct conduit exists between SWMU 17A and SPG 3 which is most likely created by solution opening along a subsurface fracture. The travel time for groundwater flow through this conduit, under similar flow conditions under which this trace test was conducted, is calculated to range between 2,095 feet/day and 3,716 feet/day.

SECTION 1

INTRODUCTION

1.1 INTRODUCTION

This document is the report for the Dye-Tracing Study conducted at the Radford Army Ammunition Plant (RAAP) located in Radford, Virginia. This report has been prepared for the U.S. Army Environmental Center (USAEC) and is submitted under the requirements of Contract No. DAAA15-90-D-0008, Task DA04.

RAAP was issued a Permit for Corrective Action and Incinerator Operation by the U.S. Environmental Protection Agency (USEPA), effective December 13, 1989. Under the criteria of Section 3004(u) of the Resource Conservation and Recovery Act (RCRA), the permit (No. VA-21-002-0730) requires RAAP to conduct Verification Investigations (VIs) at sites of suspected contamination, RCRA Facility Investigations (RFIs) at sites of known contamination, and Corrective Measures Studies (CMSs) at sites requiring remediation.

In 1992, RAAP completed several VIs and RFIs at selected solid waste management units (SWMUs) throughout the installation. Specifically, in the south-central section of the Main Manufacturing Area, VIs were conducted at the Sanitary Landfill (NG Area) (SWMU 40), the Flash Burn Parts Area (SWMU 71), and the Waste Oil Underground Storage Tank Area (UST) (South of Oleum Plant) (SWMU 76), and an RFI was conducted at the Contaminated Waste Burning Areas (SWMUs 17A-E). Site hydrogeology could not be fully characterized during these investigations due to the karst geology in this area of the facility. Groundwater flow determination in the vicinity of SWMUs 17 and 40 has been complicated by abundant solution features and numerous zones of intense weathering and fracturing in the limestone and dolostone bedrock. Therefore, a dye-tracing study was conducted in the south-central section of the Main Manufacturing Area at RAAP to better characterize groundwater flow through the karst aquifer in this vicinity and to identify future sampling locations.

1.2 PROJECT OBJECTIVES

The objective of this study was to determine groundwater flow directions through the karst limestone in the south-central section of the Main Manufacturing Area at RAAP by identifying hydrologic connections between areas of groundwater recharge (upland sinkholes near SWMUs 17 and 40) and their respective discharge areas in and around the facility.

This objective was met by the injection of two groundwater dye tracers, specifically Fluorescein and Direct Yellow 96, into two sinkholes at SWMU 17. On September 23, 1993 Fluorescein was introduced into the sinkhole in which SWMU 17A (Stage and Burn Area) is situated and Direct Yellow was introduced into the Runoff Drainage Basin (SWMU 17E) located in the sinkhole adjacent to the Fluorescein injection site. Selected monitoring wells, the New River, and springs and streams both on- and off-site were monitored for the appearance of dye. A semi-quantitative, dye-tracing approach was utilized in this investigation.

1.3 REPORT ORGANIZATION

This report consists of six sections and three supporting appendices. Section 1 provides an introduction to the project history and a statement of the project objectives. A detailed description of the current conditions at RAAP, including facility background and environmental setting, is presented in Section 2. Section 3 outlines the dye-trace study field activities including elements such as dye selection rationale, methodologies for dye injection and recovery, and analysis of results. Results of the dye-tracing test are discussed in Section 4. A summary of the conclusions and recommendations for the investigation are presented as Section 5. References are provided in Section 6 and Appendices A through C include well logs, field data sheets, and laboratory analysis sheets.

SECTION 2

DESCRIPTION OF CURRENT CONDITIONS

2.1 FACILITY BACKGROUND

The background information in this section has been adapted from previous VI and RFI reports prepared for the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA), now USAEC (Dames & Moore, 1992). RAAP is a government-owned, contractor-operated (GOCO) military industrial installation supplying solvent and solventless propellant grains and TNT explosives. The present contractor-operator is Hercules Incorporated (formerly Hercules Powder Company).

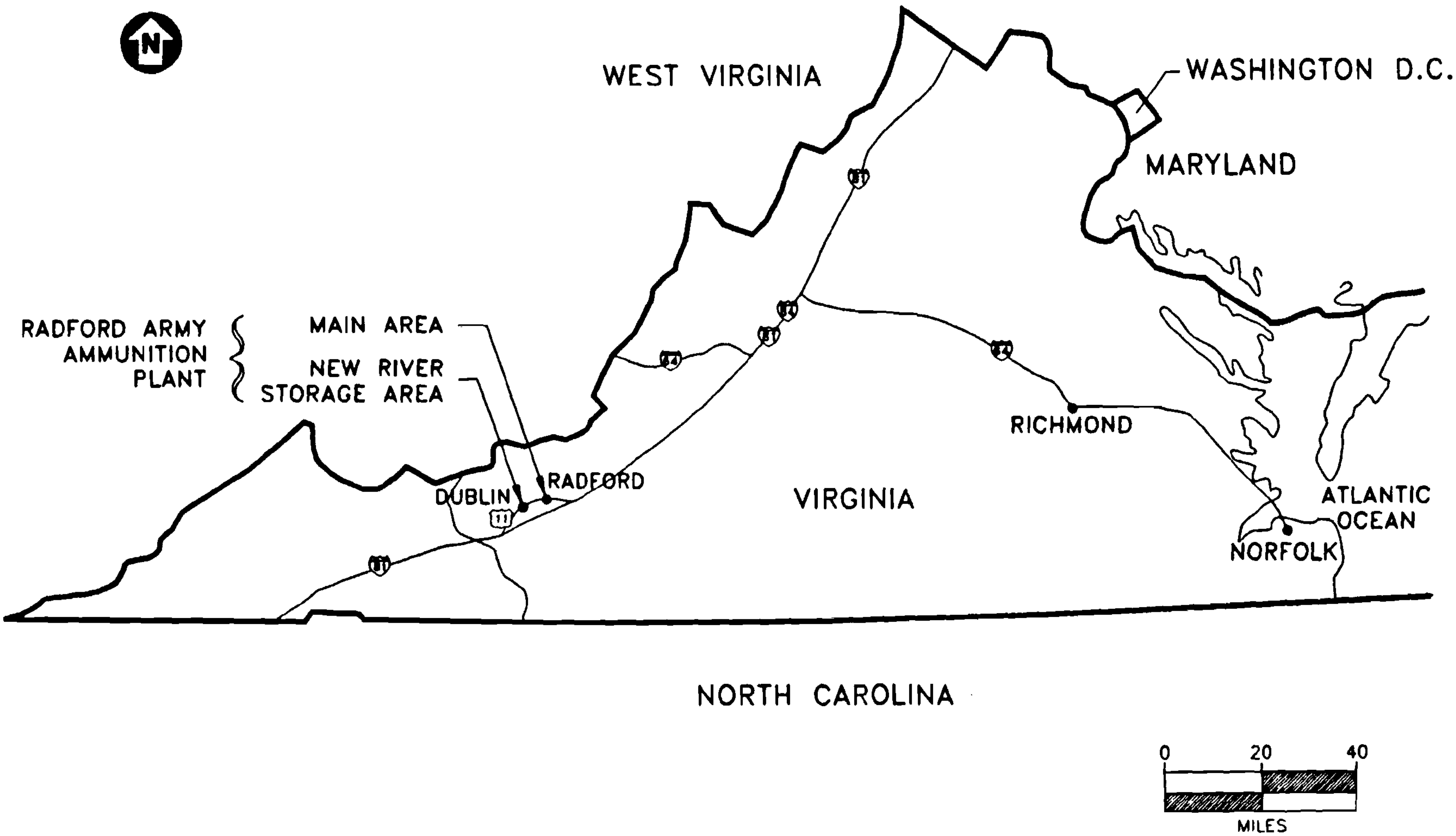
2.1.1 Location

RAAP is located in the mountains of southwest Virginia (Figure 2.1) in Pulaski and Montgomery Counties. The installation consists of two noncontiguous areas - the Radford Unit (or Main Section) and the New River Ammunition Storage Area Unit. The Main Section is located approximately 5 miles northeast of the city of Radford, Virginia, approximately 10 miles west of Blacksburg and 47 miles southwest of Roanoke. The New River Unit is located about 6 miles west of the Main Section, near the town of Dublin (Figure 2.2). The Main Section of RAAP (Figure 2.3) is the focus of this report; all uses of the terms "RAAP," "the facility," or "the installation" in this report refer to the Main Section only.

RAAP lies in one of a series of narrow valleys typical of the Appalachian Mountain region. Oriented in a northeast-southwest direction, the valley is approximately 25 miles long, with a width of 8 miles at the southwest end, narrowing to 2 miles at its northeast end. The plant is situated along the New River in the relatively narrow northeast corner of the valley.

The New River divides the Main Section of RAAP into two areas. Within the New River meander is the "Horseshoe Area." Located in the Horseshoe Area are the Nitroglycerin (NG) No. 2 Area, the Cast Propellant Area, and the Continuous Solvent Propellant Area. Many of the landfills at RAAP are located in this area, including the Hazardous Waste Landfill, the currently active Sanitary Landfill, and the Waste Propellant Burning Ground.

FIGURE 2.1
LOCATION MAP
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



SOURCE: USAEHA, 1980, AS CITED IN DAMES & MOORE, 1992

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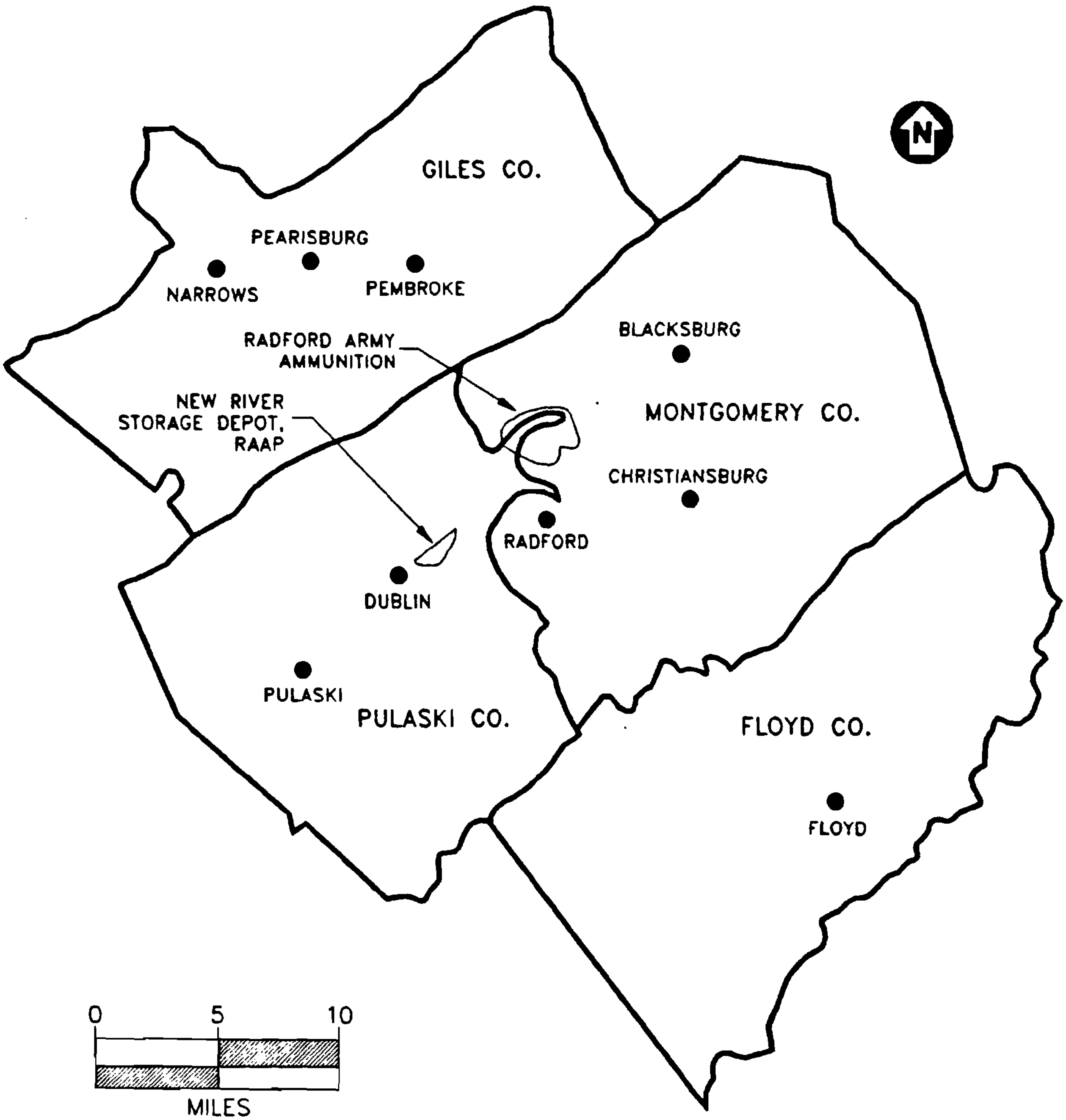
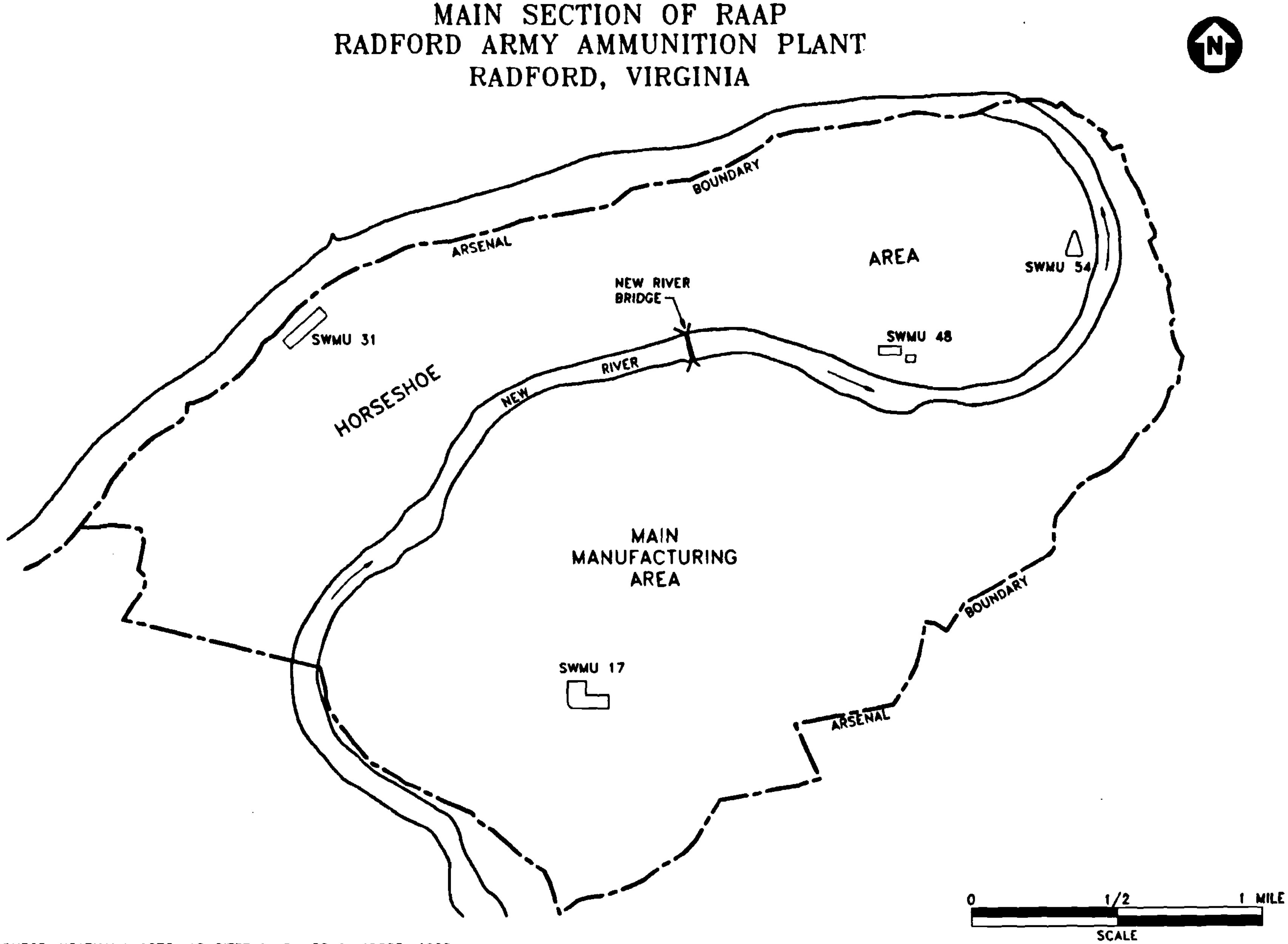
FIGURE 2.2

RAAP AND VICINITY MAP
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



SOURCE: USAEHA, 1980, AS CITED IN DAMES & MOORE, 1992

FIGURE 2.3
MAIN SECTION OF RAAP
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



BASE MAP SOURCE: USATHAMA 1976, AS CITED IN DAMES & MOORE, 1992

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South of the New River is the "Main Manufacturing Area," which includes the Finishing Area, the Trinitrotoluene (TNT) Area, the Nitroglycerin (NG), Nitrocellulose (NC) and Acid Areas, the Automated Propellant Area, and the Administration Area.

2.1.2 Facility Responsibility

RAAP is assigned the following general responsibilities (USATHAMA, 1976):

- Manufacture of explosives and propellants;
- Handling and storage of strategic and critical materials as directed for other government agencies;
- Operation and maintenance, as directed, of active facilities in support of current operations. Maintenance and/or lay-away, in accordance with Ammunition Procurement and Supply Agency instructions, of standby facilities, including any machinery and packaged lines received from industry, in such conditions as will permit rehabilitation and resumption of production within the time limitations prescribed;
- Receipt, surveillance, maintenance, renovation, demilitarization, salvage, storage, and issue of assigned Field Service Stock and industrial stock as required or directed;
- Procurement, receipt, storage, and issue of necessary supplies, equipment, components, and essential materials;
- Mobilization planning, including review and revision of plant as required;
- Custodial maintenance and administrative functions of sub installations; and
- Support services for tenants.

This mission is accomplished through the efforts of the operating contractor, Hercules, Inc. The Administrative Contracting Officer (ACO) and his staff provide technical assistance and administer the contracts with the civilian operating contractors. RAAP provides logistics support for tenant activities such as the U.S. Army Research, Development and Acquisition

Information Systems Agency, which is charged with performing data processing activities during peacetime and mobilization.

2.1.3 Facility History

Construction of the current RAAP production facility began in 1940 with the impending participation of the United States in World War II, and the determination by Congress of a need for increased ammunition production facilities. Initially, RAAP consisted of two distinct areas - a smokeless-powder plant (Radford Ordnance Works [ROW]) and a bag-manufacturing and loading plant for artillery, cannon, and mortar projectiles (New River Ordnance Works [NROW]). These two production facilities continued to be operated separately from 1940 to 1945. Late in 1945, ROW was designated Radford Arsenal, and NROW was a subpost. By January 1950, NROW was made an integral part of Radford Arsenal and no longer considered a subpost. The arsenal was renamed Radford Ordnance Plant in 1961 and was finally redesignated RAAP in August 1963 (USATHAMA, 1984).

Since its inception as a GOCO facility in 1940, RAAP has been operated by Hercules. Expansion of both ROW and NROW continued throughout World War II. Late in 1945, the Radford Unit was placed on standby status. The following year, the nitric acid area of the plant was reactivated to produce ammonium nitrate fertilizer, an activity that continued until 1949 under contract with Hercules Powder Company (now Hercules Inc.). In September 1945, the New River Unit was declared surplus; but in April 1946, the magazine areas were changed from surplus status to standby. Between December 1946 and January 1948, large parcels of the New River plant manufacturing area were sold (USATHAMA, 1984).

Between 1952 and 1958, Goodyear Aircraft Corp., of Akron, Ohio, contracted to manufacture component parts used in missile production at RAAP. The close coordination required between Goodyear and Hercules led to Goodyear moving its assembly and coating operations to RAAP. In 1958, Hercules took over the Goodyear operations at this plant (USATHAMA, 1984).

The continuous TNT plant was put into production in mid-1968 and remained in operation until destroyed by explosion in May 1974. This plant had five main operational areas: the nitration lines, the finishing buildings, the red water concentration facility, the acid neutralization facility, and the spent acid recovery plant. C-line in the TNT area ran from 1983 to 1986, when the plant was placed on standby. Later, in December 1988, a facility cleanup was conducted and the plant was prepared for long-term standby status. A chronological listing of major RAAP facilities and activities is presented in Table 2.1.

2.1.4 Industrial Operations

The principal end products produced at RAAP since 1941 are TNT, single-base and multi-base propellants, and cast and solventless propellants. Intermediate products produced are oleum (concentrated sulfuric acid), nitric acid, NG, and NC.

The production mission of RAAP is accomplished at the primary and secondary manufacturing areas. The primary manufacturing processes are the production of single-base and multi-base solvent propellants, cast and solventless propellants, and TNT. Separate process areas are provided for the production of solvent-type propellant, referred to as rolled powder. The process steps are essentially the same in the production of solvent-type single-, double-, and triple-base propellants. Major differences are in the special chemical and explosive ingredients added. Single-base and double-base propellants may include one or more of the following chemicals: barium nitrate, potassium nitrate, ethyl centralite, graphite, carbon black, potassium sulfate, lead carbonate, dibutylphthalate, and diphenylamine. Triple-base propellants consist of ethyl centralite and potassium sulfate cryolite, while special high-energy propellants contain HMX. The secondary manufacturing operations at RAAP are the production of oleum, sulfuric and nitric acids, NG, and NC.

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TABLE 2.1

CHRONOLOGICAL LIST OF MAJOR ACTIVITIES AT RAAP

DATE	ACTIVITY
August 1940	Contract signed with Hercules powder Company for construction and operation of smokeless powder plant
September 1940	Construction of Radford Plant
April 1941	Production started at Radford Plant
1941	Separate New River bag loading plant constructed
1941/45	Construction of various facilities continued
1945	Consolidation of Radford and New River plants
1945	Production stopped-plant in standby
1946/49	Ammonium nitrate produced in Acid Area
1949	Limited resumption of powder production
1950	Plant reactivated for Korean Conflict
1950/51	Large areas of plant rehabilitated
1951	Multibase propellant and cast rocket grain facilities constructed
1967/68	Continuous TNT lines constructed
1970/72	New acid plants constructed
1971	Preproduction project work on Continuous Automated Multibase Line (CAMBL) started
1972	Continuous Automated Single-Base Line (CASBL) construction started
1972	Continuous nitrocellulose nitration construction started
1973	Military Construction, Army (MCA) pollution abatement facilities construction started
May 1974	TNT plant explosion
1976	Continuous Automated Single-Base Line M6/M1 conversion started
1978	Construction started on biological wastewater treatment plant
1980	C-line Nitrocellulose Manufacturing Area closed
1983	TNT plant reopened
1986	TNT plant placed on standby
1987	C-line Nitrocellulose Manufacturing Area reopened
December 1988	TNT plant cleanup, preparation for long-term standby

Source: Modified from USATHAMA, 1976, as cited in Dames & Moore, 1992a.

of the following chemicals: barium nitrate, potassium nitrate, ethyl centralite, graphite, carbon black, potassium sulfate, lead carbonate, dibutylphthalate, and diphenylamine. Triple-base propellants consist of ethyl centralite and potassium sulfate cryolite, while special high-energy propellants contain HMX. The secondary manufacturing operations at RAAP are the production of oleum, sulfuric and nitric acids, NG, and NC.

2.2 ENVIRONMENTAL SETTING

2.2.1 Climate

The climate of the area encompassing Montgomery and Pulaski Counties is classified as "moderate continental" and is characterized by moderately mild winters and warm summers. The climate is determined, for the most part, by the prevailing westerly wind, with a southerly component in the warm season and a northerly component during the cold season. The year-round average surface-air velocity is 8 miles per hour (mph).

The mean annual precipitation in the two-county area is about 39 inches. In general, the most precipitation occurs during July, with an average of 4.39 inches. Conversely, the driest time period occurs in November, with an average of only 2.23 inches. Tables 2.2 and 2.3 list the average monthly precipitation and temperatures for several stations in and around each county. Snowfall in the same area averages 17 inches annually. Both counties lie in one of the areas in the United States most susceptible to dense fog, which can be expected to occur between 20 and 45 days per year.

2.2.2 Physiography

RAAP lies within the Valley and Ridge Province of the Appalachian Physiographic Division. The Valley and Ridge Province is characterized by a series of long, narrow, flat-topped mountain ridges separated by valleys of varying widths. Either of these land forms may predominate; the mountains may be widely spaced and isolated or so closely spaced that the lowlands are disconnected or absent. A distinctive feature of the installation area is the absence of mountain ridges.

TABLE 2.2

AVERAGE MONTHLY PRECIPITATION FOR LOCATIONS NEAR RAAP

Station	Annual Precipitation (inches)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Years of Record
Allisonia	36.14	2.50	3.04	4.03	3.74	3.21	2.86	3.96	3.44	2.96	2.13	1.60	2.58	9
Blacksburg	40.73	3.18	3.08	3.61	3.17	3.73	4.21	4.70	3.90	3.03	2.77	2.35	3.03	70
Floyd	44.73	3.40	3.36	3.64	3.59	3.97	4.25	4.86	4.31	4.56	2.96	2.66	3.17	28
Glen Lyn	37.38	3.10	2.97	3.38	2.90	3.23	3.50	4.17	3.92	2.54	2.61	2.27	2.79	47
Pulaski	38.23	2.86	2.84	3.72	2.98	3.44	3.72	4.40	4.42	2.70	2.02	2.39	2.79	18
Claytor Dam	36.53	2.96	2.67	3.26	2.81	3.31	3.49	4.25	3.34	2.78	2.74	2.13	2.79	55

Source: NOAA, 1973, as cited in Dames & Moore, 1992a.

TABLE 2.3

AVERAGE MONTHLY TEMPERATURES (°F) - 1931-1960 FOR LOCATIONS NEAR RAAP

													Period of Record	
Station	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**High**	**Low**
Blacksburg	35.3	36.5	42.5	53.0	62.0	69.4	72.5	71.4	65.4	55.0	43.6	35.6	100	-27
Floyd	35.3	37.8	42.7	53.2	61.9	69.2	72.0	71.1	64.8	55.1	43.9	36.9	103	-8
Glen Lyn	36.6	38.0	44.3	55.2	64.5	71.7	74.6	73.6	67.5	56.9	45.0	36.5	102	-9

Source: NOAA, 1973, as cited in Dames & Moore, 1992a.

The topography within the installation varies from a relatively flat flood plain to elevated uplands in the extreme southeast section. The New River forms the RAAP boundary on the north, with the elevation approximately 1,675 feet above mean sea level (msl). The eastern boundary represents a transition from flood plain elevation (1,680 feet msl) to an elevation of 1,900 feet msl in the upland. The southern boundary traverses terrain consisting of creek bottoms and sharply rising summits. The western boundary follows the bluff line overlooking the New River to the point where the Norfolk and Western Railroad crosses the lower arm of the Horseshoe Area. In the Horseshoe Area to the north and east, the New River has a narrow flood plain. Just west of the Waste Propellant Burning Ground, the flood plain is terminated by steep bluffs that extend westward to the plant boundary. The Horseshoe area exhibits rolling karst terrain, with three prominent terraces and escarpments that are remnants of ancient New River flood plains.

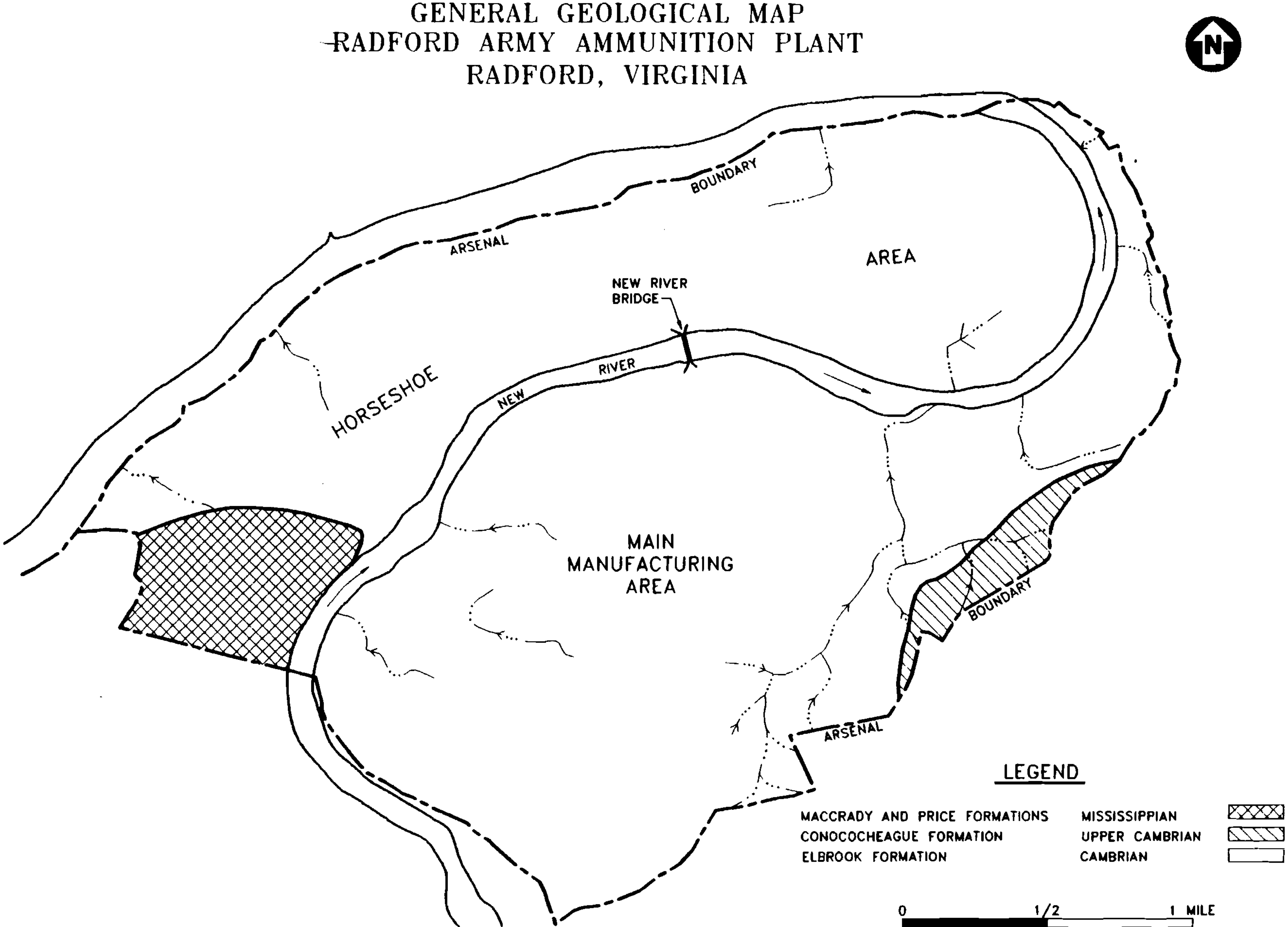
2.2.3 Geology

2.2.3.1 Stratigraphy

RAAP is underlain by four major rock units and one unconsolidated sedimentary unit that range in geologic age from Cambrian to Quaternary. The rock units are as follows: Cambrian Formations (Rome, Elbrook, and Conococheaque) and the Mississippian Formation (McCrady/Price). Dip of the rock units varies over RAAP from nearly horizontal to 50 degrees. The unconsolidated sediments are Quaternary in age and include alluvial, residual, and colluvial deposits. Figure 2.4 is a general geologic map of the major consolidated rock formations at RAAP. The following paragraphs describe the consolidated and unconsolidated formations at RAAP (USAEHA, 1980).

The Elbrook Formation is the major rock unit outcropping at RAAP. This formation is composed of thickly bedded, blue-gray dolomite interspersed with bluegray to white limestones; brown, green, and red shales; argillaceous limestones; and brecciated limestones (colors of which range from mottled light to dark gray and yellow brown). Sinkholes, solution channels, pinnacled surfaces, and vugs are common to the Elbrook. This formation ranges from 1,400 to 2,000 feet in thickness. The strike of bedding in the Elbrook Formation is variable throughout the region. In the vicinity of RAAP, bedding strikes roughly west/southwest to east/northeast and dips to the south/southeast. Dips ranging between 10 degrees and 60 degrees are common in the area. The orientation of bedding can best be seen

FIGURE 2.4
GENERAL GEOLOGICAL MAP
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



BASE MAP SOURCE: USATHAMA, 1976, AS CITED IN DAMES & MOORE, 1992

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in the nearly east-west alignment of sinkholes at RAAP and surrounding areas. Most sinkholes in the area are oval shaped and elongated with respect to the strike of bedding planes, and most likely represents less competent zones within the underlying Elbrook.

The Rome Formation underlies the Elbrook Formation, but it is not known if the Rome crops out at RAAP due to the complex tilted and fractured structure of the overlying Elbrook. The Rome is composed of red and green shales, sandstone, dolomite, and limestone. The red shales commonly mark the basal unit. Thickness ranges from 1,000 to 2,000 feet.

Mississippian rocks of the McCrady/Price Formation outcrop in a fenster (window) east of the main plant area along and south of Stroubles Creek. This formation consists of mottled red and green shale and mudstone interspersed with brownish-green siltstone and sandstone. The formation may be up to 1,500 feet in thickness.

Unconsolidated sediments (overburden) mantle the major portion of RAAP. These sediments include alluvial plain sediments deposited by the New River prior to entrenchment; residual deposits from in-place weathering of parent bedrock; and colluvial deposits developed by residual slope wash. Alluvial plain deposits commonly line the New River and Stroubles Creek as recent flood-plain material or as geologically older terraces. On the horseshoe loop, three terraces are in evidence. In general, there is a textural fining upwards, with gravels and silty, clayey sands forming the basal unit followed by finer micaceous silts and clays. Sporadic cobbles and boulders (known as river jack) occur as lenses throughout the alluvial strata. Thickness of the alluvial deposits varies from a few feet to 50 feet, with an average of 20 feet.

Residual deposits (clays and silts) are a result of the mechanical, physical, and chemical weathering of the parent bedrock (primarily Elbrook Dolomite at RAAP). Most of RAAP is covered by residual deposits. In most cases along the New River and in the Horseshoe Area, these residual deposits underlie the alluvium, except where the residuum has been eroded to bedrock and replaced by alluvium. The depth of the residuum varies from a few feet to 40 feet.

Colluvial deposits are generally formed from mass-wasting of slopes and escarpments. In general these deposits are a heterogeneous mixture of alluvium, residuum, and rock debris that has migrated from the original position. These deposits are generally interbedded between the strata of alluvium and residuum; thickness is variable.

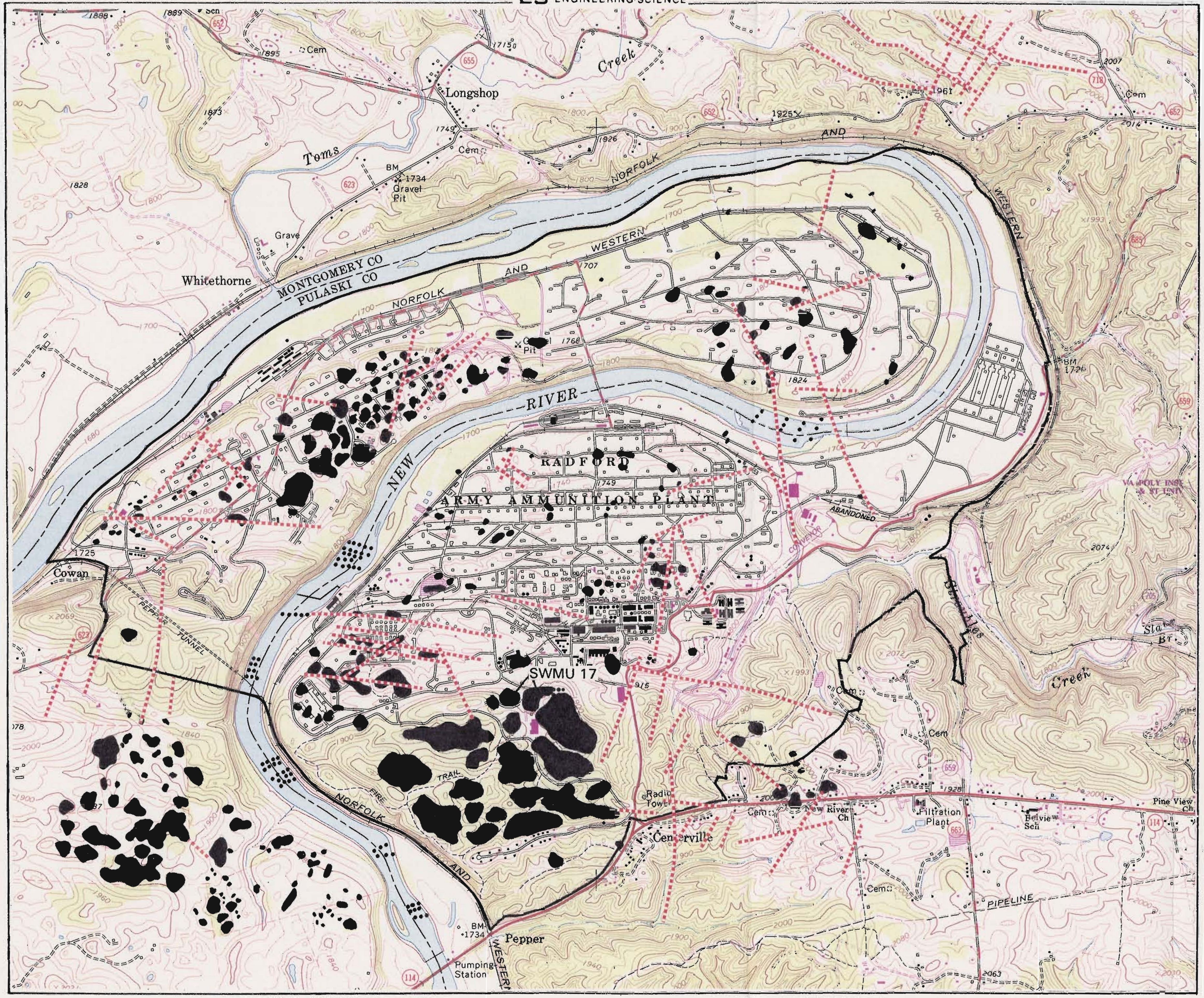
2.2.3.2 Structural Geology

RAAP occupies the Blacksburg-Pulaski Synclinorium and rests on the Pulaski Fault thrust sheet. The rocks have been thrust approximately 8 miles west-southwest. The thrust plate has been breached by erosion, exposing Mississippian sandstones and shales of the McCrady/Price Formation in a fenster east of the main plant area along Stroubles Creek. The fault trace is exposed above the computer complex bunker where the Mississippian McCrady/Price Formation can be seen underlying the Cambrian Elbrook Formation. No evidence of recent faulting exists; however, the Radford area has experienced seven earth tremors in the last 200 years with a recorded intensity of VI or higher on the Modified Mercalli Scale (USAEHA, 1980).

A total of 66 fracture traces was identified within and around RAAP in a photo geologic study conducted by the USEPA's Environmental Photographic Interpretation Center (EPIC) in 1992. Fracture traces are linear features identified in aerial photographs representing the surface expression of major fractures and/or zones of fracturing. These features may be expressed as soil-tonal variations and vegetational and topographic alignments and are significant in consideration of groundwater flow at RAAP. The fractures or fracture zones can act as conduits for groundwater flow, increasing flow rates, and in some cases, redirecting flow away from the "expected" flow direction. In karst terrain's, such features are environmentally significant because solutionization and resulting conduits develop along bedding planes as well as fractures (USEPA, 1992).

Figure 2.5 shows the primary fracture traces identified at RAAP in the USEPA (1992) report. Also shown in the figure are the sinkholes mapped during the EPIC study and bedding plane structures, seen as ledges in the New River channel.

FIGURE 2.5
FRACTURE TRACE/SINKHOLE LOCATIONS



LEGEND

- PROPERTY LINE
- FRACTURE TRACE
- BEDDING PLANE LEDGE
- SINKHOLE

SOURCE: USEPA, 1992
USGS, RADFORD (NORTH)
VIRGINIA QUADRANGLE

SCALE 1:24,000

2.2.4 Groundwater Conditions

The conditions at RAAP are complex in terms of defining the water table and the available supply of groundwater. Several borings within the Horseshoe Area of RAAP indicate that the water table within the flood plain is approximately the same elevation as the surface water of the river. These conditions also exist in the flood plain across the river in the Main Manufacturing Area of RAAP.

In areas of high elevations within the Horseshoe Area and south of the river within the Manufacturing Area, the water table is extremely variable. Because of impervious layers, solution cavities, and the thickness of overburden, extreme caution must be exercised in projecting water table data from existing borings into a new area. The limestone and dolomite underlying RAAP is severely folded, fractured, and faulted as a result of movement along the Pulaski Fault System. The topographic maps clearly show evidence of solution cavities and collapse structures oriented along bedding planes within the less competent limestone units (Figure 2.5). As a result, there is a significant potential for movement of water through these features in a rough east-west direction depending on location at the facility and water levels.

Groundwater flow in the south-central section of the Main Manufacturing Area, specifically in the vicinity of dye-injection locations (SWMU 17), is very complex. Groundwater which recharges the aquifer from the SWMU 17 Area discharges to the New River. However, the specific discharge area is unknown. Groundwater may move northward from the site toward the main plant area, to discharge at the New River at locations which are clearly downgradient from the site. Alternatively, groundwater may move westward from the site directly to the New River about one mile west of SWMU 17. Additionally, groundwater may move eastward from the site and discharge to tributaries of Stroubles Creek during high flow conditions. The residual alignment of sinkholes and fracture traces in an east to west direction, which is apparent in Figure 2.5, suggests that pathways to discharge areas east and west of the site may be present.

Groundwater levels in the bedrock aquifer generally respond to heavy precipitation within approximately 14 hours and may rise several feet in a short time (ES, 1993). This illustrates the direct connection between the groundwater and surface water that could compromise the quality of groundwater for domestic use. This condition exists throughout

RAAP and especially in areas where surface water infiltrates through sinkholes. Stormwater flows to the bottom of the sinkholes and rapidly travels downward through conduits into the unconfined aquifer. The New River is the discharge area for groundwater at RAAP and for regional groundwater flow. The saturated zone at RAAP can be generally in either the soil or bedrock. Open fractures and karst structures beneath the soil mantle, coupled with the relatively low elevation of the New River (1,680 feet msl), provide accessible conduits for groundwater flow, thereby rapidly draining the overlying, less permeable soils (CTM, 1988).

Water levels from monitoring wells throughout RAAP were measured during previous VI and RFI activities, and elevations were determined in order to evaluate groundwater flow directions at the facility. Table 2.4 summarizes groundwater elevation data collected during the 1992 VI and RFI investigations. Several wells had unusually shallow or deep water levels compared with other nearby wells. These wells probably intercepted perched groundwater zones or were influenced by karst features, such as sinkholes or conduits, which exerted a strong local influence which was not reflective of the overall unconfined water table. The overall water table resulting from these measurements would normally be expected in an area dominated by a major river. Groundwater flow was generally towards the New River and away from areas of higher elevation. The southernmost area of RAAP consists of folded rocks which have numerous sinkholes and a deep water table. The karst nature of the geologic units probably determines flow through the bedrock in this area. Bedrock groundwater in this southern area probably flows towards and discharges into either the New River to the west or the unnamed tributary of Stroubles Creek to the east.

2.2.5 Surface Water

The New River is the major surface water feature within RAAP. The river varies from 200 to 1,000 feet in width, but averages approximately 410 feet. Generally, the depth is approximately 4 to 6 feet; however, pools may be 10 feet deep between rock outcrops in the river bed. The flow through RAAP is regulated by a control structure located approximately 7 miles south of the installation. There are 13 miles of river shoreline within the RAAP boundaries.

TABLE 2.4
GROUNDWATER ELEVATION SUMMARY
RADFORD ARMY AMMUNITION PLANT

Well	Ground Sur. Elevation (feet msl)	Stickup (feet)	TOC Elevation (feet msl)	Measure Date	Depth to Water (feet TOC)	Groundwater Elevation (feet msl)	Survey Source
MW13	1801.14	2.40	1803.54	3/12/92	43.57	1759.97	BCM, 1984; USACE, 1981
7WCA	1713.23	2.58	1715.81	3/12/92	24.80	1691.01	USACE, 1981
S7W9	1710.48	2.11	1712.59	3/12/92	23.00	1689.59	USACE, 1981
W10	1704.98	1.88	1706.86	3/12/92	17.20	1689.66	USACE, 1981
H-1	1712.48	3.05	1715.53	3/12/92	29.47	1686.06	USACE, 1981
H-2	1709.90	2.80	1712.70	3/12/92	25.00	1687.70	USACE, 1981
H-3	1709.66	3.32	1712.98	3/12/92	25.80	1687.18	USACE, 1981
H-4	1710.90	3.00	1713.90	3/12/92	26.10	1687.80	USACE, 1981
HDH2	1713.81	3.00	1716.81	3/12/92	30.90	1685.91	BCM, 1984; USACE, 1981
10MW1	1701.28	2.34	1703.62	3/12/92	16.67	1686.95	Dames & Moore, 1992
D-3	1700.51	2.44	1702.95	3/12/92	16.00	1686.95	Dames & Moore, 1992
D3D	1700.70	1.94	1702.64	3/12/92	16.05	1686.59	Dames & Moore, 1992
D-4	1713.42	0.96	1714.38	3/12/92	22.00	1692.38	Dames & Moore, 1992
D5	1696.12	2.89	1699.01	3/12/92	6.30	1692.71	BCM, 1984; USACE, 1981
D6	1699.64	2.49	1702.13	3/12/92	11.02	1691.11	BCM, 1984; USACE, 1981
DDH2	1700.78	1.75	1702.53	3/12/92	15.87	1686.66	Dames & Moore, 1992
DDH4	1713.16	2.69	1715.85	3/12/92	24.95	1690.90	Dames & Moore, 1992
DG-1	1709.96	2.12	1712.08	3/12/92	22.30	1689.78	Dames & Moore, 1992
D-2	1713.12	2.82	1715.94	3/12/92	20.85	1695.09	BCM, 1984; USACE, 1981
DDH3	1715.70	3.00	1718.70	3/12/92	24.95	1693.75	BCM, 1984; USACE, 1981
D8	1711.75	2.65	1714.40	3/12/92	22.68	1691.72	BCM, 1984; USACE, 1981
DDH1	1699.00	3.00	1702.00	3/12/92	15.58	1686.42	BCM, 1984; USACE, 1981
D7	1701.04	2.57	1703.61	3/12/92	18.00	1685.61	BCM, 1984; USACE, 1981
17PZ1	1904.70	2.32	1907.02	6/10/93	80.21	1826.81	Dames & Moore, 1992
17MW2	1903.99	2.30	1906.29	6/10/93	79.83	1826.46	Engineering-Science, 1993
17MW3	1904.27	2.51	1906.78	6/10/93	147.33	1759.45	Engineering-Science, 1993
40MW2	1881.10	1.41	1882.51	6/10/93	dry	dry	Dames & Moore, 1992
40MW3	1856.02	2.19	1858.21	6/10/93	91.95	1766.26	Engineering-Science, 1993
40MW4	1906.10	2.01	1908.11	6/10/93	dry	dry	Dames & Moore, 1992
41MW1	1802.87	2.28	1805.15	3/12/92	20.03	1785.12	Dames & Moore, 1992
41MW2	1795.44	2.01	1797.45	3/12/92	52.05	1745.40	Dames & Moore, 1992
41MW3	1757.26	2.09	1759.35	3/12/92	27.74	1731.61	Dames & Moore, 1992
43MW1	1703.90	1.97	1705.87	3/12/92	17.99	1687.88	Dames & Moore, 1992
43MW2	1704.95	2.67	1707.62	3/12/92	24.00	1683.62	Dames & Moore, 1992
43MW3	1701.15	2.20	1703.35	3/12/92	20.89	1682.46	Dames & Moore, 1992
43MW4	1700.90	1.88	1702.78	3/12/92	19.80	1682.98	Dames & Moore, 1992
43MW5	1700.40	2.54	1702.94	3/12/92	17.77	1685.17	Dames & Moore, 1992
43MW6	1701.24	2.64	1703.88	3/12/92	19.07	1684.81	Dames & Moore, 1992
45MW1	1707.53	2.17	1709.70	3/12/92	25.00	1684.70	Dames & Moore, 1992
45MW2	1703.74	2.43	1706.17	3/12/92	21.21	1684.96	Dames & Moore, 1992
45MW3	1704.14	2.38	1706.52	3/12/92	21.42	1685.10	Dames & Moore, 1992
8B	1738.20	1.94	1740.14	3/12/92	11.00	1729.14	Dames & Moore, 1992
9B	1734.30	2.48	1736.78	3/12/92	17.22	1719.56	USACE, 1988
OMW1	1777.60	2.44	1780.04	3/12/92	17.40	1762.64	Dames & Moore, 1992
P-1	1777.10	2.59	1779.69	3/12/92	12.32	1767.37	Dames & Moore, 1992
P-2	1756.80	1.84	1758.64	3/12/92	3.12	1755.52	Dames & Moore, 1992
P-3	1753.20	1.39	1754.59	3/12/92	4.60	1749.99	Dames & Moore, 1992
P-4	1771.20	1.97	1773.17	3/12/92	22.90	1750.27	Dames & Moore, 1992
S4W1	1750.70	2.57	1753.27	3/12/92	8.90	1744.37	Dames & Moore, 1992
S4W2	1734.63	2.00	1736.63	3/12/92	14.00	1722.63	USACE, 1988
S4W3	1719.56	1.70	1721.26	3/12/92	16.37	1704.89	USACE, 1988
S4W4	1733.72	1.98	1735.70	3/12/92	12.33	1723.37	USACE, 1988
WC1-2	1784.80	1.78	1786.58	3/12/92	39.48	1747.10	Dames & Moore, 1992
WC2-2	1738.14	1.84	1739.98	3/12/92	18.17	1721.81	USACE, 1988
WC3-2	1723.43	2.37	1725.80	3/12/92	17.70	1708.10	USACE, 1988
5WCA	1777.37	2.59	1779.96	3/12/92	12.00	1767.96	USACE, 1988

TABLE 2.4
GROUNDWATER ELEVATION SUMMARY
RADFORD ARMY AMMUNITION PLANT

Well	Ground Sur. Elevation (feet msl)	Stickup (feet)	TOC Elevation (feet msl)	Measure Date	Depth to Water (feet TOC)	Groundwater Elevation (feet msl)	Survey Source
5WC1-1	1787.55	2.44	1789.99	3/12/92	17.00	1772.99	USACE, 1988
S5W5	1773.82	1.43	1775.25	3/12/92	2.50	1772.75	USACE, 1988
S5W6	1769.42	2.01	1771.43	3/12/92	5.70	1765.73	USACE, 1988
S5W7	1776.59	2.00	1778.59	3/12/92	11.50	1767.09	USACE, 1988
13MW1	1698.66	2.78	1701.44	3/12/92	19.32	1682.12	Dames & Moore, 1992
13MW2	1701.21	1.41	1702.62	3/12/92	20.42	1682.20	Dames & Moore, 1992
13MW3	1693.81	0.66	1694.47	3/12/92	12.70	1681.77	Dames & Moore, 1992
13MW4	1695.18	1.22	1696.40	3/12/92	16.00	1680.40	Dames & Moore, 1992
13MW5	1695.26	1.14	1696.40	3/12/92	16.03	1680.37	Dames & Moore, 1992
13MW6	1693.85	2.19	1696.04	3/12/92	15.77	1680.27	Dames & Moore, 1992
13MW7	1693.77	1.44	1695.21	3/12/92	14.72	1680.49	Dames & Moore, 1992
B2	1769.77	2.88	1772.65	3/12/92	80.37	1692.28	USACE, 1981
B3	1765.09	2.80	1767.89	3/12/92	74.91	1692.98	USACE, 1981
B4	1764.64	2.86	1767.50	3/12/92	71.90	1695.60	USACE, 1981
BDH2	1783.77	1.47	1785.24	3/12/92	89.73	1695.51	Dames & Moore, 1992
BDH3	1829.55	1.18	1830.73	3/12/92	86.30	1744.43	Dames & Moore, 1992
7	1772.10	2.50	1774.60	3/12/92	26.40	1748.20	USAEHA, 1980b
FAL2	1756.13	1.80	1757.93	3/12/92	35.92	1722.01	USEPA, 1989
FAL3	1757.43	1.00	1758.43	3/12/92	66.50	1691.93	USEPA, 1989
16-1	1814.54	1.28	1815.82	3/12/92	50.40	1765.42	Dames & Moore, 1992
16-2	1809.24	1.75	1810.99	3/12/92	55.78	1755.21	Dames & Moore, 1992
16-3	1823.37	1.40	1824.77	3/12/92	59.03	1765.74	Dames & Moore, 1992
16-4	1835.84	0.92	1836.76	3/12/92	53.72	1783.04	Dames & Moore, 1992
28MW1	1825.71	1.47	1827.18	3/12/92	31.73	1795.45	Dames & Moore, 1992
28MW2	1819.91	1.65	1821.56	3/12/92	62.84	1758.72	Dames & Moore, 1992
51MW1	1821.24	1.89	1823.13	3/12/92	7.74	1815.39	Dames & Moore, 1992
51MW2	1833.29	1.48	1834.77	3/12/92	49.54	1785.23	Dames & Moore, 1992
C-1	1836.94	3.20	1840.14	3/12/92	52.12	1788.02	Dames & Moore, 1992
C-4	1824.74	2.10	1826.84	3/12/92	54.71	1772.13	Dames & Moore, 1992
CDH-2	1823.79	2.49	1826.28	3/12/92	56.92	1769.36	Dames & Moore, 1992
MW-9	1806.54	2.34	1808.88	3/12/92	65.15	1743.73	Dames & Moore, 1992
WC-1A	1810.54	2.07	1812.61	3/12/92	68.93	1743.68	Dames & Moore, 1992
WC-2A	1816.07	1.98	1818.05	3/12/92	64.62	1753.43	Dames & Moore, 1992
32MW1	1736.40	1.91	1738.31	3/12/92	56.90	1681.41	Dames & Moore, 1992
54MW1	1705.68	2.10	1707.78	3/12/92	18.52	1689.26	Dames & Moore, 1992
54MW2	1698.86	2.55	1701.41	3/12/92	21.61	1679.80	Dames & Moore, 1992
54MW3	1700.56	1.59	1702.15	3/12/92	22.64	1679.51	Dames & Moore, 1992
74MW1	1732.59	2.26	1734.85	3/12/92	24.28	1710.57	Dames & Moore, 1992

Modified from Dames & Moore, 1992
msl = Mean Sea Level
TOC = Top of Casing

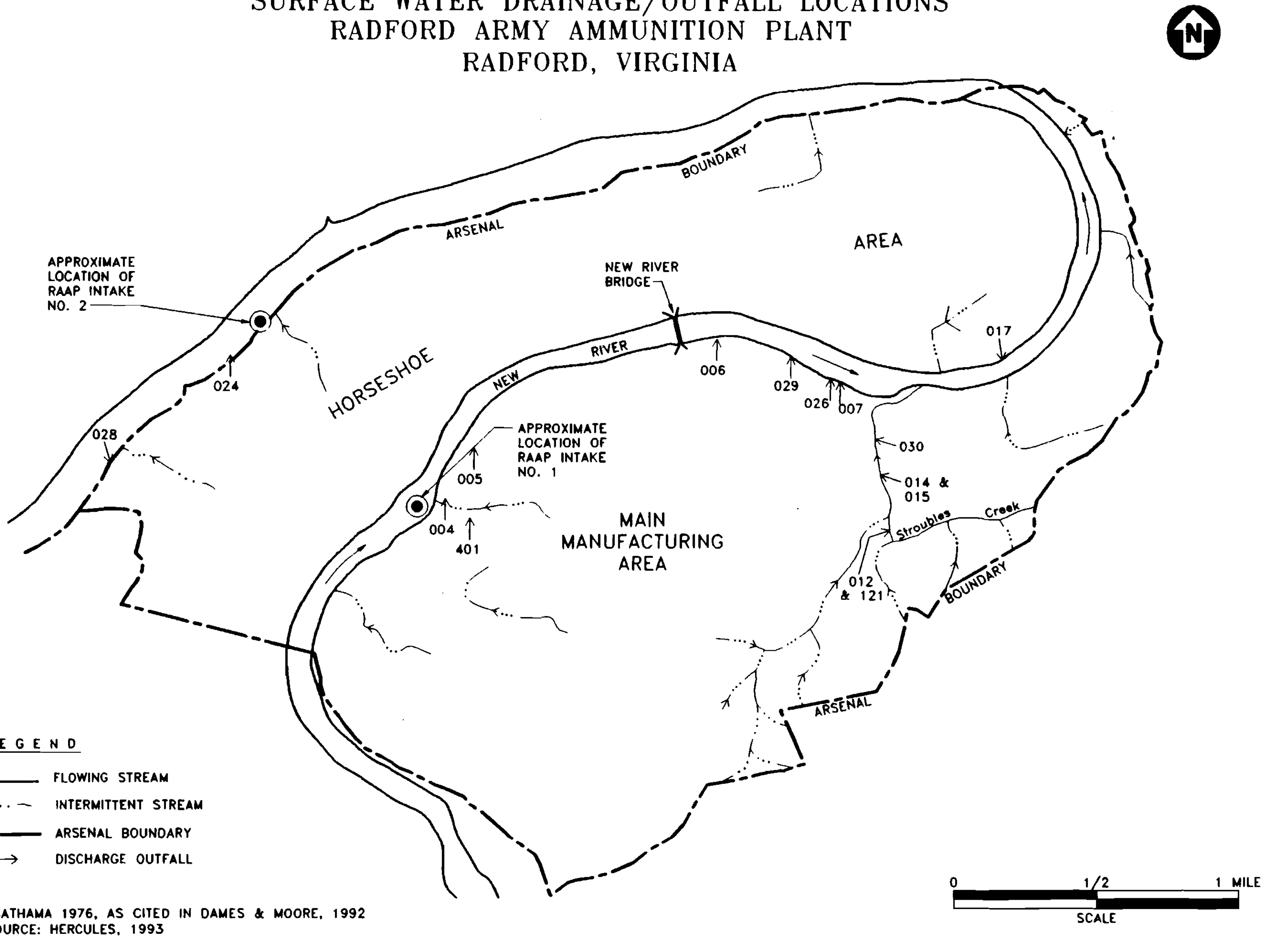
Stroubles Creek is the largest tributary of the New River and originates in the southeast sector of RAAP. This creek is fed by several branches that originate on and off post. The larger surface drainageways within the installation and their direction of flow are shown in Figure 2.6. Manmade surface drainageways at RAAP also influence local drainage. Regardless of location, the direction of surface drainage flow is ultimately to the New River. Subsurface drainage is present in RAAP through the sinks or solution cavities formed by percolating waters within the underlying limestone. These cavities vary in size and shape and may be interconnected, forming underground drainageways. Groundwater flow at RAAP is discussed in Section 2.2.5.

Stroubles Creek consists primarily of stormwater runoff and effluent from the Blacksburg, Virginia, Municipal Wastewater Treatment Plant. The creek empties into the New River on the RAAP installation and contributes significant loadings of domestic and industrial wastewater (USATHAMA, 1976). As mentioned in Section 2.2.5, groundwater discharging from the karst bedrock in the southern areas may supply significant stream flow. The Commonwealth of Virginia has classified Stroubles Creek and the stretch of New River passing through the confines of RAAP as water generally satisfactory for beneficial uses, which include public or municipal water supply, secondary contact recreation, and propagation of fish and aquatic life (USATHAMA, 1976).

Both industrial and domestic wastewaters are discharged into the New River from the city of Radford, upstream from RAAP. Previously, Radford provided only primary sewage treatment before discharging 2.5 million gallons per day (mgd) into the New River (USATHAMA, 1976). Secondary treatment is now provided at the Peppers Ferry Regional Wastewater Treatment Plant.

RAAP discharges approximately 25 mgd at fifteen locations along the New River and Stroubles Creek under VPDES permit number VA0000248. The effluent consists of various treated process water, wash water, cooling water, run off, sanitary wastewater, and stormwater. The approximate locations of the discharge outfalls are shown in Figure 2.6.

FIGURE 2.6
SURFACE WATER DRAINAGE/OUTFALL LOCATIONS
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



All water used at RAAP is taken from the New River. The river flow varies due to water management at Claytor Dam, approximately 9 miles upgradient from RAAP (see Figure 2.2). Typical flows are about 3,800 mgd. Separate water systems are provided for the main plant and the Horseshoe Area. Intake No. 1 is located approximately 2 miles upstream of the mouth of Stroubles Creek. Intake No. 2 is located approximately 6 miles downstream of the mouth of Stroubles Creek (see Figure 2.6). Upstream of RAAP, the New River serves as a source of drinking water for the towns of Blacksburg and Christiansburg.

In 1976, water quality analyses of the New River were conducted both where the river enters the RAAP installation and where it exits the installation. The analyses indicated that the quality of the water when it leaves the installation was essentially the same as when it enters. Table 2.5 provides a summary of the general water quality of the New River, determined in 1976.

TABLE 2.5

ANALYSES OF THE NEW RIVER WATER
RADFORD ARMY AMMUNITION PLANT, VIRGINIA

PARAMETER	CONCENTRATION (mg/L)	
	Entering	Leaving
Alkalinity (as CaC03)	45	45
BOD	2	2
COD	10	10
Total Solids	66	66
Total Dissolved Solids	61	61
Total Suspended Solids	5	5
Total Volatile Solids	29	29
Ammonia	0	0
Kjeldahl Nitrogen	0.4	0.4
Nitrate (as Nitrogen)	0.4	0.7
Phosphorus Total	< 0.3	< 0.3
Color (Color Units)	16	15
Nitrite	< 0.01	< 0.01
Sulfate	4	10
Sulfide	< 0.1	< 0.1
Bromide	0.59	0.59
Aluminum	< 0.10	< 0.10
Cadmium	< 0.005	0.005
Chloride	5.2	5.7
Copper	< 0.010	< 0.010
Iron	0.35	0.33
Lead	< 0.010	< 0.010
Magnesium	5	4
Mercury	< 0.002	< 0.002
Beryllium	0	0
Boron	0	0

Source: USATHAMA, 1976, as cited in Dames & Moore, 1992a.

SECTION 3

DYE-TRACE INVESTIGATION

3.1 DYE SELECTION

Groundwater tracing can be accomplished using a wide variety of tracers, including radioisotopes, chemicals, fluorescent dyes, bacterial tracers, and particulate tracers. Desirable properties in a groundwater tracer include:

- Easily detectable by the researcher(s);
- Not detectable by the public;
- Should not react with the rock or soil matrix;
- Chemically stable over the length of the test;
- Not commonly found in the environment;
- Non-toxic; and,
- Relatively inexpensive.

These criteria are to some extent contradictory. No tracer will meet all of these criteria; however, some will meet most of them. Generally, the fluorescent dyes are the most cost-effective and reliable tracers of the above list.

Four types of fluorescent dyes are commonly used in groundwater tracing in the United States (Quinlan, 1987). These include Sodium Fluorescein, Rhodamine WT, Direct Yellow 96, and a number of compounds within the general category of optical brighteners. From this list, Sodium Fluorescein, and Direct Yellow 96 were chosen for this study.

Fluorescein (CI Acid Yellow 73) is a green fluorescent dye that is recovered on activated coconut charcoal. Sodium Fluorescein is also known and marketed as Uranine. Fluorescein is provided as a powder which must be mixed with water prior to or during injection and is usually cut with fillers such as sodium chloride, sodium sulfate or starch derivatives (Quinlan, 1987). Fluorescein is very susceptible to photochemical decay (Smart and Laidlaw, 1977). Therefore, detectors should be shielded from sunlight and placed at locations where the water has been exposed to as little sunlight as possible. Fluorescein is somewhat resistant to sorption on clays (Quinlan, 1987). Jones (1984) reports that Fluorescein is the most popular dye used in karst studies in the United States.

Direct Yellow 96 is a yellow fluorescent dye recovered on unbleached, unwhitened cotton detectors. It is supplied as a powder that must be mixed with water prior to injection. Direct Yellow is not subject to photochemical decay and is a common dye used in systems where the water has resurgences that allow it to be exposed to the sun (Quinlan, 1987). Reaction with soils and rock matrices is very slight (Jones, 1984). Direct Yellow reacts with cellulose to a greater degree than Fluorescein (Quinlan, 1987). Direct Yellow has been used extensively in groundwater tracing in karst terrains in Kentucky.

3.2 DYE TRACE INVESTIGATION

3.2.1 Well Installation

As part of the dye-tracing study, three bedrock monitoring wells and two temporary dye-injection wells were installed in the study area (Figure 3.1). The bedrock wells range in depth between 120 feet and 190 feet and are designed to intercept the regional water table associated with the New River. The two dye-injection wells, located in the sinkholes comprising SWMUs 17A and 17B-E, were installed to a maximum depth of 23.5 feet and were installed through the fill overburden to the bedrock interface.

All well installation procedures were performed in accordance with the Dye-Tracing Study Work Plan (ES, 1993) or using methods approved by USAEC when unusual conditions were encountered. The boring logs/well completion records for all wells installed as part of this investigation are presented in Appendix A.

The bedrock borings were advanced using air-hammer drilling techniques. This drilling method was selected based on the abundant solution features encountered during previous drilling activities in the area to reduce the potential for loss of drilling fluids. Drill cuttings were examined for lithology during the drilling activities and periodically placed into glass jars for further examination, when needed.

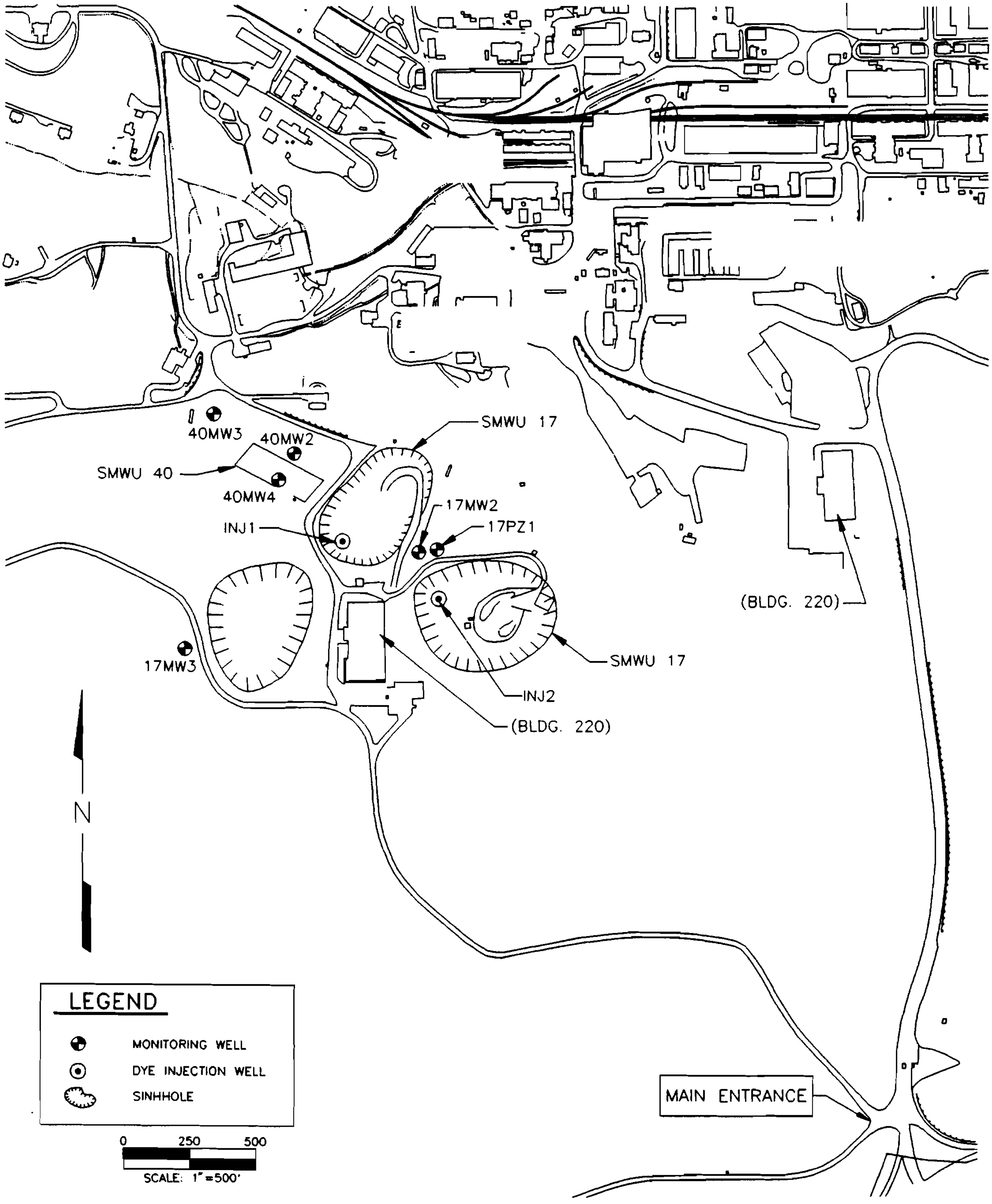
Prior to well placement, a color television camera was lowered into each borehole to facilitate examination of structural features (bedding planes and fractures) and physical condition (solution features). The wells were then constructed in the borehole with 4-inch

FIGURE 3.1

MONITORING/INJECTION WELL LOCATIONS

RADFORD ARMY AMMUNITION PLANT : SWMU 17

RADFORD, VIRGINIA



843FIG1 3/9/94

MAP SOURCE: ANDERSON & ASSOCIATES, INC., OCT. 1993

ENGINEERING–SCIENCE

inner diameter, flush-joint, schedule 40 PVC pipe and screened over the lower 20 feet. Each well was developed with a submersible pump following well completion.

The first bedrock well (17MW2) was located between the two dye-injection points at SWMUs 17A and 17E, adjacent to existing piezometer 17PZ1. The well was installed to a depth of 173 feet with a screened interval between 150 feet and 170 feet. Lithology in the 17MW2 boring generally consisted of a hard, massive dolostone interbedded with a soft, highly weathered, argillaceous dolostone. Numerous voids and weathered zones were encountered during drilling activities; between 22 feet and 23 feet, 78 feet and 80 feet, and a major water producing void between 129 feet and 132 feet. The rate of groundwater recharge to 17MW2 was extremely rapid during well installation and development activities.

The second bedrock well (17MW3) was located along the axis of sinkhole alignment in the area to evaluate the influence of structural features and/or solution features on dye transport. Monitoring well 17MW3 was completed at a depth 190 feet and screened between 159 feet and 179 feet. Lithology in the 17MW3 boring was similar to that observed at the 17MW2 location. A large void was encountered between 11 feet and 20 feet requiring the installation of an 8-inch ID, PVC surface casing to 20 feet. Smaller voids (< 1 foot) were observed at 52 feet and 73 feet. An intensely weathered zone was encountered between 162 feet and 168 feet across which the well was screened. Recharge to this well was very slow during installation and development.

The third well (40MW3) was located in a downgradient flow direction from SWMUs 17 and 40. Monitoring well 40MW3 was installed to a depth of 120 feet and screened between 97 feet and 117 feet. Approximately 53 feet of soil overburden was encountered at this drilling location. The soil was composed of micaceous silt which graded downward into a micaceous sand and finally into a well to subrounded gravel. Bedrock was encountered at 53 feet below ground surface at this boring location. An 8-inch ID, PVC surface casing was installed to seal off the overburden material at 40MW3. Bedrock lithology was similar to that observed at the previous boring locations. Voids were encountered between 62 feet and 63 feet, 79 feet and 80 feet, 105 feet and 106 feet, and 107 feet to 109 feet. Groundwater recharge to this well was rapid.

Two temporary dye-injection wells (INJ1 and INJ2) were installed in the southwest corner of the Stage and Burn Area (SWMU 17A) and adjacent to the Runoff Drainage Area (SWMU 17E) as shown in Figure 3.2. The wells were installed to facilitate dye injection at these locations. The borings were advanced using either air rotary or hollow stem augers drilling methods and were designed to extend through the soil fill material in the bottom of the sinkhole to the bedrock interface. The injection wells were constructed with an open ended 4-inch, inner diameter PVC pipe.

Lithology in the INJ1 boring consisted of black, sandy, fill material to a depth of 23 feet. Below the fill material, bedrock was encountered consisting of soft, argillaceous dolostone. The overburden lithology was considerably different at the INJ2 location, however. Black sand and gravel was encountered to a depth of 10 feet; underlain by a light brown to gray colored clay extending to bedrock at 23.5 feet. Bedrock lithology was similar to that observed at the INJ2 boring location. Due to the proximity of INJ2 to the ponded water in the runoff drainage basin, water was encountered at a depth of two feet in INJ2, suggesting poor drainage in that area.

3.2.2 Field Reconnaissance and Pretest Screening

Prior to injecting the dye for this study, field reconnaissance activities were conducted of the study area between late May, 1993 to early June, 1993. These efforts were conducted to locate and verify dye monitoring points and to locate additional monitoring points not previously identified in the Work Plan. During field reconnaissance for the final selection of dye monitoring locations, dye-detectors 'bugs' were placed in all prospective monitoring locations that were to be utilized during the dye-trace test. They were retrieved prior to dye injection and tested for background levels of Fluorescein and Direct Yellow dyes.

3.2.3 Dye Preparation

Fluorescein and Direct Yellow are supplied in powder form. The Fluorescein was mixed with unchlorinated water at the rate of one pound per gallon prior to the test. Direct Yellow was mixed at the rate of two pounds per gallon. The dye solutions were stored in five-gallon plastic jugs and were prepared on the day of injection. Precautions were taken during

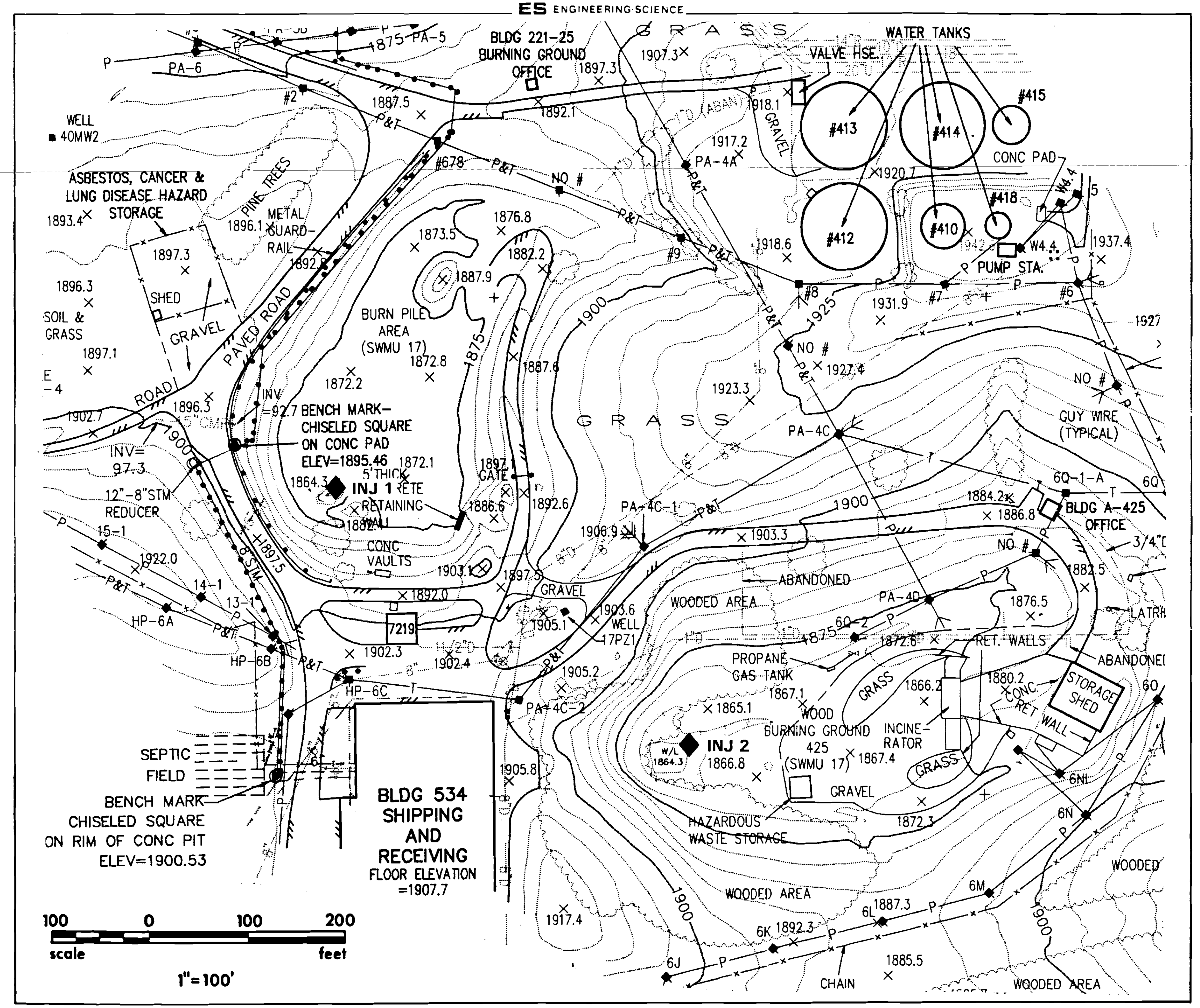


FIGURE 3.2
DYE INJECTION LOCATIONS

◆ INJ DYE INJECTION LOCATION

SOURCE: ANDERSON AND ASSOCIATES, 1992

mixing, storage, and transportation of the dye solutions to minimize the chance of dyes contaminating the detectors.

Quinlan (1987) suggests a dosage of one pound of Fluorescein per mile of travel. The travel distance for the dye was estimated to range between one and two miles from the injection location; however, a five pound dosage was used for this investigation to account for potential losses to organics and/or the soil fill in SWMU 17A.

The appropriate dosage for Direct Yellow is two pounds per mile of travel, up to ten pounds (Quinlan, 1987). The travel distance for the dye was estimated to range between one and two miles from the injection location. As a result, a dose of approximately four pounds of Direct Yellow dye was required. However; because of the restricted inflow at SWMU 17E, an additional four pounds of dye was applied to account for adsorption of the dye on leaf litter and other cellulose.

3.2.4 Dye Injection

The dyes were introduced on September 23, 1993 during relatively low flow conditions after a storm event. This ensured that dilution of the dye was minimal and groundwater flow rates would be average. Additionally, the loss of dye due to storage in isolated pools within the karst system matrix would be minimized.

Fluorescein dye was injected into INJ1, located in SWMU 17A. Prior to introduction of the dye, approximately 1,200 gallons of unchlorinated water was pumped into the injection well to saturate the potential flow pathways. The dye was then introduced directly into the well after the slug of water infiltrated into the sinkhole. Following injection, the dye was followed by a chaser of 1,200 gallons of unchlorinated water injected at a moderate and constant rate.

A similar injection method was attempted at INJ2, located in the runoff drainage basin (SWMU 17E). Initially, unchlorinated water was pumped into the injection well; however, the water did not infiltrate into the surrounding formation. The remaining 1,150 gallons of water was pumped onto the ground surrounding the injection well in an effort to saturate the entire area. The Direct Yellow dye introduced into the well and also poured into the ponded water in the runoff basin. Another 1,200 gallons of unchlorinated water were pumped on the ground at the runoff drainage basin to further saturate the soil overburden and to speed up dye infiltration.

3.2.5 Dye Monitoring

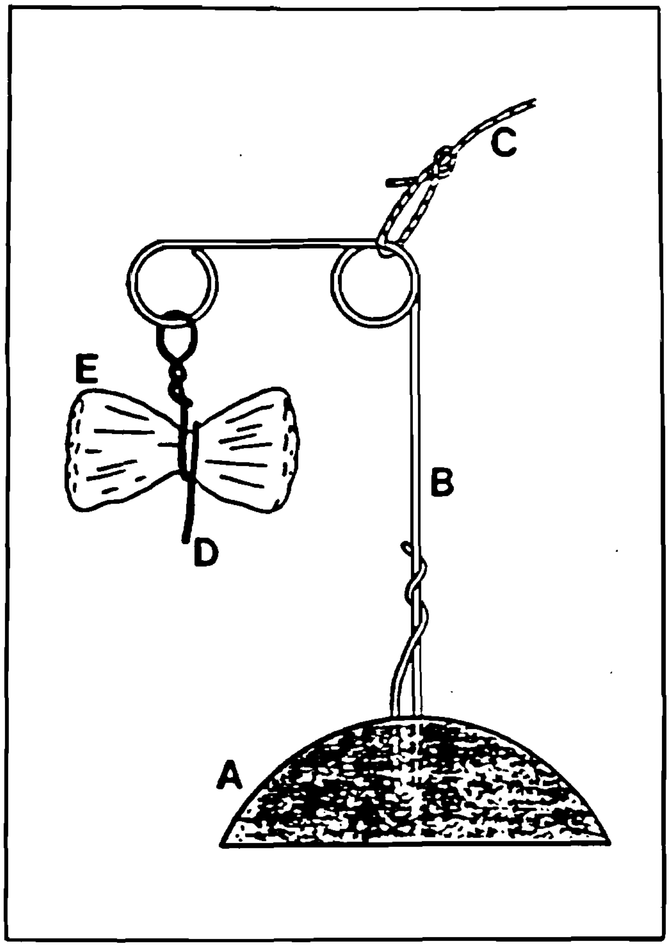
3.2.5.1 Dye Detection

Passive detectors, or "bugs," were used to accumulate dyes for visual examination during this investigation. Fluorometric techniques were used to detect the dye and to provide qualitative and/or semi-quantitative measures of the dye concentration. Visual examination was chosen for this study in order to reduce the complexity of the detector processing while still meeting the objectives of the study. Activated charcoal was used to adsorb Fluorescein dye for detection and Direct Yellow was detected on cotton bugs.

The detectors used to detect Fluorescein were composed of three to four tablespoons of 6 to 14 mesh-activated coconut charcoal enclosed in a pouch of nylon window screen. Surgical cotton pads, enclosed in a screen pouch similar to the charcoal, were used to detect Direct Yellow. Both the charcoal and cotton detectors were prepared daily. In addition each new roll of cotton was checked with an ultraviolet light for the presence of optical brighteners or other fluorescence that might interfere with detection of the dye prior to being used for this investigation.

Both a cotton and a charcoal bug were placed at each monitoring location. The bugs were suspended above the stream bed using a weighted, stable stand known as a "gumdrop." Typical gumdrop construction is illustrated in Figure 3.3. A laminated tag was affixed to each gumdrop to identify the monitoring location and to discourage removal by unauthorized personnel. The detectors were placed within the main channel of flow in an effort to maximize the amount of water passing through the bug and secured to an immovable object on-shore to insure that a sudden rise in the current would not wash the detectors away. Detectors installed in wells were suspended below the water table by a piece of weighted polypropylene rope.

Figure 3.3
Gumdrop Construction



A: Concrete semi-hemisphere, approximately 6 inches in diameter and 2 to 3 inches high.
B: Galvanized steel wire, #9 gage
C: Nylon cord, 3/32 inches in diameter
D: Paper Clip
E: Surgical cotton detector for Direct Yellow, 4 inches long by 2 inches Cotton is contained in a nylon screen pouch.
Note : A second dector, consisting of activated charcoal in a nylon screen packet, is suspended from a loop for Fluorescein detection.

From: Quinlan, 1987

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3.2.5.2 Monitoring Locations

A total of 35 locations were monitored for the resurgence of dye during this investigation (15 stream locations, 9 river locations, 7 spring locations, and 4 well locations). The monitoring locations are shown in Figure 3.4.

Fifteen monitoring points were located in streams on and off site. Primarily, Stroubles Creek and several unnamed tributaries flowing into the creek were monitored for transport of dye east from the injection area (SMPs 4-15, and 17). An unnamed tributary flowing into the New River, located northeast of the Rolled Powder Area, was also monitored for dye (SMP16). Spring fed Pepper Creek and its two tributaries, located south of RAAP, was monitored in three locations (SMPs 1-3) to determine if groundwater is discharging south from the dye injection site.

Seven springs were located during the field reconnaissance activities and subsequently monitored for dye during this investigation. The springs were primarily located along the northwestern shoreline of the New River (SPG 2 through SPG 7) with the exception of SPG 1, which was located at the base of the bluff along the Norfolk & Western Rail Road (RAAP southwest property boundary).

Four monitoring wells were monitored for dye (WMPs 1-4). These wells include piezometer 17PZ1 (WMP1), and newly installed bedrock wells 17MW2 (WMP2), 40MW3 (WMP3), and 17MW3 (WMP4).

Ten monitoring points (RMPs 1-10) were placed along the southern shore of the New River. The monitoring points extend from the confluence of Pepper Creek, near the Route 114 bridge, to the Rolled Powder Area near the northeastern RAAP boundary. The monitoring locations were spaced at approximately 3,000-foot intervals. Where possible, the monitoring points were sighted offshore from structural lineaments at the facility, such as fracture traces and sinkhole alignments.

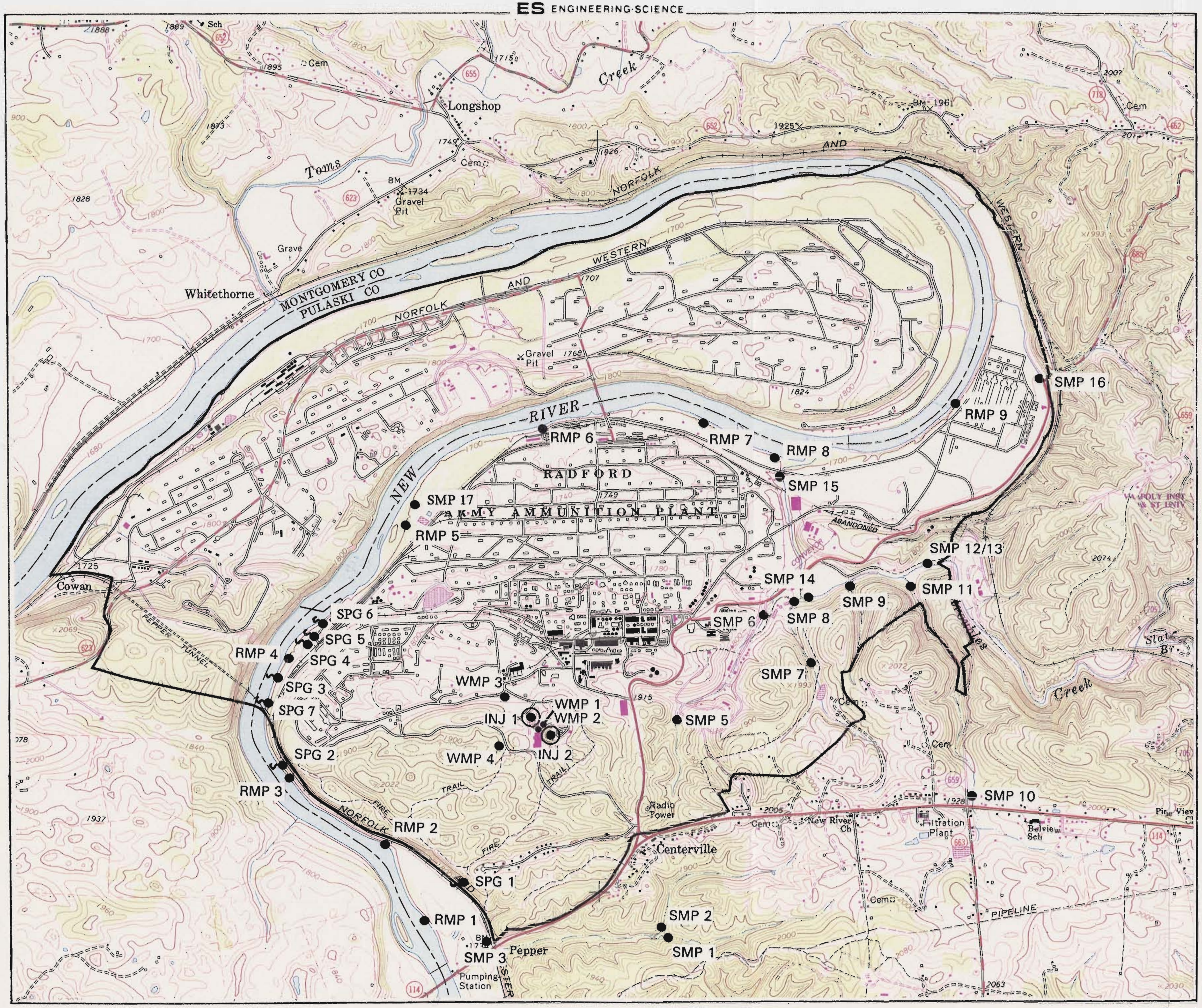


FIGURE 3.4
DYE MONITORING LOCATIONS

LEGEND

- PROPERTY LINE
- DYE MONITORING POINT
- SPRING LOCATION
- DYE INJECTION LOCATION

NOTE:
- **SMP** STREAM MONITORING POINT
- **SPG** SPRING MONITORING POINT
- **WMP** WELL MONITORING POINT
- **RMP** RIVER MONITORING POINT

SOURCE: VIRGINIA USGS, RADFORD NORTH QUADRANGLE

SCALE 1:24,000

The New River monitoring points were selected to determine the most likely area where groundwater in the karst flow system is discharging into the New River. The resurgences may be either from surface water flow, diffuse flow through the river alluvium, springs and seeps below the water line, springs in the river bottom, or any combination of the above.

3.2.5.3 Monitoring Schedule

During the field reconnaissance phase, detectors placed at each of the monitoring locations were collected prior to dye injection and tested for background levels of the dyes.

During the tracing study, the bugs were collected from each monitoring location and analyzed for dye on a daily basis during the first week after dye injection. A biweekly monitoring schedule was implemented during weeks two through twelve. Both the charcoal and cotton bugs were collected from all locations during the monitoring program and daily tasks associated with the test were recorded on a field data sheets shown in Appendix B.

Each pair of bugs (one charcoal, one cotton) were drained of water and placed in labeled whirl-pac plastic bags immediately upon retrieval. Each bag will be labeled with the detector location and the date and time of retrieval. If the bugs could not be processed within 12 hours of retrieval, they were air dried to minimize microbial activity that may mask a positive detection.

3.2.5.4 Detector Analysis

Charcoal Detectors - Approximately one-third of the charcoal in the detector was placed into a glass jar labeled with the same number as the sample. The unused portion of the charcoal detector was returned to the plastic bag and retained for later confirmation if required.

Dye collected on the charcoal was eluted using a basic potassium hydroxide (KOH) and 70 percent propanol (common rubbing alcohol) solution that was prepared daily. A distinctive kelly-green color would develop if dye was present on the charcoal and a muted green color would develop due to the extraction of algae and organic matter. Practice in eluting weak positive spike samples was performed to reduce the chance of confusion resulting in false positives. The degree of positiveness was judged based upon the following scheme taken from Aley and Fletcher (1976):

1. **Very Strongly Positive:** 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:** Same as above, but after 15 minutes and before 3 hours.
3. **Moderately Positive:** 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:** 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:** 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.

The results of the bug analysis were recorded on the data sheets shown in Appendix C.

Cotton Detectors - The cotton detectors were examined for the presence of Direct Yellow using a long-wave ultraviolet lamp. The detector was removed from the screen pouch and placed in a view box under the ultraviolet lamp. A positive test was indicated by a uniform yellow color. After examination, the detector was returned to the plastic bag and retained for later confirmation if required. The results of the bug analysis were recorded on the data sheets shown in Appendix C.

3.2.5.5 Quality Assurance

Quality assurance samples were analyzed both before and during the tracer test. These samples included detectors spiked with varying concentrations of the dyes, detectors that have not been exposed to dyes. The spiked detectors were used to confirm that the detectors and analysis techniques will detect the dye. In addition, by using spikes of varying concentration, information on the range of detection was obtained. The blank samples insured that there is no dye or material that would interfere with the detection of dye in the unexposed detectors. The background samples will be used to identify algal growths or organics that may interfere with detection of dye, or be confused with the presence of dye. Pretest screening of the monitoring sites has been previously discussed. Duplicate detectors on separate holders will be placed at two of the monitoring sites.

SECTION 4

DYE-TRACING STUDY RESULTS

The objective of this study was to determine groundwater flow directions through the karst limestone in the south-central section of the Main Manufacturing Area at RAAP by identifying hydrologic connections between areas of groundwater recharge (upland sinkholes near SWMUs 17 and 40) and their respective discharge areas in and around the facility.

This objective was met by the injection of two groundwater dye tracers, specifically Fluorescein and Direct Yellow 96, into two sinkholes at SWMU 17. On September 23, 1993 Fluorescein was introduced into the sinkhole in which SWMU 17A (Stage and Burn Area) is situated and Direct Yellow was introduced into the Runoff Drainage Basin (SWMU 17E) located in the sinkhole adjacent to the Fluorescein injection site. The following section describes the results of the dye-trace test.

4.1 FLUORESCEIN TRACE RESULTS

Three monitoring locations sampled during this investigation (SPG 3, RMP 4, and RMP 5) showed a positive trace for Fluorescein. The dye was injected into INJ 1 at approximately 1400 hours on September 23, 1993. Analyses of the charcoal samples for all monitoring points collected on September 24 were negative. By 0900 hours on September 25, Fluorescein dye was visibly noticeable in the groundwater discharging from SPG 3. By 0900 hours on September 26, a 10-foot wide band of green colored water extended along the shoreline from the discharge point at SPG 3 to the RAAP water intake, located approximately 0.4 miles downstream (Figure 3.4). This area encompasses the locations for sampling points RMP 4 and RMP 5, thus explaining the positive trace results observed at these points. This pattern was observed until September 30, 1993.

Visible detection of dye in the water discharging from SPG 3 decreased until September 30,1993 when dye was no longer visible. One additional sighting of Fluorescein dye issuing from SPG 3 was reported by Hercules personnel to have occurred after a significant precipitation event during the week of October 4, 1993 (Pers. Comm., 1993a).

The most likely explanation of continued detection of dye at SPG 3 is due to recharge events flushing out residual dye trapped in isolated pools in the karst matrix. Laboratory analysis of the SPG 3 charcoal samples, however, showed continued high concentrations of Fluorescein dye throughout the duration of the test.

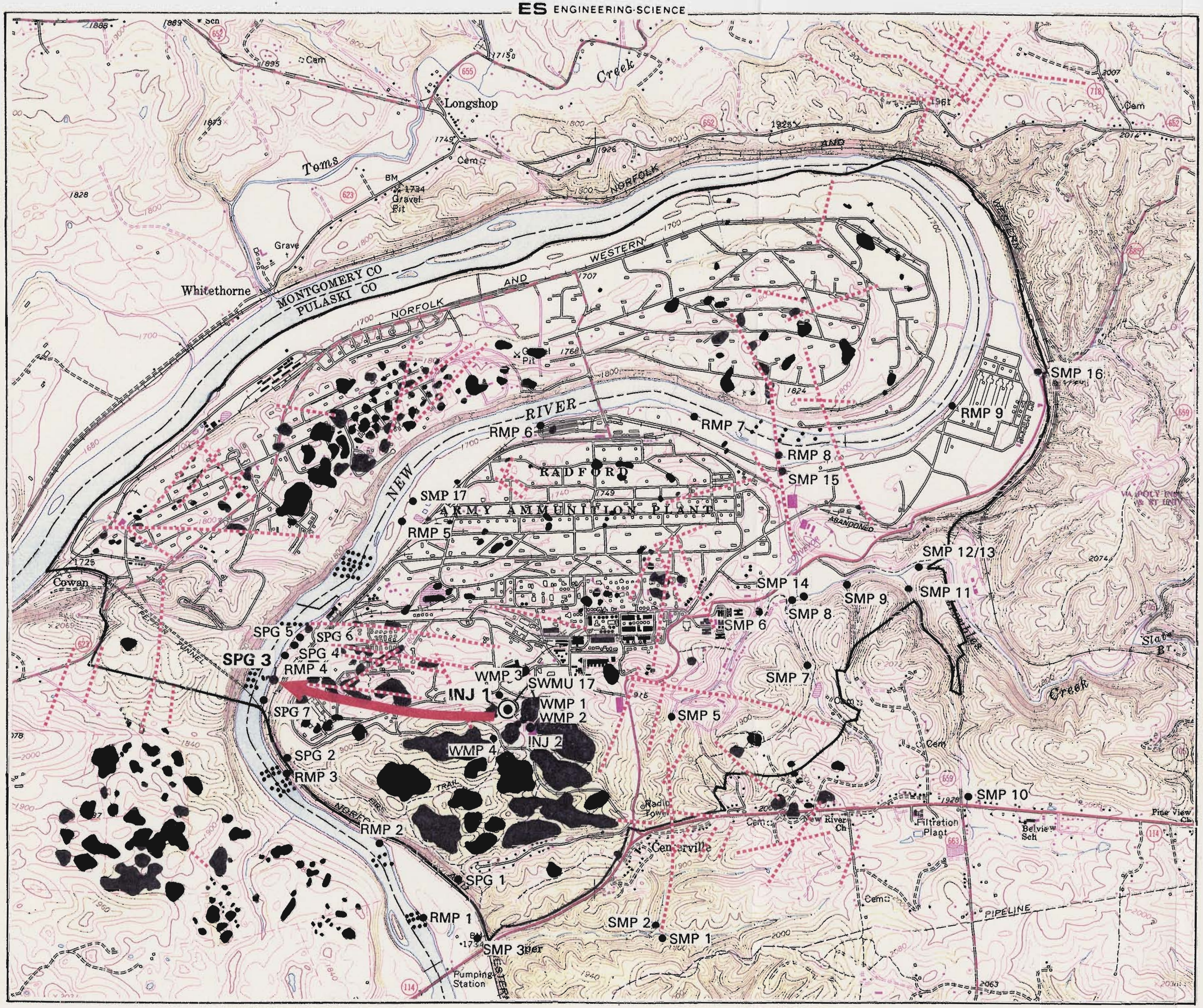
Based on the field observations and laboratory analyses for monitoring point SPG 3, groundwater travel times were calculated for the flow path originating from SWMU 17A and discharging to SPG 3. The distance between INJ 1 and SPG 3 is approximately 4,800 feet (0.9 miles). The fist appearance of dye is estimated to have occurred around 2100 hours on September 24, 1993 (31 hours after injection) and the peak concentration is estimated to have reached SPG 3 around 2100 hours on September 25, 1993 (55 hours after injection) as shown in Figure 4.2. Using these times and the approximate travel distance, groundwater travel times for water originating at SWMU 17A and discharging to SPG 3 is calculated to range between 2,095 feet/day and 3,716 feet/day.

Figure 4.1 shows the results of the Fluorescein dye-trace test. The red arrow in the figure denotes approximate flow route from recharge area in SWMU 17A and the discharge point at SPG 3. Also shown in Figure 4.1 are the fracture traces (shown as red hatched lines) and sinkholes (in black) described in the EPIC (USEPA, 1992) report. This figure clearly shows an alignment of the SWMU 17 sinkholes, SPG 3, and a west-northwest to east-southeast trending fracture trace connecting the two points. Solutionization along this fracture has most likely created a direct conduit for groundwater flow and contaminant transport from SWMU 17A and explains the extremely rapid travel times calculated for this test.

4.2 DIRECT YELLOW TRACE RESULTS

No Direct Yellow dye has been observed to date during this test. This can be explained in three ways. First, the dye may have infiltrated into the bedrock and is traveling at a slow enough rate that it has yet to reach any of the dye monitoring points. The second explanation is that the dye has infiltrated into the bedrock and has discharged at one or more locations that were not monitored during this investigation. Lastly, the dye may not have infiltrated into the bedrock aquifer and is still located in the SWMU 17E sinkhole and fill material.

FIGURE 4.1
DYE TRACE TEST RESULTS



LEGEND

- PROPERTY LINE
- FRACTURE TRACE
- BEDDING PLANE LEDGE
- SINKHOLE
- FLOW ROUTE AS DETERMINED BY D TRACE AND SUGGESTED BY FRACTU TRACES AND REGIONAL POTENTIOMETF CONTOURS
- DYE MONITORING POINT
- SPRING LOCATION
- DYE INJECTION LOCATION

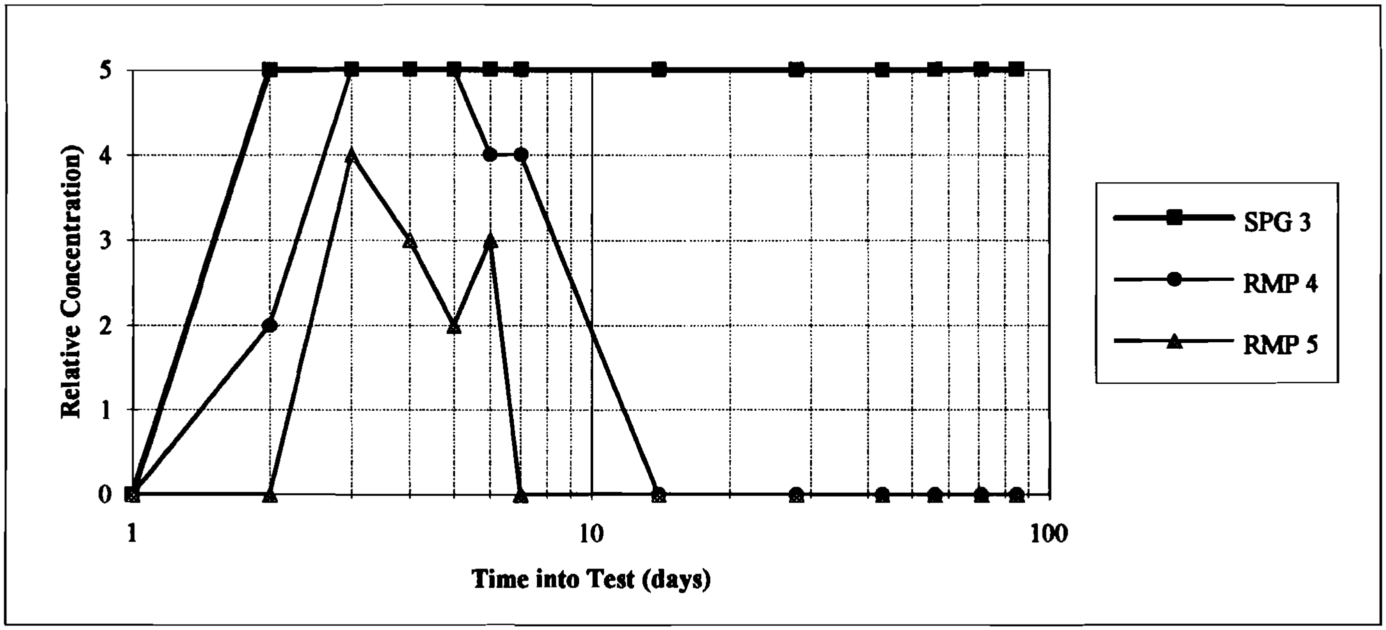
NOTE:
SMP STREAM MONITORING POI
SPG SPRING MONITORING POIN
WMP WELL MONITORING POINT
RMP RIVER MONITORING POINT

SOURCE: USEPA, 1992
USGS, RADFORD (NORTH)
VIRGINIA QUADRANGLE

SCALE 1:24,000

jdt\rasp\brkthrgh.xls

Figure 4.2
Fluorescein Dye Breakthrough Curve
Radford Army Ammunition Plant, Radford Virginia



Degree of positiveness judged upon the following scheme (Aley and Fletcher, 1976):

0	Negative Result
1	Very Weakly Positive
2	Weakly Positive
3	Moderately Positive
4	Strongly Positive
5	Very Strongly Positive

The most probable explanation for the lack of Direct Yellow detection at the dye monitoring points is that the dye is still sitting in the sinkhole where it was injected. This explanation is likely do to the clay fill material in observed during installation of INJ 2 in SWMU 17A and the slow infiltration rate observed during dye injection activities.

4.3 BACKGROUND DYE OBSERVATIONS

A common class of fluorometric dye, known as optical brighteners, was detected at several dye monitoring locations during this investigation. Cotton bugs, after having come into contact with optical brighteners, will fluoresce a blue color under examination with a long-wave ultraviolet lamp. Optical brighteners are commonly used as whitening agents in laundry detergents and are thus extremely common in sanitary sewer water and in septic tank water.

New River monitoring points RPM 8 and RMP 9 showed high concentrations of optical brighteners in the water. These two monitoring locations are immediately downstream of RAAP outfall number 026 and Hercules personnel indicate that this outfall receives discharges from various processes including the RAAP laundry facility (Pers. Comm., 1993b). The observed concentrations of optical brighteners at the RMP 8 and RMP 9 can therefore be explained by the effluent from RAAP outfall number 026. Optical brighteners were occasionally detected at low concentrations in several other monitoring points including SMP 1, RMP 1 through RMP 7, SMP 12/13, SMP 14, SMP 7, SMP 9, and SMP 10. These observations are most likely the result of sanitary sewer effluent from the cities of Radford and Blacksburg, other RAAP outfalls, or area home septic discharges.

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The dye-trace test conducted between September 23, 1993 and December 23, 1993 was designed to determine groundwater flow directions through the karst limestone in the south-central section of the Main Manufacturing Area at RAAP by identifying hydrologic connections between areas of groundwater recharge (upland sinkholes near SWMUs 17 and 40) and their respective discharge areas in and around the facility. Based on the results of this investigation, one spring, SPG 3, was identified as being hydraulically connected to the sinkhole which SWMU 17A occupies. Furthermore, the flow path identified by the dye trace closely parallels a west-northwest to east-southeast trending fracture trace which can be extended to connect both the dye injection point and the dye resurgence point. This leads to the conclusion that a direct conduit exists between SWMU 17A and SPG 3 which is most likely created by solution opening along a subsurface fracture. The travel time for groundwater flow through this conduit, under similar flow conditions, is calculated to range between 2,095 feet/day and 3,716 feet/day.

5.2 RECOMMENDATIONS

The dye-trace study conducted in the south-central section of the Main Manufacturing Area at RAAP was successful in identifying one dye monitoring location (SPG 3) to be hydraulically connected to SWMU 17A. As a result of the positive trace at this spring, groundwater, surface water, and sediments at this location should be sampled during future RFI sampling activities being conducted at SWMU 17.

This dye-trace test was conducted during moderately low-flow groundwater conditions (September 23 through December 23). The results of this study only identify flow directions and discharge points that may be expected under similar flow conditions. The results may not accurately describe flow patterns that could be expected during periods of high-flow conditions. During high flow conditions, higher elevation conduits or fractures may receive flow that are not normally saturated during low flow conditions. As a result, groundwater flow directions may change significantly as different conduits are used or flow may short-circuit the normal discharge areas and discharge elsewhere. Some springs or discharge areas that were selected during the field reconnaissance, which was conducted during higher flow conditions, were not flowing during the majority of this test. For these reasons, additional dye-trace testing is recommended for the south-central section of the Main Manufacturing Area at RAAP. At a minimum, one additional dye trace-test should be conducted during high groundwater flow conditions (late spring to early summer). Any additional locations proven to be hydraulically connected to SWMU 17 during the second test should also be included on locations to be sampled during future RFI activities at SWMU 17. Based on the results of the high flow trace test, a third dye-tracing test may be considered to identify groundwater flow paths during average flow conditions.

If additional tracing is conducted at the site, measures should be taken to enhance dye infiltration in SWMU 17E. This may include relocation of injection well INJ 2 and/or improving construction methods for the well. Furthermore, Optical Brighteners should not be considered for use in future dye-tracing efforts at this site due to the high background levels observed at many of the monitoring locations at this site.

Extreme caution should be exercised during future dye-trace test at RAAP if Fluorescein and Direct Yellow are used as tracers. Residual Fluorescein from this trace may still be present in isolated pools and discharge into the karst matrix during high flow conditions. Similarly, Direct Yellow dye from this test has not yet been detected and is still present in the aquifer. Careful background testing for Fluorescein and Direct Yellow should be conducted prior to use of these dyes as tracers at this site to ensure that no false positives are detected in future tests.

SECTION 6

REFERENCES

Aley, T., and Fletcher, M.W., 1976, The Water Tracers Cookbook: Missouri Speleology, V. 16, No. 3, p. 1-32.

Anderson and Associates, 1992. Topographic Study of SWMU 17.

Chas. T. Main of Virginia, Inc. (CTM), 1988. Preliminary Hvdrogeologic Investigation for Ash Landfill Permit Application. Prepared for the Corps of Engineers, Revised 1989.

Dames & Moore, 1992. RFI and VI Reports for the Radford Army Ammunition Plant. Prepared for the U.S. Army Toxic and Hazardous Materials Agency.

Engineering-Science, Inc., 1993. Dye-Tracing Study Work Plan, Radford Army Ammunition Plant. Prepared for the U.S. Army Environmental Center.

Hercules, 1993. VPDES Permit: Outfall Locations Map, December.

Jones, W.K., 1984, Analysis and Interpretation of Data From Tracer Tests in Karst Areas: National Speleological Society Bulletin, V. 46, no. 2, p. 42-47.

National Oceanic and Atmospheric Administration (NOAA), 1973. Climatology of the United States--Virginia, Vol. 38, nos. 1 and 86. U.S. Department of Commerce, NOAA Environmental Data Service, Asheville, North Carolina.

Quinlan, J.F., 1987, Qualitative Water-Tracing With Dyes in Karst Terranes: in, Quinlan, J.F., Ed., Practical Karst Hydrogeology, With Emphasis On Groundwater Monitoring (Course Manual), National Water Well Association, Dublin, Ohio, V.6, P. E1-E24.

Personal Communication, 1993a. Discussion between Jeffrey Titus (Engineering-Science, Inc.) and William Hendon (Hercules Inc.) on November 5, 1993 at the Radford Army Ammunition Plant.

Personal Communication, 1993b. Discussion between Jeffrey Titus (Engineering-Science, Inc.) and William Hendon (Hercules Inc.) on December 17, 1993 at the Radford Army Ammunition Plant.

Smart, P.L., and Laidlaw, I.M.S., 1977, An Evaluation of Some Fluorescent Dyes for Water Tracing: Water Resources Research, V. 13, No. 1, p. 15-33.

U.S. Army Environmental Hygiene Agency (USAEHA), 1980. Hazardous Waste Management Survey No. 39-26-0134-82. Radford Army Ammunition Plant, Radford, Virginia.

U.S. Army Toxic and Hazardous Materials Agency (USATHAMA), 1976. Installation Assessment of Radford Army Ammunition Plant, Records Evaluation Report No. 103.

U.S. Army Toxic and Hazardous Materials Agency (USATHAMA), 1984. Installation Reassessment of Radford Army Ammunition Plant, Radford, Virginia, Report No. 103R.

U.S. Environmental Protection Agency (USEPA), 1989. Permit for Corrective Action and Incinerator Operation.

U.S. Environmental Protection Agency (USEPA), 1992. Installation Assessment, Radford Army Ammunition Plant, Radford, Virginia. Environmental Photographic Interpretation Center.

U.S. Geologic Survey, 1984. Radford North Topographic Quadrangle, Virginia. 7.5 Minute Series.

APPENDIX A

WELL LOGS

ENGINEERING-SCIENCE, INC.
DRILLING RECORD

BORING/WELL ID: 17MW2

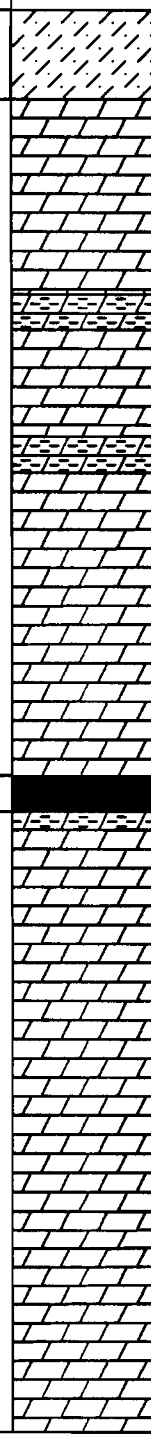
DRILL. CONTR.: EDI	INSTALLATION: RAAP	TOTAL DEPTH (feet): 173
DRILLER: T. Lynch	SITE: SWMU 17	BOREHOLE DIAM.: 8 in.
GEOLOGIST: J. Titus	CLIENT: USAEC	CASING DIAM.: 4 in.
RIG TYPE: Mobile B-80	PROJECT NO.: FB517	TOC ELEV.: 1906.29 ft. msl
DRILLING METHOD: Air Hammer	DATE/TIME START: 19-May-93; 0745	GS ELEV.: 1903.99 ft. msl
	DATE/TIME END: 20-May-93; 1505	

WATER LEVEL MEASUREMENT

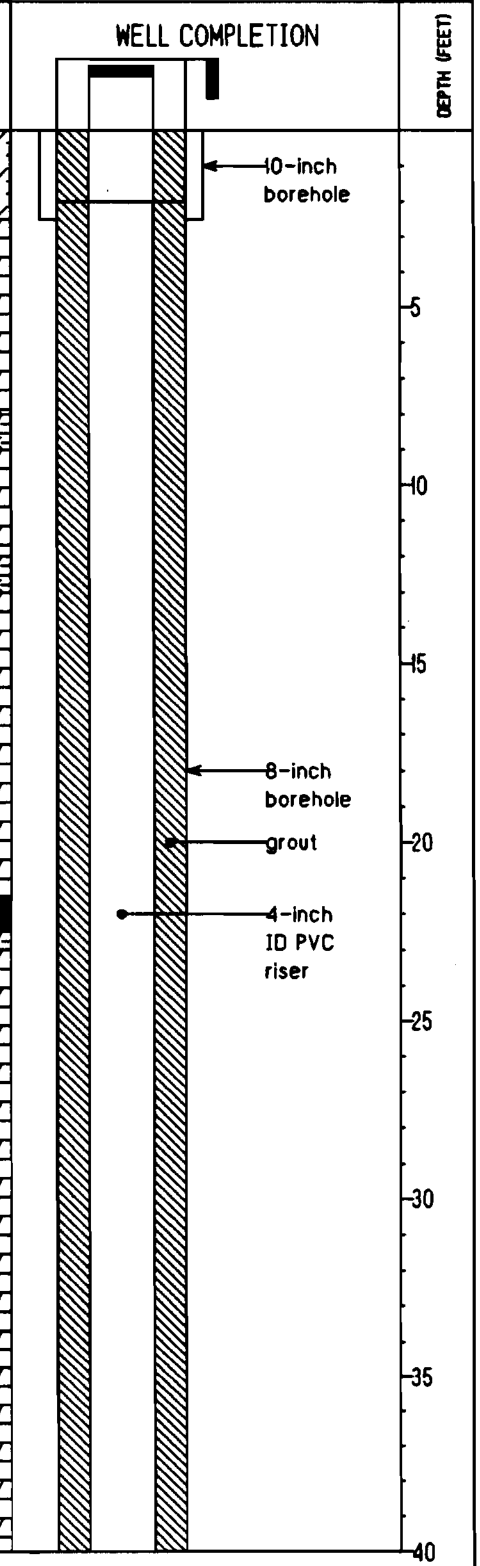
MEASUREMENT POINT: TOC
DATE/TIME: 10-Jun-93; 0956
DEPTH TO WATER: 79.83 ft.

DEPTH (FEET)	DRILL RATE	HCl TEST	LITHOLOGY/REMARKS
0			DRILLING WITH 10-INCH AIR ROTARY BIT SILT and CLAY; color: dark yellowish brown (10YR4/4)
2.5			BEDROCK SWITCH TO 8-INCH AIR HAMMER
5			
	1ft/4min	+pwd	interbedded DOLOTONE and argillaceous DOLOSTONE
10	1ft/4min		DOLOSTONE: massive, hard color: gray (10YR5/1 to 2.5YR6/0)
15			argillaceous DOLOSTONE: weathered, soft weathered color: light, yellowish brown (2.5Y7/6) unweathered color: gray (2.5Y6/0)
	1ft/5min		
20			
			VOID, filled with fine SAND and SILT color: reddish brown
25	1ft/4.5min		
30	1ft/7min		
35			
40			

LITHOLOGIC COLUMN



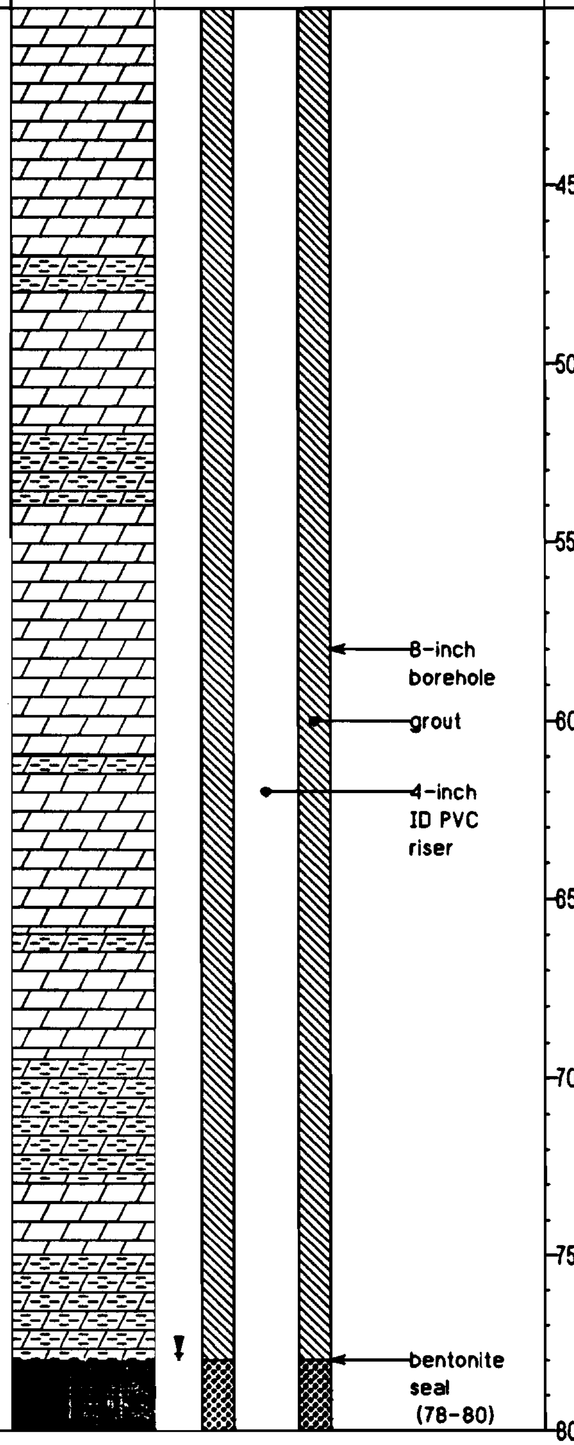
WELL COMPLETION



DRILL. CONTR.: EDI DRILLER: T. Lynch GEOLOGIST: J. Titus RIG TYPE: Mobile B-80 DRILLING METHOD: Air Hammer	ENGINEERING-SCIENCE, INC. DRILLING RECORD	BORING/WELL ID: 17MW2
WATER LEVEL MEASUREMENT MEASUREMENT POINT: TOC DATE/TIME: 10-Jun-93; 0956 DEPTH TO WATER: 79.83 ft.	INSTALLATION: RAAP SITE: SWMU 17 CLIENT: USAEC PROJECT NO.: FB517 DATE/TIME START: 19-May-93; 0745 DATE/TIME END: 20-May-93; 1505	TOTAL DEPTH (feet): 173 BOREHOLE DIAM.: 8 in. CASING DIAM.: 4 in. TOC ELEV.: 1906.29 ft. msl GS ELEV.: 1903.99 ft. msl

DEPTH (FEET)	DRILL RATE	HCl TEST	LITHOLOGY/REMARKS
45			
50			
55			interbedded DOLOSTONE and argillaceous DOLOSTONE
			DOLOSTONE massive, hard color: gray (10YR5/1 to 2.5YR6/0)
60			
			argillaceous DOLOSTONE weathered, soft weathered color: light, yellowish brown (2.5Y7/6) unweathered color: gray (2.5Y6/0)
65		+pwd	
70			
75			
			VOID, some clayey SILT color: reddish brown (7.5YR6/8)
80			

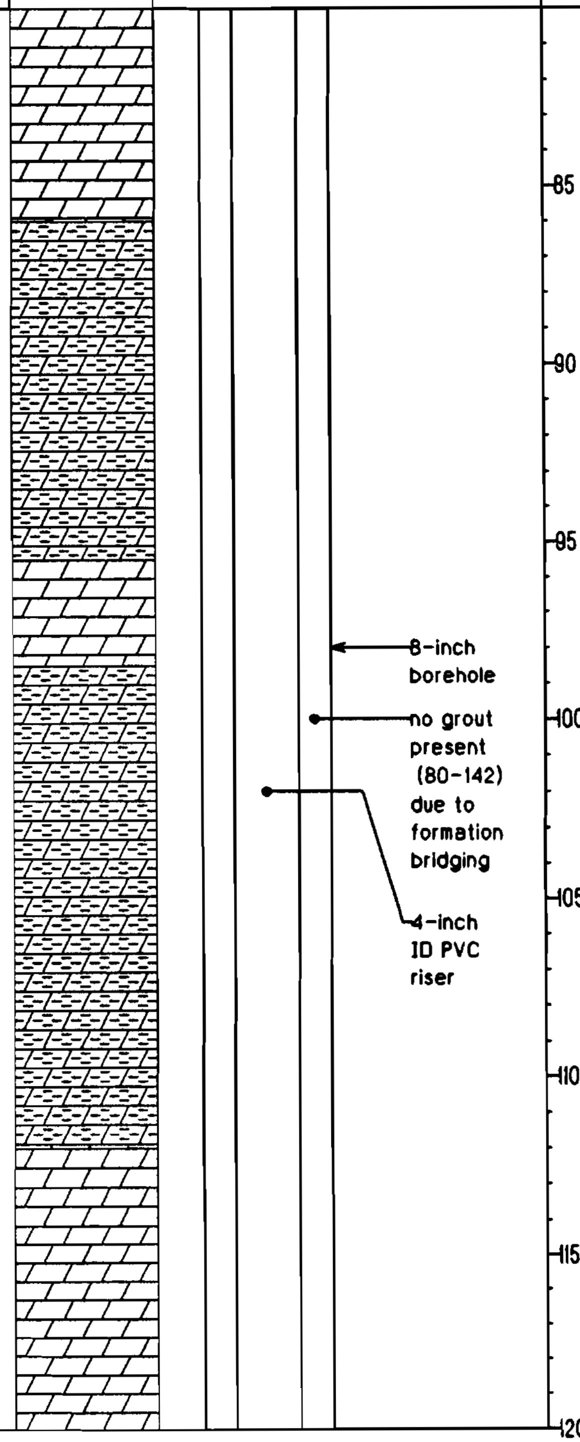
LITHOLOGIC COLUMN / WELL COMPLETION



DRILL. CONTR.: EDI	**ENGINEERING-SCIENCE, INC. DRILLING RECORD**		BORING/WELL ID: 17MW2
DRILLER: T. Lynch			
GEOLOGIST: J. Titus	INSTALLATION: RAAP		TOTAL DEPTH (feet): 173
RIG TYPE: Mobile B-80	SITE: SWMU 17		BOREHOLE DIAM.: 8 in.
DRILLING METHOD: Air Hammer	CLIENT: USAEC		CASING DIAM.: 4 in.
WATER LEVEL MEASUREMENT	PROJECT NO.: FB517		
MEASUREMENT POINT: TOC			
DATE/TIME: 10-Jun-93; 0956	DATE/TIME START: 19-May-93; 0745		TOC ELEV.: 1906.29 ft. msl
DEPTH TO WATER: 79.83 ft.	DATE/TIME END: 20-May-93; 1505		GS ELEV.: 1903.99 ft. msl

DEPTH (FEET)	DRILL RATE	HCl TEST	LITHOLOGY/REMARKS
	1ft/6min	+pwd	
85			
90			
95			interbedded DOLOSTONE and argillaceous DOLOSTONE
			DOLOTONE massive, hard color: gray (10YR5/1 to 2.5YR6/0)
100			argillaceous DOLOSTONE weathered, soft weathered color: light, yellowish brown (2.5Y7/6) unweathered color: gray (2.5Y6/0)
	1ft/1min		
105			
110			
115			
120			

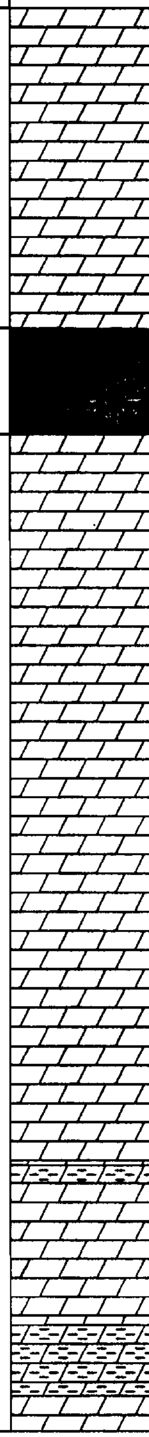
LITHOLOGIC COLUMN / WELL COMPLETION



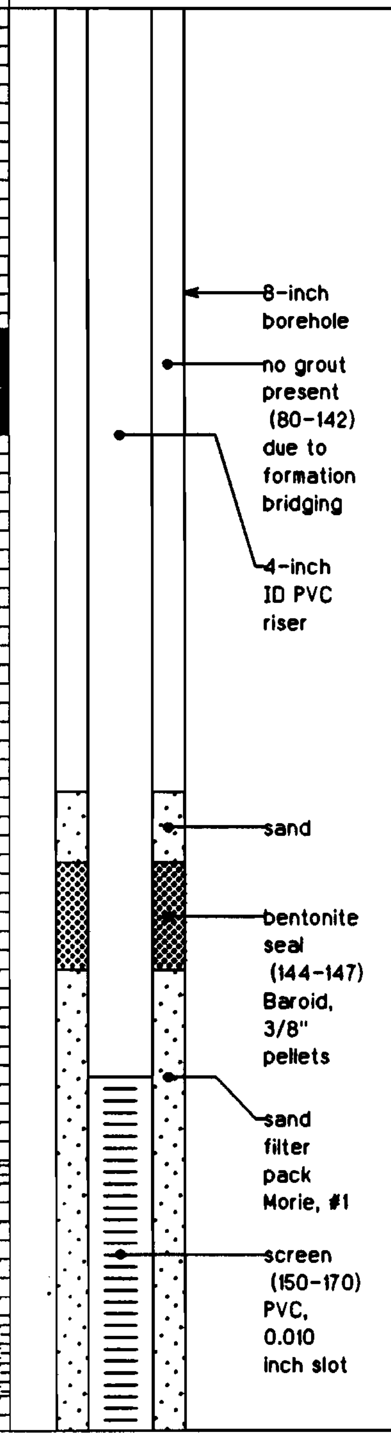
DRILL. CONTR.: EDI	**ENGINEERING-SCIENCE, INC.**	**BORING/WELL ID: 17MW2**
DRILLER: T. Lynch	**DRILLING RECORD**	
GEOLOGIST: J. Titus	INSTALLATION: RAAP	TOTAL DEPTH (feet): 173
RIG TYPE: Mobile B-80	SITE: SWMU 17	BOREHOLE DIAM.: 8 in.
DRILLING METHOD: Air Hammer	CLIENT: USAEC	CASING DIAM.: 4 in.
WATER LEVEL MEASUREMENT	PROJECT NO.: FB517	TOC ELEV.: 1906.29 ft. msl
MEASUREMENT POINT: TOC	DATE/TIME START: 19-May-93; 0745	
DATE/TIME: 10-Jun-93; 0956	DATE/TIME END: 20-May-93; 1505	GS ELEV.: 1903.99 ft. msl
DEPTH TO WATER: 79.83 ft.		

DEPTH (FEET)	DRILL RATE	HCl TEST	LITHOLOGY/REMARKS
125			
130			VOID, some CLAY and v. fine SAND MAJOR WATER PRODUCING ZONE
135	1ft/5.5min	+pwd	interbedded DOLOSTONE and argillaceous DOLOSTONE DOLOSTONE massive, hard color: gray (10YR5/1 to 2.5Y6/0)
140			argillaceous DOLOSTONE weatherd, soft weathered color: light, yellowish brown (2.5Y7/6) unweathered color: gray (2.5Y6/0)
145			
150			
155			
	1ft/1.3min		
160			

LITHOLOGIC COLUMN



WELL COMPLETION



DRILL. CONTR.: EDI	
DRILLER: T. Lynch	
GEOLOGIST: J. Titus	
RIG TYPE: Mobile B-80	
DRILLING METHOD: Air Hammer	

ENGINEERING-SCIENCE, INC.
DRILLING RECORD

BORING/WELL ID: 17MW2

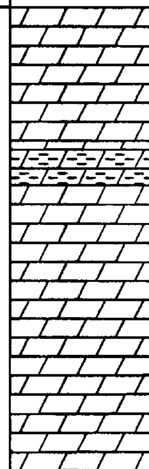
INSTALLATION: RAAP
SITE: SWMU 17
CLIENT: USAEC
PROJECT NO.: FB517
DATE/TIME START: 19-May-93; 0745
DATE/TIME END: 20-May-93; 1505

TOTAL DEPTH (feet): 173
BOREHOLE DIAM.: 8 in.
CASING DIAM.: 4 in.
TOC ELEV.: 1906.29 ft. msl
GS ELEV.: 1903.99 ft. msl

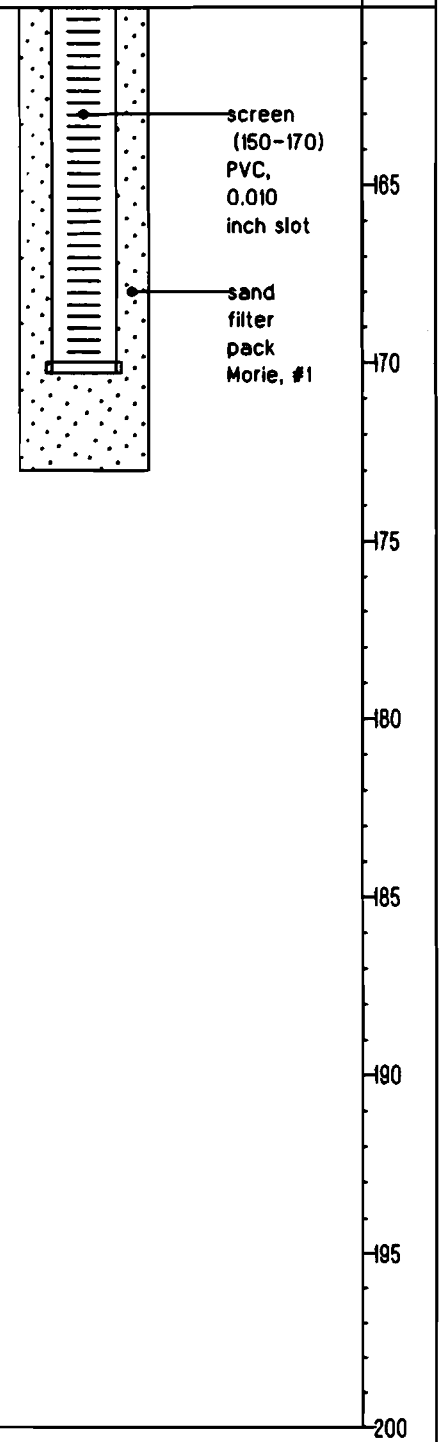
WATER LEVEL MEASUREMENT
MEASUREMENT POINT: TOC
DATE/TIME: 10-Jun-93; 0956
DEPTH TO WATER: 79.83 ft.

DEPTH (FEET)	DRILL RATE	HCl TEST	LITHOLOGY/REMARKS
	1ft/4min		interbedded DOLOSTONE and argillaceous DOLOSTONE
165			DOLOSTONE massive, hard color: gray (10YR5/1 to 2.5YR6/0)
			argillaceous DOLOSTONE weathered, soft weathered color: light, yellowish brown (2.5Y7/6) unweathered color: gray (2.5Y6/0)
170			
		+pwd	
175			
180			
185			
190			
195			
200			

LITHOLOGIC COLUMN



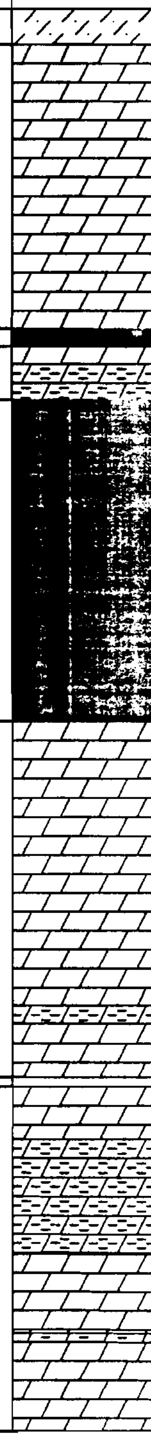
WELL COMPLETION



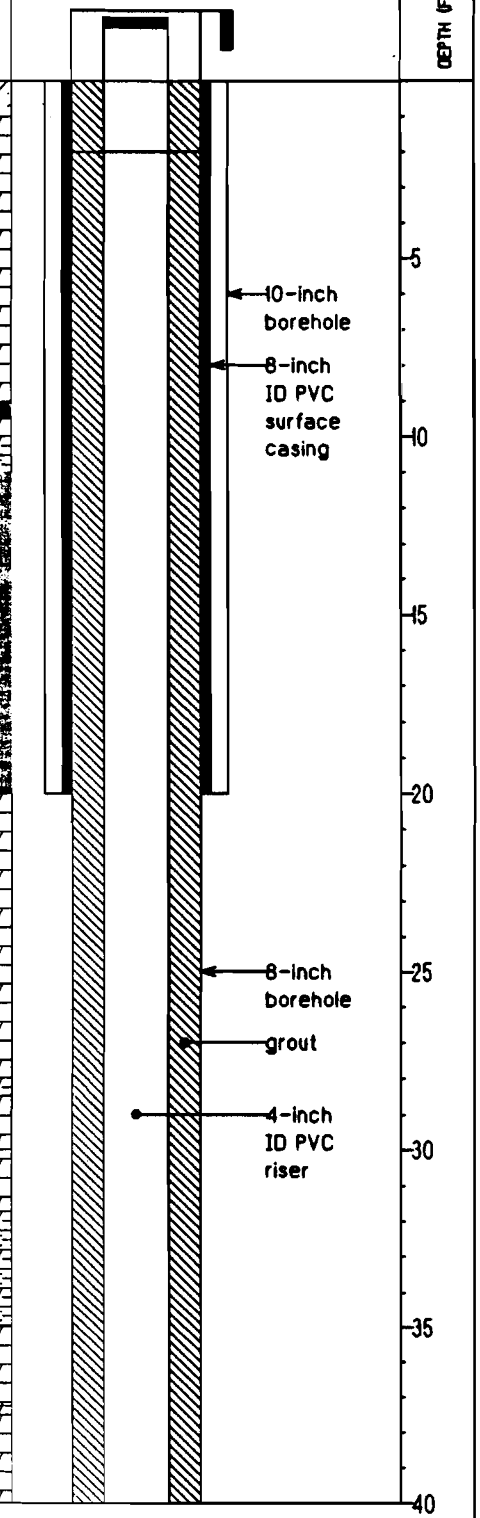
DRILL. CONTR.: EDI DRILLER: T. Lynch GEOLOGIST: J. Titus RIG TYPE: Mobile B-80 DRILLING METHOD: Air Hammer	**ENGINEERING-SCIENCE, INC.** **DRILLING RECORD**	BORING/WELL ID: **17MW3**
WATER LEVEL MEASUREMENT MEASUREMENT POINT: TOC DATE/TIME: 10-Jun-93; 0956 DEPTH TO WATER: 147.33 ft.	INSTALLATION: RAAP SITE: SWMU 17 CLIENT: USAEC PROJECT NO.: FB517 DATE/TIME START: 21-May-93; 1630 DATE/TIME END: 24-May-93; 0925	TOTAL DEPTH (feet): 190 BOREHOLE DIAM.: 8 in. CASING DIAM.: 4 in. TOC ELEV.: 1906.78 ft. msl GS ELEV.: 1904.27 ft. msl

DEPTH (FEET)	DRILL RATE	HCl TEST	LITHOLOGY/REMARKS
0–2			DRILLING WITH 10-INCH AIR ROTARY BIT SILT and CLAY; color: dark yellowish brown (10YR4/4)
2–9		+pwd (5)	BEDROCK SWITCH TO 8-INCH AIR HAMMER interbedded DOLOSTONE and argillaceous DOLOSTONE DOLOSTONE: massive, hard; color: gray (10YR5/1 to 2.5YR6/0)
9–15			argillaceous DOLOSTONE: weathered, soft; weathered color: light, yellowish brown (2.5Y7/6); unweathered color: gray (2.5Y6/0)
15–16			VOID, filled with silty CLAY
16–20			VOID, filled with silty CLAY; color: reddish brown (7.5YR6/8)
23	1ft/10min		
26	1ft/14min		
28	1ft/4min		
30–31	1ft/4.5min		calcite vein
34		+pwd	
37	1ft/3.8min		
39	1ft/6min		
40			

LITHOLOGIC COLUMN



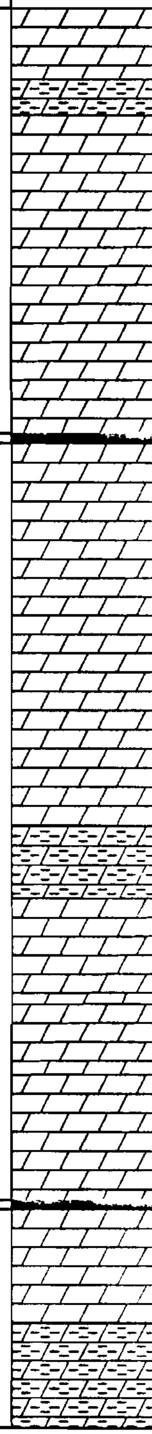
WELL COMPLETION



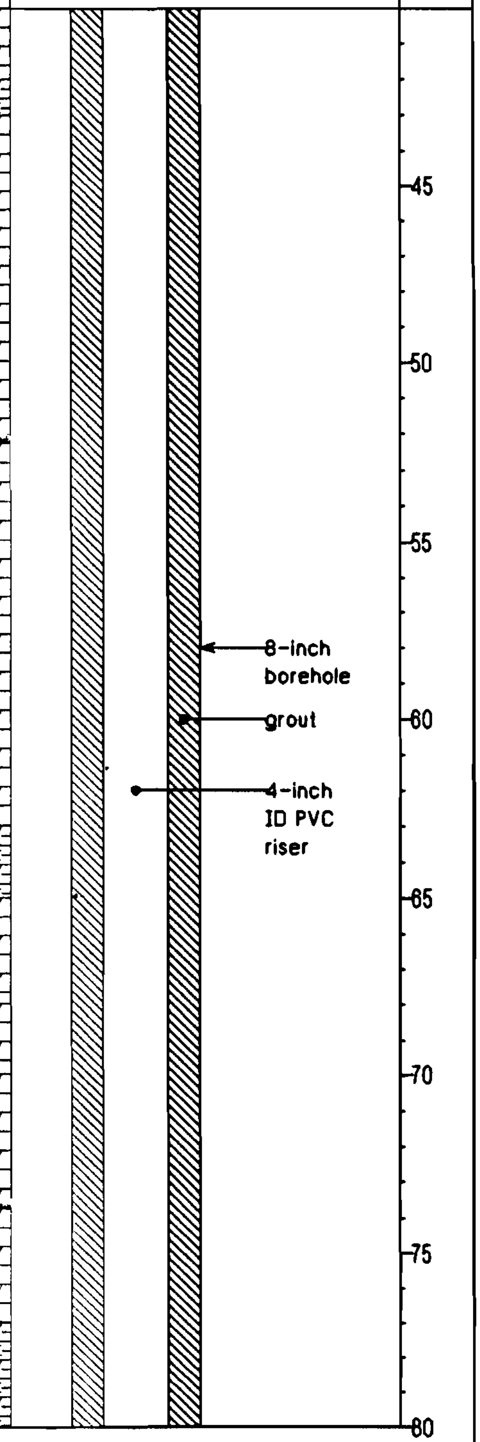
DRILL. ONTR.: ECI	**ENGINEERING-SCIENCE, INC.**	**BORING/WELL ID: 17MW3**
DRILLER: T. Lynch	**DRILLING RECORD**	
GEOL IST: J. Titus	INSTALLATION: RAAP	TOTAL DEPTH (feet): 190
RIG TYPE: Mobile B-80	SITE: SWMU 17	BOREHOLE DIAM.: 8 in.
DRILLING METHOD: Air Hammer	CLIENT: USAEC	CASING DIAM.: 4 in.
WATER LEVEL MEASUREMENT	PROJECT NO.: FB517	TOC ELEV.: 1906.78 ft. msl
MEASUREMENT POINT: TOC	DATE/TIME START: 21-May-93; 1630	GS ELEV.: 1904.27 ft. msl
DATE/TIME: 10-Jun-93; 0956	DATE/TIME END: 24-May-93; 0925	
DEPTH TO WATER: 147.33 ft.		

DEPTH (FEET)	DRILL RATE	HCl TEST	LITHOLOGY/REMARKS
45			
50	1ft/4min		
			VOID, filled with orange brown silty CLAY moist
55	1ft/6min	+pwd	interbedded DOLOSTONE and argillaceous DOLOSTONE
			DOLOSTONE massive, hard color: gray (10YR5/1 to 2.5YR6/0)
60			argillaceous DOLOSTONE weathered, soft weathered color: light, yellowish brown (2.5Y7/6) unweathered color: gray (2.5Y6/0)
65			
70	1ft/5.8	+pwd	
			VOID, filled with silty CLAY
75	1ft/5min		
80	1ft/3.5min		

LITHOLOGIC COLUMN



WELL COMPLETION



DRILL. CNTR.: E?I
DRILLER: T. Lynch
GEOLOGIST: J. Titus
RIG TYPE: Mobile B-80
DRILLING METHOD: Air Hammer

WATER LEVEL MEASUREMENT
MEASUREMENT POINT: TOC
DATE/TIME: 10-Jun-93; 0956
DEPTH TO WATER: 147.33 ft.

ENGINEERING-SCIENCE, INC.
DRILLING RECORD

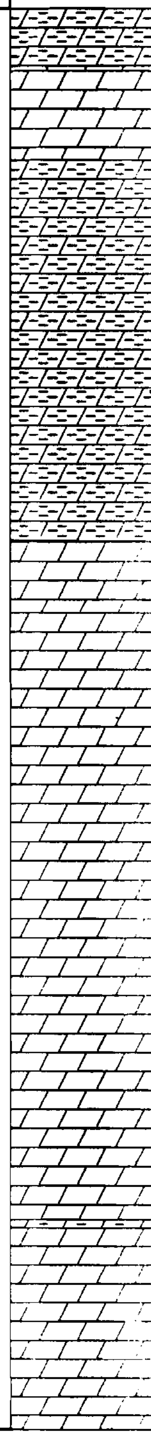
INSTALLATION: RAAP
SITE: SWMU 17
CLIENT: USAEC
PROJECT NO.: FB517
DATE/TIME START: 21-May-93; 1630
DATE/TIME END: 24-May-93; 0925

BORING/WELL ID: 17MW3

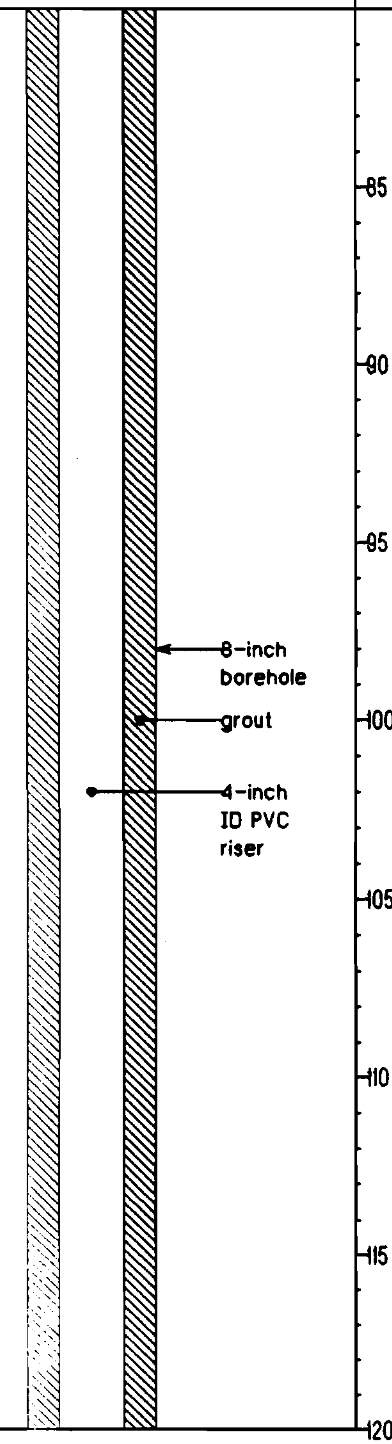
TOTAL DEPTH (feet): 190
BOREHOLE DIAM.: 8 in.
CASING DIAM.: 4 in.
TOC ELEV.: 1906.78 ft. msl
GS ELEV.: 1904.27 ft. msl

DEPTH (FEET)	DRILL RATE	HCl TEST	LITHOLOGY/REMARKS
	1ft/4min		
	1ft/2min		
85	1ft/1min		
90			
	1ft/2.5min		
95			interbedded DOLOSTONE and argillaceous DOLOSTONE
			DOLOSTONE massive, hard color: gray (10YR5/1 to 2.5YR6/0)
100			
			argillaceous DOLOSTONE weathered, soft weathered color: light, yellowish brown (2.5Y7/6) unweathered color: gray (2.5Y6/0)
	1ft/2min		
105	1ft/1min		
			interbedded DOLOSTONE and argillaceous DOLOSTONE
	1ft/1.8min		
			DOLOSTONE massive, hard color: gray (10YR5/1 to 2.5Y6/0)
110			
			argillaceous DOLOSTONE weathered, soft weathered color: light, yellowish brown (2.5Y7/6) unweathered color: gray (2.5Y6/0)
115			
120			

LITHOLOGIC COLUMN



WELL COMPLETION

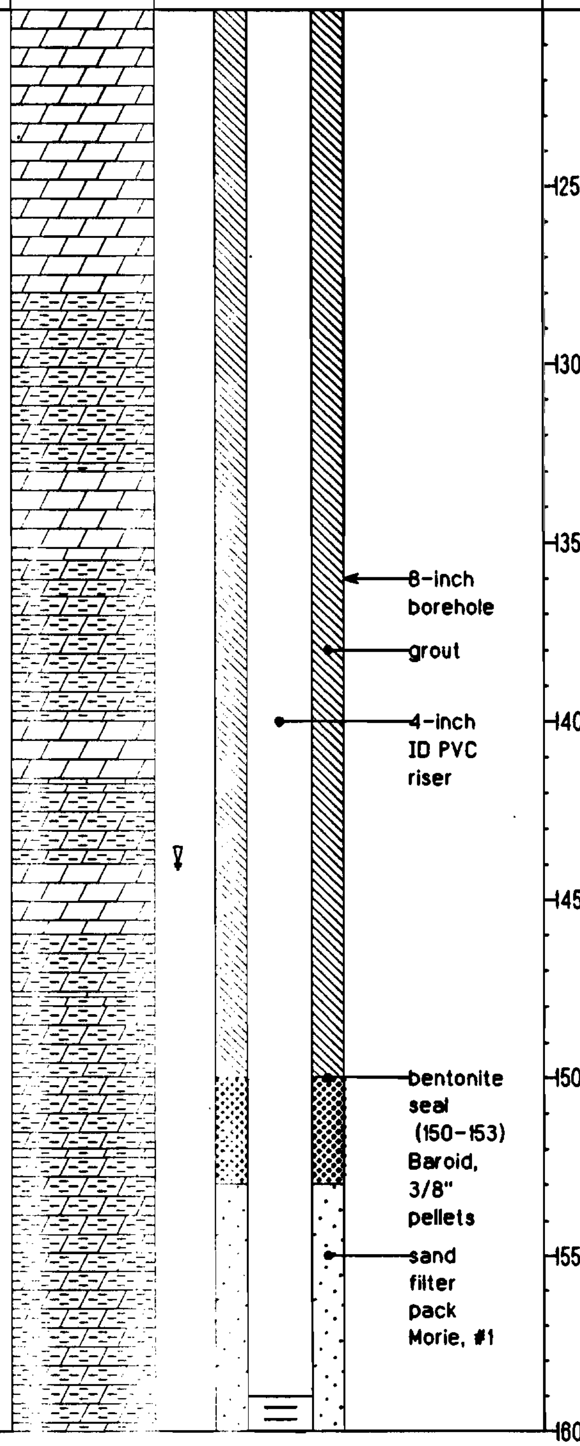


DEPTH (FEET)

DRILL. CNTR.: E.I	**ENGINEERING-SCIENCE, INC. DRILLING RECORD**	**BORING/WELL ID: 17MW3**
DRILLER: T. Lynch	INSTALLATION: RAAP	TOTAL DEPTH (feet): 190
GEOLOGIST: J. Tilts	SITE: SWMU 17	BOREHOLE DIAM.: 8 in.
RIG TYPE: Mobile B-80	CLIENT: USAEC	CASING DIAM.: 4 in.
DRILLING METHOD: Air Hammer	PROJECT NO.: FB517	TOC ELEV.: 1908.78 ft. msl
WATER LEVEL MEASUREMENT MEASUREMENT POINT: TOC	DATE/TIME START: 21-May-93; 1630	GS ELEV.: 1904.27 ft. msl
DATE/TIME: 10-Jun-93; 0956	DATE/TIME END: 24-May-93; 0925	
DEPTH TO WATER: 147.33 ft.		

DEPTH (FEET)	DRILL RATE	HCl TEST	LITHOLOGY/REMARKS
125			
130			
	1ft/5min		
135			
140	1ft/6.5min		
145	1ft/5min		
150			
	1ft/3.2min		
155			
160			

LITHOLOGIC COLUMN / WELL COMPLETION



DRIL[illegible] [illegible]NTR.: E[illegible]
DRIL[illegible]: T. Lyn[illegible]
GEO[illegible]ST: J. T[illegible]s
RIG T[illegible]: Mobil[illegible]-80
DRIL[illegible] METHOD: Air Hammer

WATER L[illegible]VEL MEASUREMENT
MEAS[illegible]ENT POI[illegible]: TOC
DATE/[illegible]: 10-J[illegible]-93; 0956
DEPT[illegible] WATER: [illegible]47.33 ft.

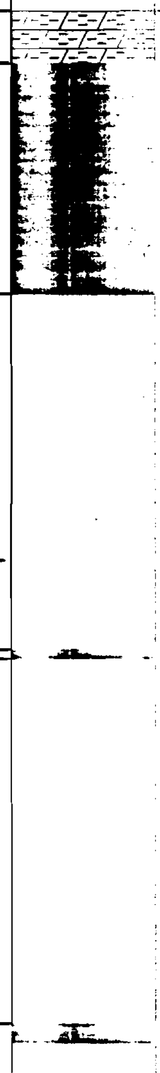
ENGINEERING-SCIENCE, I[illegible]C.
DRILLING RECORD

INSTALLATION: RAAP
SITE: SWMU 17
CLIENT: USAEC
PROJECT NO.: FB517
DATE/TIME START: 21-May-93; 1630
DATE/TIME END: 24-May-93; 0925

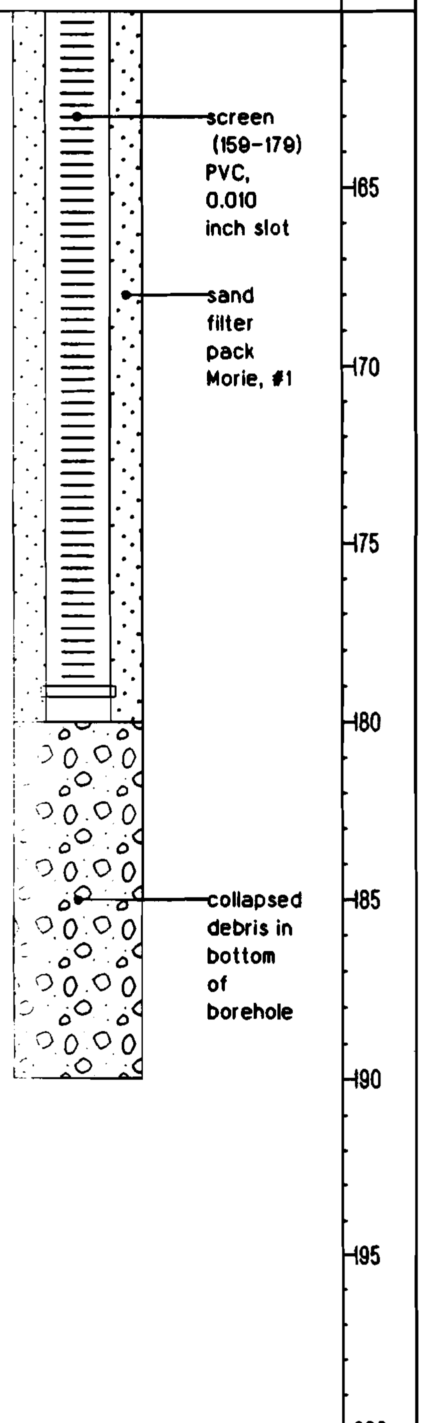
BORI[illegible]G/WELL ID: 17MW3
TOTAL DEPTH (feet): 190
BOREH[illegible]LE DIAM.: 8 in.
CASING DIAM.: 4 in.
TOC ELEV.: 1906.78 ft. msl
GS ELEV.: 1904.27 ft. msl

DEPTH (FEET)	DRILL RATE	HCl TEST	LITHOLOGY/REMARKS
	1ft/1min		extremely soft-highly weathered argillaceous DOLOSTONE cuttings are moist, becoming more wet at 167 feet
16[illegible]			
	[illegible]t/2.5m[illegible]		rock becoming harder at 168 feet no return of cuttings, loss of circulation due to void (161.5-168 feet)
17[illegible]			
	[illegible]t/1.3m[illegible]		
17[illegible]			rock becoming harder
			VOID
1[illegible]			little return on cuttings some cuttings coming out of bore hole damp to wet
	[illegible]t/2m[illegible]		
18[illegible]	[illegible]/40s[illegible]		
	1ft/1.5m[illegible]		
			VOID
19[illegible]			END OF BORING AT 190 FEET
19[illegible]			
20[illegible]			

LITHOLOGIC COLUMN



WELL COMPLETION



DRILL. CONTR.: EDI	
DRILLER: T. Lynch	
GEOLOGIST: J. Titus	
RIG TYPE: Mobile B-80	
DRILLING METHOD: Air Hammer	

ENGINEERING-SCIENCE, INC.
DRILLING RECORD

BORING/WELL ID: 40MW3

WATER LEVEL MEASUREMENT

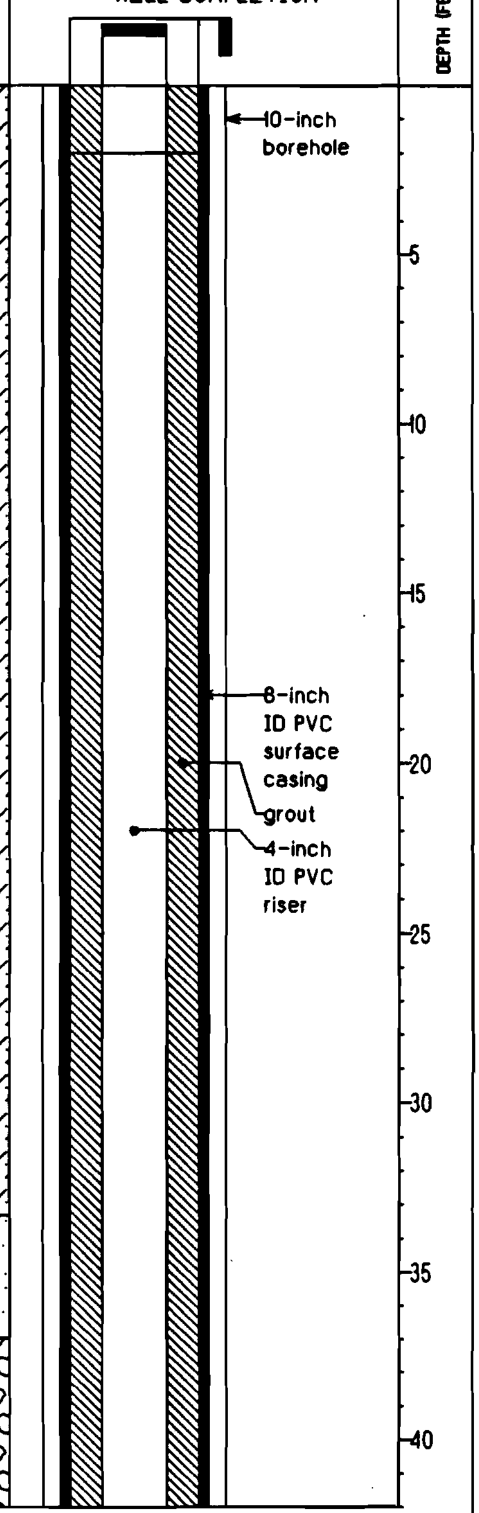
MEASUREMENT POINT: TOC
DATE/TIME: 06-Jun-93; 0930
DEPTH TO WATER: 91.95 ft.

INSTALLATION: RAAP
SITE: SWMU 17
CLIENT: USAEC
PROJECT NO.: FB517
DATE/TIME START: 21-May-93; 0900
DATE/TIME END: 25-May-93; 1317

TOTAL DEPTH (feet): 120
BOREHOLE DIAM.: 8 in.
CASING DIAM.: 4 in.
TOC ELEV.: 1858.21 ft. msl
GS ELEV.: 1856.02 ft. msl

DEPTH (FEET)	DRILL RATE	HCl TEST	LITHOLOGY/REMARKS	LITHOLOGIC COLUMN
			DRILLING WITH 10-INCH AIR ROTARY BIT CLAYEY SILT; color: yellowish red (5YR5/8) dry to moist	
5				
10				
15			becoming more micaceous with depth	
20			micaceous CLAYEY SILT; color: yellowish red (5YR5/8)	
25				
30				
35			micaceous fine SAND; color: yellowish red (5YR5/8)	
40			well to subrounded GRAVEL (0.5 to 1.5 in. diam.) and micaceous clayey fine SAND	

WELL COMPLETION



DRILL. CONTR.: EDI
DRILLER: T. Lynch
GEOLOGIST: J. Titus
RIG TYPE: Mobile B-80
DRILLING METHOD: Air Hammer

WATER LEVEL MEASUREMENT
MEASUREMENT POINT: TOC
DATE/TIME: 06-Jun-93; 0930
DEPTH TO WATER: 91.95 ft.

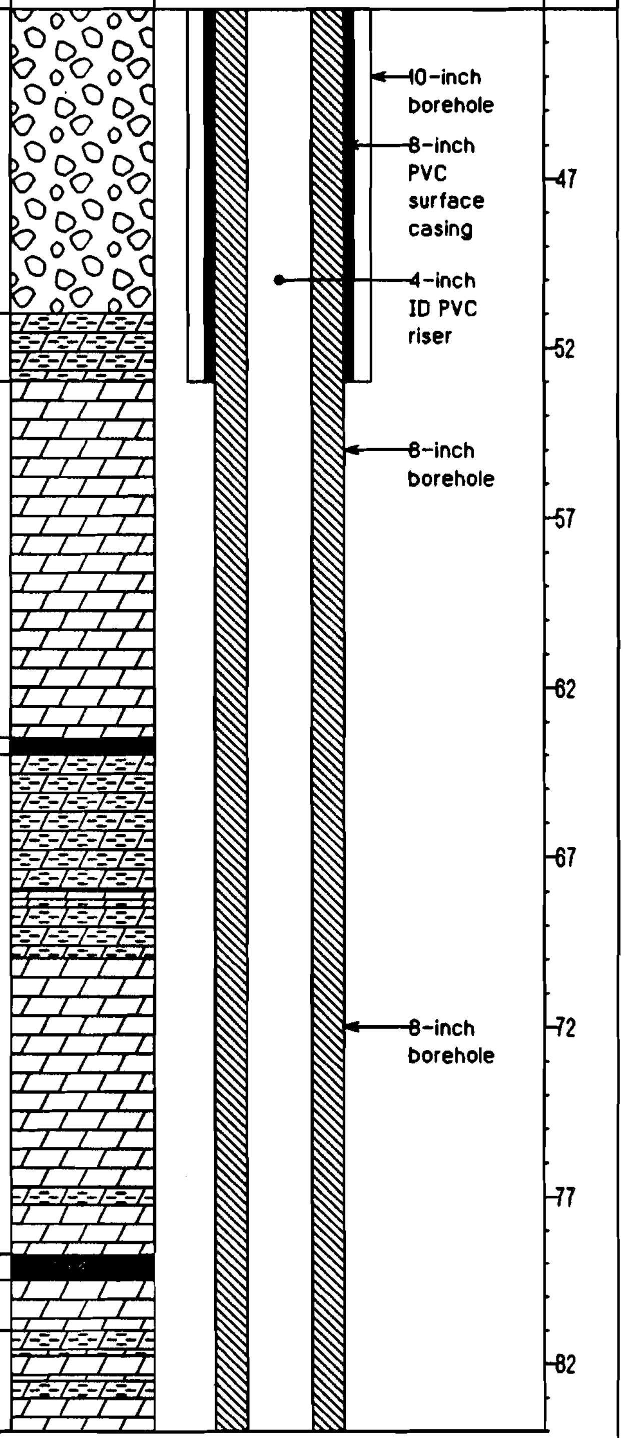
ENGINEERING-SCIENCE, INC.
DRILLING RECORD

INSTALLATION: RAAP
SITE: SWMU 17
CLIENT: USAEC
PROJECT NO.: FB517
DATE/TIME START: 21-May-93; 0900
DATE/TIME END: 25-May-93; 1317

BORING/WELL ID: 40MW3
TOTAL DEPTH (feet): 120
BOREHOLE DIAM.: 8 in.
CASING DIAM.: 4 in.
TOC ELEV.: 1858.21 ft. msl
GS ELEV.: 1856.02 ft. msl

DEPTH (FEET)	DRILL RATE	HCl TEST	LITHOLOGY/REMARKS
			well to subrounded GRAVEL (0.5 to 1.5 in. diam.) and micaceous clayey fine SAND
47			
52			weathered BEDROCK
			COMPETENT BEDROCK SWITCH TO 8-INCH AIR HAMMER argillaceous DOLOSTONE
57			color: light gray (2.5YR7/0) weathered color: reddish yellow (7.5YR6/6) color: gray (10YR5/1 to 2.5YR6/0)
	1ft/45sec	+pwd	
62	1ft/4min		becoming more massive with depth
			argillaceous DOLOSTONE: color: gray
			void filled with silty CLAY,dry color: olive yellow (2.5Y6/6)
67			
72	1ft/3.8min		
77			
			VOID, filled with silty CLAY, moist
82			highly weathered zone, argillaceous DOLOSTONE, moist clay surrounding cuttings

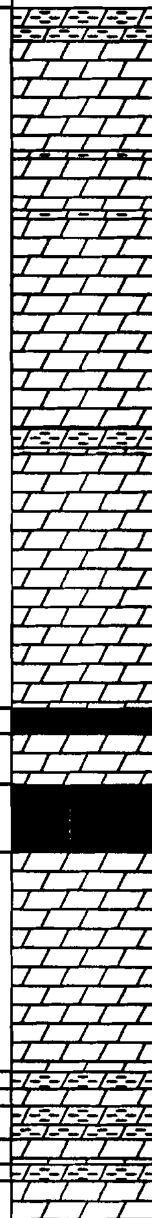
LITHOLOGIC COLUMN / WELL COMPLETION



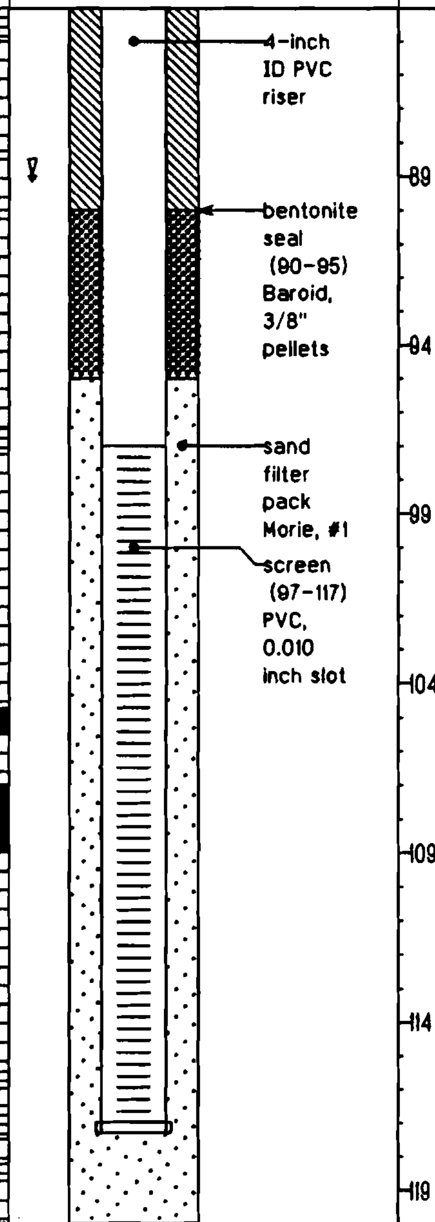
DRILL. CONTR.: EDI	**ENGINEERING-SCIENCE, INC.**	**BORING/WELL ID: 40MW3**
DRILLER: T. Lynch	**DRILLING RECORD**	
GEOLOGIST: J. Titus	INSTALLATION: RAAP	TOTAL DEPTH (feet): 120
RIG TYPE: Mobile B-80	SITE: SWMU 17	BOREHOLE DIAM.: 8 in.
DRILLING METHOD: Air Hammer	CLIENT: USAEC	CASING DIAM.: 4 in.
WATER LEVEL MEASUREMENT	PROJECT NO.: FB517	TOC ELEV.: 1858.21 ft. msl
MEASUREMENT POINT: TOC	DATE/TIME START: 21-May-93; 0900	
DATE/TIME: 06-Jun-93; 0930		
DEPTH TO WATER: 91.95 ft.	DATE/TIME END: 25-May-93; 1317	GS ELEV.: 1856.02 ft. msl

DEPTH (FEET)	DRILL RATE	HCl TEST	LITHOLOGY/REMARKS
	1ft/2.5min		interbedded DOLOSTONE and argillaceous DOLOSTONE
			DOLOSTONE massive, hard color: gray (2.5Y7/0 to 2.5YR6/0)
89			
			argillaceous DOLOSTONE weathered, soft weathered color: light, yellowish brown (2.5Y7/6) unweathered color: gray (2.5Y6/0) cuttings becoming wet
94	1ft/3.5min		
99	1ft/4min		
	1ft/4min		
104			VOID, containg calcite
			VOID
109	1ft/2.5min		
114			
	1ft/1min		weathered zone, argillaceous
			weathered zone, argillaceous
119	1ft/1.5min		weathered zone, argillaceous
			END OF BORING AT 120 FEET
124			

LITHOLOGIC COLUMN



WELL COMPLETION



CONTRACTOR: EDI

DRILLER: T. LYNCH

GEOLOGIST: J. TITUS

RIG TYPE: MOBIL-B80

DRILLING METHOD: AIR ROTARY

ENGINEERING-SCIENCE, INC.
DRILLING RECORD

PROJECT NAME: RAAP

CLIENT: USAEC

PROJECT NO.: FB517

BORING NO: INJ-1

LOCATION: SWMU 17A

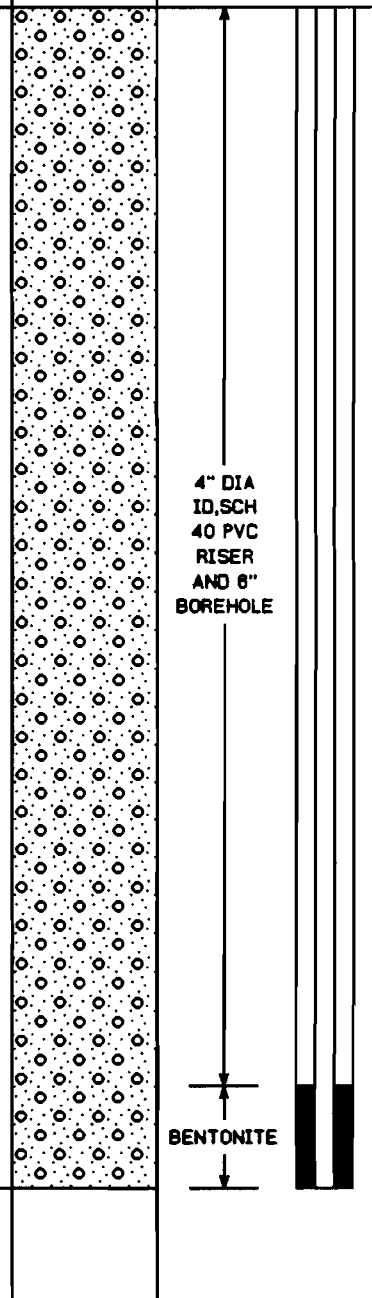
CITY/STATE: RADFORD, VA

WEATHER: CLOUDY, 65° F

DATE/TIME START: 5/25/93 1430

DATE/TIME FINISH: 5/25/93 1600

DEPTH (FT)	SAMPLE ID	RECOVERY %	BLOW COUNT	PID (ppm)	READING AT	TIME	SAMPLE TYPE	LITHOLOGY/REMARKS	LITHOLOGIC COLUMN	WELL COMPLETION	DEPTH (FT)
0–23								FILL, sand and silt, fine gravel, black color, dry			0–23
23–25								BEDROCK at 23 feet, argillaceous dolostone, weathered, soft, tan-pale yellow colored			23–25



SPT = STANDARD PENETRATION TEST
CAL = CALIBRATION
BZ = BREATHING ZONE
SS = SPLIT SPOON
A = AUGER CUTTINGS
C = CORED
BH = BORE HOLE
GS = GRAB SAMPLE
C = COMPOSITE
HS = HEADSPACE
▽ = WATER LEVEL

COMMENTS:
INJECTION WELL: OPEN PIPE AT ROCK INTERFACE

CONTRACTOR: EDI

DRILLER: S. HAUGE

GEOLOGIST: J. TITUS

RIG TYPE: MOBIL-B80

DRILLING METHOD: HSA

ENGINEERING-SCIENCE, INC.
DRILLING RECORD

PROJECT NAME: RAAP

CLIENT: USAEC

PROJECT NO.: FB517

BORING NO: INJ-2

LOCATION: SWMU 17E

CITY/STATE: RADFORD, VA

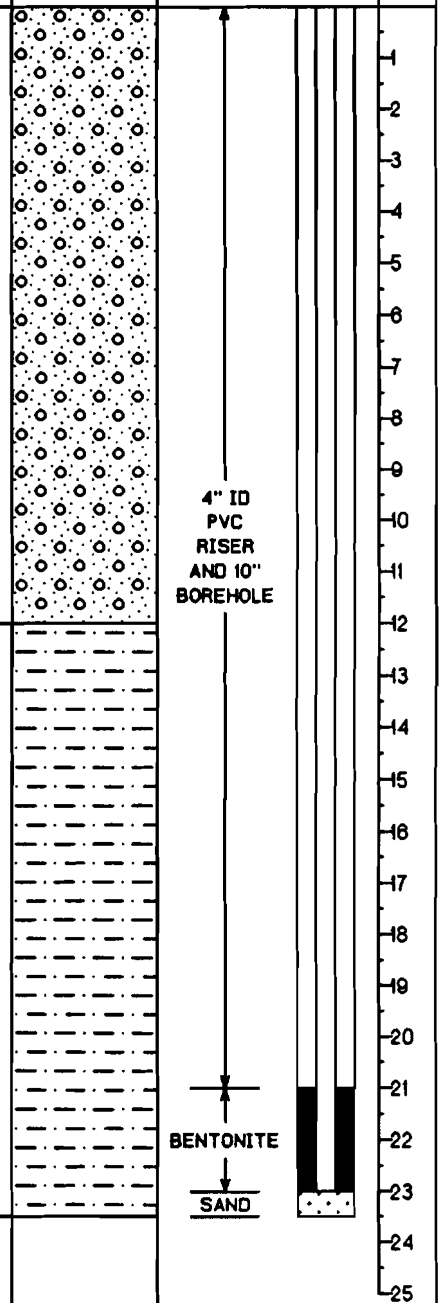
WEATHER: CLEAR, 70° F

DATE/TIME START: 6/17/93 0950

DATE/TIME FINISH: 6/17/93 1111

DEPTH (FT)	SAMPLE ID	RECOVERY %	BLOW COUNT	PID (ppm)	READING AT	TIME	SAMPLE TYPE	LITHOLOGY/REMARKS
0–12								SAND and fine well-rounded gravel, some silt, black color, wet at 2 feet
12–23.5								light brown-gray CLAY, becoming drier
23.5–25								BEDROCK at 23.5 feet, argillaceous dolostone, soft, weathered

LITHOLOGIC COLUMN / WELL COMPLETION



SPT = STANDARD PENETRATION TEST
CAL = CALIBRATION
BZ = BREATHING ZONE
SS = SPLIT SPOON
A = AUGER CUTTINGS
C = CORED
BH = BORE HOLE
GS = GRAB SAMPLE
C = COMPOSITE
HS = HEADSPACE
▽ = WATER LEVEL

COMMENTS:
INJECTION WELL: OPEN PIPE AT ROCK INTERFACE

APPENDIX B

FIELD DATA SHEETS

78

DAILY FIELD DATA SHEET

Dye – Tracing Study
Radford Army Ammunition Plant

TEST: SWMU 17
RUN BY: JDT / BBW
DATE: 9-Jun-93

Jar ID	AY73 Flour. Charcoal	DY 96 Cotton	Site Code	Location	Pull Gum Drop	Pull All Bugs	Hang Charcoal	Hang Cotton	Rig Gum Drop
				RMP1			X	X	X
				RMP2					
				RMP3					
				RMP4					
				RMP5					
				RMP6					
				RMP7					
				RMP8					
				RMP9					
				SMP1					
				SMP2					
				SMP3					
				SMP5					
				SMP6					
				SMP7					
				SMP8					
				SMP9					
				SMP10					
				SMP11					
			SMP 12, SMP13	SMP12/13 – combined due to P.L					
				SMP14					
				SMP15					
				SMP16					
				SMP17					
				SPG1					
				SPG2					
				SPG3					
				SPG4					
				SPG5					
				SPG6					
				SPG7					
				WMP1					
				WMP2					
				WMP3					
				WMP4					

Modified from Alexander and Quinlan, 1992

jdt\fb517\dyewp\fieldfm1.wk3

DAILY FIELD DATA SHEET

Dye – Tracing Study
Radford Army Ammunition Plant

TEST: SWMU 17
RUN BY: JDT / JCC
DATE: Wed, 22 Sept -93

Jar ID	AY73 Flour. Charcoal	DY 96 Cotton	Site Code	Location	Pull Gum Drop	Pull All Bugs	Hang Charcoal	Hang Cotton	Rig Gum Drop
				RMP1					
				RMP2					
				RMP3					
				RMP4					
				RMP5					
				RMP6					
				RMP7					
				RMP8					
				RMP9					
				SMP1 no cotton		X *	X	X	
				SMP2		X	X	X	
				SMP3 no cotton		X *	X	X	
				SMP5					
				SMP6					
				SMP7					
				SMP8					
				SMP9					
				SMP10					
				SMP11					
				SMP12/13					
				SMP14					
				SMP15					
				SMP16					
				SMP17					
				SPG1 dry / gumdrop gon			X	X	X
				SPG2					
				SPG3					
				SPG4					
				SPG5					
				SPG6					
				SPG7					
				WMP1					
				WMP2					
				WMP3					
				WMP4					

Modified from Alexander and Quinlan, 1992

jdt\fb517\dyewp\fieldfm1.wk3

DAILY FIELD DATA SHEET

Dye – Tracing Study
Radford Army Ammunition Plant

TEST: SWMU 17
RUN BY: JDT/JCC
DATE: Thurs., 23-Sept-93 – INJECTION at INJ 1, INJ 2 1300–1500 hrs.

Jar ID	AY73 Flour. Charcoal	DY 96 Cotton	Site Code	Location	Pull Gum Drop	Pull All Bugs	Hang Charcoal	Hang Cotton	Rig Gum Drop
				RMP1					
				RMP2					
				RMP3					
				RMP4					
				RMP5					
				RMP6					
				RMP7					
				RMP8					
				RMP9					
				SMP1					
				SMP2					
				SMP3					
				SMP5 dry		X	X	X	
				SMP6		X	X	X	
				SMP7		X	X	X	
				SMP8		X	X	X	
				SMP9		X	X	X	
				SMP10 gumdrop	gone		X	X	X
				SMP11		X	X	X	
				SMP12/13		X	X	X	
				SMP14		X	X	X	
				SMP15		X	X	X	
				SMP16		X	X	X	
				SMP17					
				SPG1					
				SPG2					
				SPG3					
				SPG4					
				SPG5					
				SPG6					
				SPG7					
				WMP1		X	X	X	
				WMP2		X	X	X	
				WMP3		X	X	X	
				WMP4		X	X	X	

Modified from Alexander and Quinlan, 1992

DAILY FIELD DATA SHEET

Dye – Tracing Study
Radford Army Ammunition Plant

TEST: SWMU 17
RUN BY: JOT / JCC
DATE: Fri, 24-Sept-93

Jar ID	AY73 Flour. Charcoal	DY 96 Cotton	Site Code	Location	Pull Gum Drop	Pull All Bugs	Hang Charcoal	Hang Cotton	Rig Gum Drop
				RMP1 gumdrop	gone		X	X	X
				RMP2		X	X	X	
				RMP3 gumdrop	gone		X	X	X
				RMP4 could not	find		X	X	X
				RMP5		X	X	X	
				RMP6					
				RMP7					
				RMP8					
				RMP9					
				SMP1					
				SMP2					
				SMP3					
				SMP5 dry					
				SMP6					
				SMP7					
				SMP8					
				SMP9					
				SMP10					
				SMP11					
				SMP12/13					
				SMP14					
				SMP15					
				SMP16					
				SMP17					
				SPG1 dry					
				SPG2					
				SPG3					
				SPG4					
				SPG5					
				SPG6					
				SPG7					
				WMP1					
				WMP2					
				WMP3		↓	↓	↓	
				WMP4		forgot	to	pull	

Modified from Alexander and Quinlan, 1992

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DAILY FIELD DATA SHEET

Dye – Tracing Study
Radford Army Ammunition Plant

TEST: SWMU 17
RUN BY: JDT / JCC
DATE: Sat, 25-Sept-93

Heavy Rains throughout day

Jar ID	AY73 Flour. Charcoal	DY 96 Cotton	Site Code	Location	Pull Gum Drop	Pull All Bugs	Hang Charcoal	Hang Cotton	Rig Gum Drop
				RMP1		X	X	X	
				RMP2					
				RMP3					
				RMP4					
				RMP5					
				RMP6					
				RMP7					
				RMP8					
				RMP9					
				SMP1					
				SMP2					
				SMP3					
				SMP5 Dry					
				SMP6					
				SMP7					
				SMP8					
				SMP9					
				SMP10					
				SMP11					
				SMP12/13					
				SMP14					
				SMP15					
				SMP16					
				SMP17					
				SPG1 Dry					
				SPG2					
	visible			SPG3					
				SPG4					
				SPG5					
				SPG6					
				SPG7					
				WMP1					
				WMP2					
				WMP3					
				WMP4		↓	↓	↓	

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DAILY FIELD DATA SHEET

Dye – Tracing Study
Radford Army Ammunition Plant

TEST: SWMU 17
RUN BY: JDT / JCC
DATE: Sun, 26 - Sept - 93

Jar ID	AY73 Flour. Charcoal	DY 96 Cotton	Site Code	Location	Pull Gum Drop	Pull All Bugs	Hang Charcoal	Hang Cotton	Rig Gum Drop
				RMP1		X	X	X	
				RMP2					
				RMP3					
	visible			RMP4					
	visible			RMP5					
				RMP6					
				RMP7					
				RMP8					
				RMP9					
				SMP1					
				SMP2					
				SMP3					
				SMP5 DRY					
				SMP6					
				SMP7					
				SMP8					
				SMP9					
				SMP10					
				SMP11					
				SMP12/13					
				SMP14					
				SMP15					
				SMP16					
				SMP17					
				SPG1 DRY					
				SPG2					
	visible			SPG3					
				SPG4					
				SPG5					
				SPG6					
				SPG7					
				WMP1					
				WMP2					
				WMP3					
				WMP4		↓	↓	↓	

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jdt\fb517\dyewp\fieldfm1.wk3

DAILY FIELD DATA SHEET

Dye – Tracing Study
Radford Army Ammunition Plant

TEST: SWMU 17
RUN BY: JDT / JCC
DATE: Mon, 27-Sept-93

Heavy Rain until 1030

Jar ID	AY73 Flour. Charcoal	DY 96 Cotton	Site Code	Location	Pull Gum Drop	Pull All Bugs	Hang Charcoal	Hang Cotton	Rig Gum Drop
				RMP1		X	X	X	
				RMP2					
				RMP3					
	visible			RMP4					
	visible			RMP5					
				RMP6					
				RMP7					
				RMP8					
				RMP9					
				SMP1					
				SMP2					
				SMP3					
				SMP5 - DRY					
				SMP6					
				SMP7					
				SMP8		↓	↓	↓	
				SMP9	can't	get to	bugs (High	Stream)	
				SMP10		X	X	X	
				SMP11	can't	get to	bugs (High	Stream)	
				SMP12/13		X	X	X	
				SMP14					
				SMP15					
				SMP16					
				SMP17					
				SPG1 Flowing					
				SPG2					
	visible,	decreasing	intensity	SPG3					
				SPG4					
				SPG5					
				SPG6					
				SPG7					
				WMP1					
				WMP2					
				WMP3					
				WMP4		↓	↓	↓	

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DAILY FIELD DATA SHEET

Dye – Tracing Study
Radford Army Ammunition Plant

TEST: SWMU 17
RUN BY: JOT / JCC
DATE: Tues, 28-Sept-94

Jar ID	AY73 Flour. Charcoal	DY 96 Cotton	Site Code	Location	Pull Gum Drop	Pull All Bugs	Hang Charcoal	Hang Cotton	Rig Gum Drop
				RMP1		X	X	X	
				RMP2					
				RMP3					
				RMP4					
				RMP5					
				RMP6					
				RMP7		left cotton			
				RMP8					
				RMP9					
				SMP1					
				SMP2					
				SMP3					
				SMP5					
				SMP6					
				SMP7					
				SMP8					
				SMP9					
				SMP10					
				SMP11					
				SMP12/13					
				SMP14					
				SMP15					
				SMP16					
				SMP17					
				SPG1 not flowing,					
				SPG2 bugs wet					
	slight green tint			SPG3					
				SPG4					
				SPG5					
				SPG6					
				SPG7					
				WMP1					
				WMP2					
				WMP3					
				WMP4		↓	↓	↓	

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Y

DAILY FIELD DATA SHEET

Dye – Tracing Study
Radford Army Ammunition Plant

TEST: SWMU 17
RUN BY: JOT / JCC
DATE: Wed, 29-Sept-93

Jar ID	AY73 Flour. Charcoal	DY 96 Cotton	Site Code	Location	Pull Gum Drop	Pull All Bugs	Hang Charcoal	Hang Cotton	Rig Gum Drop
				RMP1		X	X	X	
				RMP2					
				RMP3					
				RMP4					
				RMP5					
				RMP6					
				RMP7					
				RMP8					
				RMP9					
				SMP1					
				SMP2					
				SMP3					
				SMP5					
				SMP6					
				SMP7					
				SMP8					
				SMP9					
				SMP10					
				SMP11					
				SMP12/13					
				SMP14					
				SMP15					
				SMP16					
				SMP17					
				SPG1					
				SPG2					
	very slight green tint			SPG3					
				SPG4					
				SPG5					
				SPG6					
				SPG7					
				WMP1					
				WMP2					
				WMP3					
				WMP4		↓	↓	↓	

Modified from Alexander and Quinlan, 1992

jdt\fb517\dyewp\fieldfm1.wk3

DAILY FIELD DATA SHEET

Dye – Tracing Study
Radford Army Ammunition Plant

TEST: SWMU 17
RUN BY: JDT / JCC
DATE: Thur., 30-Sept-93

Jar ID	AY73 Flour. Charcoal	DY 96 Cotton	Site Code	Location	Pull Gum Drop	Pull All Bugs	Hang Charcoal	Hang Cotton	Rig Gum Drop
				RMP1		x	x	x	
				RMP2					
				RMP3					
				RMP4					
				RMP5					
				RMP6					
				RMP7					
				RMP8					
				RMP9					
				SMP1					
				SMP2					
				SMP3					
				SMP5 dry					
				SMP6					
				SMP7					
				SMP8					
				SMP9					
				SMP10					
				SMP11					
				SMP12/13					
				SMP14					
				SMP15					
				SMP16					
				SMP17					
				SPG1 dry					
				SPG2					
				SPG3					
				SPG4					
				SPG5					
				SPG6					
				SPG7					
				WMP1					
				WMP2					
				WMP3					
				WMP4		↓	↓	↓	

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jdt\fb517\dyewp\fieldfm1.wk3

DAILY FIELD DATA SHEET

Dye – Tracing Study
Radford Army Ammunition Plant

TEST: SWMU 17
RUN BY: TBI, BBW
DATE: 6,7 - Oct - 93

Jar ID	AY73 Flour. Charcoal	DY 96 Cotton	Site Code	Location	Pull Gum Drop	Pull All Bugs	Hang Charcoal	Hang Cotton	Rig Gum Drop
				RMP1 no charcoal		*			
				RMP2					
				RMP3 no charcoal		*			
				RMP4					
				RMP5					
				RMP6 no cotton		*			
				RMP7					
				RMP8					
				RMP9					
				SMP1					
				SMP2					
				SMP3					
				SMP5 dry					
				SMP6					
				SMP7					
				SMP8					
				SMP9					
				SMP10					
				SMP11					
				SMP12/13					
				SMP14					
				SMP15					
				SMP16					
				SMP17					
				SPG1 dry					
				SPG2					
				SPG3					
				SPG4 almost dry					
				SPG5					
				SPG6					
				SPG7					
				WMP1					
				WMP2					
				WMP3					
				WMP4					

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DAILY FIELD DATA SHEET

Dye – Tracing Study
Radford Army Ammunition Plant

TEST: SWMU 17
RUN BY: TBI, BBW
DATE: 20,21 - oct - 93

Jar ID	AY73 Flour. Charcoal	DY 96 Cotton	Site Code	Location	Pull Gum Drop	Pull All Bugs	Hang Charcoal	Hang Cotton	Rig Gum Drop
				RMP1		X	X	X	
				RMP2					
				RMP3					
				RMP4					
				RMP5					
				RMP6 no cotton no charcoal					
				RMP7					
				RMP8					
				RMP9					
				SMP1					
				SMP2					
				SMP3 no cotton		*			
				SMP5 Dry					
				SMP6 no charcoal		*			
				SMP7					
				SMP8					
				SMP9					
				SMP10					
				SMP11					
				SMP12/13					
				SMP14 no charcoal		*			
				SMP15					
				SMP16					
				SMP17					
				SPG1					
				SPG2					
				SPG3					
				SPG4					
				SPG5					
				SPG6					
				SPG7					
				WMP1					
				WMP2					
				WMP3					
				WMP4		↓	↓	↓	

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DAILY FIELD DATA SHEET

Dye – Tracing Study
Radford Army Ammunition Plant

TEST: SWMU 17
RUN BY: JDT / TBF
DATE: 4,5-nov-93

River ≈ 1-2 feet higher than normal level
rain towards end of 5-nov.

Jar ID	AY73 Flour. Charcoal	DY 96 Cotton	Site Code	Location	Pull Gum Drop	Pull All Bugs	Hang Charcoal	Hang Cotton	Rig Gum Drop
				RMP1		X	X	X	
				RMP2					
				RMP3					
				RMP4					
				RMP5					
				RMP6 no cotton		*			
				RMP7					
				RMP8					
				RMP9					
				SMP1					
				SMP2					
				SMP3					
				SMP5					
				SMP6					
				SMP7					
				SMP8					
				SMP9					
				SMP10					
				SMP11					
				SMP12/13					
				SMP14					
				SMP15					
				SMP16					
				SMP17 no cotton.		*			
				SPG1					
				SPG2					
				SPG3					
				SPG4					
				SPG5					
				SPG6					
normally above river water level, now submerged.				SPG7					
				WMP1					
				WMP2					
				WMP3					
				WMP4		↓	↓	↓	

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n

DAILY FIELD DATA SHEET

Dye – Tracing Study
Radford Army Ammunition Plant

TEST: SWMU 17
RUN BY: TBJ / SB
DATE: 17/18 - NOV - 93

Thundersorm ≈ 1700
heavy rain.

Jar ID	AY73 Flour. Charcoal	DY 96 Cotton	Site Code	Location	Pull Gum Drop	Pull All Bugs	Hang Charcoal	Hang Cotton	Rig Gum Drop
				RMP1		x	x	x	
				RMP2					
				RMP3					
				RMP4					
				RMP5					
				RMP6 dry (on shore)					
				RMP7					
				RMP8					
				RMP9					
				SMP1					
				SMP2					
				SMP3					
				SMP5 DRY					
				SMP6					
				SMP7					
				SMP8					
				SMP9					
				SMP10					
				SMP11					
				SMP12/13					
				SMP14					
				SMP15 no charcoal		*			
				SMP16 muddy					
				SMP17					
				SPG1					
				SPG2					
				SPG3					
				SPG4 dry					
				SPG5					
				SPG6					
				SPG7					
				WMP1					
				WMP2					
				WMP3					
				WMP4		↓	↓	↓	

Modified from Alexander and Quinlan, 1992

jdt\fb517\dyewp\fieldfm1.wk3

DAILY FIELD DATA SHEET

Dye – Tracing Study
Radford Army Ammunition Plant

TEST: SWMU 17
RUN BY: TBI, BBW
DATE: 2, 3 - DEC - 93

Jar ID	AY73 Flour. Charcoal	DY 96 Cotton	Site Code	Location	Pull Gum Drop	Pull All Bugs	Hang Charcoal	Hang Cotton	Rig Gum Drop
				RMP1		X	X	X	
				RMP2					
				RMP3					
				RMP4					
				RMP5					
				RMP6 no cotton		*			
				RMP7					
				RMP8					
				RMP9					
				SMP1					
				SMP2					
				SMP3					
				SMP5 dry					
				SMP6 no cotton		*			
				SMP7					
				SMP8					
				SMP9 no cotton		*			
				SMP10					
				SMP11					
				SMP12/13 no charcoal		*			
				SMP14					
				SMP15					
				SMP16					
				SMP17					
				SPG1 dry / no cotton		*			
				SPG2					
				SPG3					
				SPG4					
				SPG5					
				SPG6					
				SPG7					
				WMP1					
				WMP2					
				WMP3					
				WMP4		↓	↓	↓	

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jdt\fb517\dyewp\fieldfm1.wk3

8

DAILY FIELD DATA SHEET

Dye – Tracing Study
Radford Army Ammunition Plant

TEST: SWMU 17
RUN BY: JDT, JD
DATE: 16/17-Dec-93

last round of monitoring

River is extremely high. Level up 4-5 feet w/in last 2 weeks based on high water marks.

Jar ID	AY73 Flour. Charcoal	DY 96 Cotton	Site Code	Location	Pull Gum Drop	Pull All Bugs	Hang Charcoal	Hang Cotton	Rig Gum Drop
				RMP1	X	X			
				RMP2	↓	↓			
				RMP3	↓	↓			
				RMP4	↓	↓			
				RMP5	↓	↓			
				RMP6 gumdrop gone	↓	—			
				RMP7	↓	X			
				RMP8 gumdrop gone	↓	—			
				RMP9	↓	X			
				SMP1	↓	↓			
				SMP2	↓	↓			
				SMP3	↓	↓			
				SMP5 dry	↓	↓			
				SMP6	↓	↓			
				SMP7	↓	↓			
				SMP8	↓	↓			
				SMP9 no charcoal	↓	↓ *			
				SMP10	↓	↓			
				SMP11	↓	↓			
				SMP12/13 gumdrop gone	↓	—			
				SMP14	↓	X			
				SMP15 no cotton no charcoal	↓	—			
				SMP16	↓	X			
				SMP17	↓	↓			
				SPG1 flowing	↓	↓			
				SPG2	↓	↓			
				SPG3	↓	↓			
				SPG4	↓	↓			
				SPG5	↓	↓			
				SPG6	↓	↓			
				SPG7	↓	↓			
				WMP1	↓	↓			
				WMP2	↓	↓			
				WMP3	↓	↓			
				WMP4	↓	↓			

Modified from Alexander and Quinlan, 1992

jdt\fb517\dyewp\fieldfm1.wk3

APPENDIX C

LABORATORY ANALYSIS DATA SHEETS

FIGURE 3.8
RECORD OF DYE TEST

Radford Army Ammunition Plant

Injection Point: SWMU 17
Tracer: FLOURESCEIN
Amount:

Injection Date: THURS, SEPT. 23, 1993
Injection Time: 1400 hrs.
Observer: SUDHIR MURTHY
Ben Waller (10/6,7)

Detector Location		Date, number of days since dye injection, and results										
	Date	9/23	9/24	9/25	9/26	9/27	9/28	9/29	9/30	10/6,7		
	No. Days	0	1	2	3	4	5	6	7	14		
RMP1										L		
RMP2						(5) ? recheck						
RMP3										L		
RMP4				2	–	5	5	[illegible]	[illegible]			
RMP5					4	(3)	[illegible]	[illegible]				
RMP6												
RMP7					(4) ?		([illegible]) ?					
RMP8												
RMP9						recheck						
SMP1												
SMP2												
SMP3												
SMP5												
SMP6										B *		
SMP7												
SMP8												
SMP9												
SMP10												
SMP11		L										

Modified from Alexander and Quinlan, 1992

* Strong yellow-brown color

LEGEND

–	Negative Result	B	Background
1	Very Weakly Postive	B+	Flourescence Significantly above background
2	Weakly Postive	NR	Not Recovered (because of high water or other reason)
3	Moderately Positive	L	Bug Lost or Stolen
4	Strongly Positive	G	New or Extra Gumdrop
5	Very Strongly Positive	P	Significant Precipitation Event on this day
/	Bugs Not Changed		

REMARKS:

FIGURE 3.8
RECORD OF DYE TEST

Radford Army Ammunition Plant

Injection Point: SWMU 17
Tracer: FLOURESCEIN
Amount:

Injection Date: THURS, SEPT 23, 1993
Injection Time: 1400 hrs
Observer: SUDHIR MURTHY

Detector Location	Date, number of days since dye injection, and results											
	Date	9/23	9/24	9/25	9/26	9/27	9/28	9/29	9/30	10/67		
	No. Days	0	1	2	3	4	5	6	7	14		
SMP 12/13												
SMP 14												
SMP 15		L										
SMP 16												
SMP 17												
SPG 1												
SPG 2												
SPG 3				5	–	5	5	–	–	5		
SPG 4												
SPG 5												
SPG 6												
SPG 7												
WMP 1												
WMP 2												
WMP 3												
WMP 4												

Modified from Alexander and Quinlan, 1992

LEGEND

–	Negative Result	B	Background
1	Very Weakly Postive	B+	Flourescence Significantly above background
2	Weakly Postive	NR	Not Recovered (because of high water or other reason)
3	Moderately Positive	L	Bug Lost or Stolen
4	Strongly Positive	G	New or Extra Gumdrop
5	Very Strongly Positive	P	Significant Precipitation Event on this day
/	Bugs Not Changed		

REMARKS:

FIGURE 3.8
RECORD OF DYE TEST

Radford Army Ammunition Plant

Injection Point: SWMU 17
Tracer: FLOURESCEIN
Amount:

Injection Date: Thurs., 23 SEPT 93
Injection Time: 1400
Observer: Brian Waller

Detector Location	Date, number of days since dye injection, and results											
	Date	10/20,21	11/4,5	11/17,18	12/2,3	12						
	No. Days	28	42	55	70							
RMP 1												
RMP 2												
RMP 3												
RMP 4												
RMP 5												
RMP 6		L		L								
RMP 7												
RMP 8												
RMP 9												
SMP 1												
SMP 2												
SMP 3												
SMP 5												
SMP 6		L	B*	B*	B*							
SMP 7												
SMP 8												
SMP 9												
SMP 10												
SMP 11												

Modified from Alexander and Quinlan, 1992

LEGEND

–	Negative Result	B	Background
1	Very Weakly Postive	B+	Flourescence Significantly above background
2	Weakly Postive	NR	Not Recovered (because of high water or other reason)
3	Moderately Positive	L	Bug Lost or Stolen
4	Strongly Positive	G	New or Extra Gumdrop
5	Very Strongly Positive	P	Significant Precipitation Event on this day
/	Bugs Not Changed		

REMARKS: * strong yellow - light brown color

FIGURE 3.8
RECORD OF DYE TEST

Radford Army Ammunition Plant

Injection Point: SWMU 17
Tracer: FLOURESCEIN
Amount:

Injection Date: Thurs., 23 SEPT 93
Injection Time: 1400
Observer: Ben Walker

Detector Location	Date, number of days since dye injection, and results											
	Date	10/20,21	11/4,5	11/17,18	12/2,3	12/						
	No. Days	28	42	55	70							
SMP 12/13												
SMP 14												
SMP 15				L								
SMP 16												
SMP 17												
SPG 1												
SPG 2												
SPG 3												
SPG 4												
SPG 5		5	5	5	5	5						
SPG 6												
SPG 7												
WMP 1												
WMP 2												
WMP 3												
WMP 4												

Modified from Alexander and Quinlan, 1992

LEGEND

–	Negative Result	B	Background
1	Very Weakly Postive	B+	Flourescence Significantly above background
2	Weakly Postive	NR	Not Recovered (because of high water or other reason)
3	Moderately Positive	L	Bug Lost or Stolen
4	Strongly Positive	G	New or Extra Gumdrop
5	Very Strongly Positive	P	Significant Precipitation Event on this day
/	Bugs Not Changed		

REMARKS:

FIGURE 3.8
RECORD OF DYE TEST

Radford Army Ammunition Plant

Injection Point: SWMU 17
Tracer: DIRECT YELLOW
Amount:

Injection Date: THURS, SEPT. 23, 1993
Injection Time: 1400 hrs.
Observer: SUDHIR MURTHY
B. WALLEN (10/6,7)

Detector Location	Date	9/23	9/24	9/25	9/26	9/27	9/28	9/29	9/30	10/6,7		
	No. Days	0	1	2	3	4	5	6	7	14		
RMP1				/	1	1	1	[illegible]	—	—		
RMP2			—	/	2	1	/	[illegible]	—	B		
RMP3				/	1	2	2	[illegible]	—	—		
RMP4					2	2	2	—	1	—		
RMP5			L	2	2	2	1	[illegible]	2	B		
RMP6				2	2	2	2	2	[illegible]	L		
RMP7			L	2	1	2	[illegible]	[illegible]	1	—		
RMP8			L	4	[illegible]	5	—	5	5	B		
RMP9			L	3	4	3	—	[illegible]	3	B		
SMP1		L	—	1	—	—	1	1	[illegible]	B		
SMP2		—	—	1	—	1	—	—	—	—		
SMP3		L	—	—	—	—	—	—	—	—		
SMP5		—							2	B		
SMP6		—	—	—	—	—	—	[illegible]	—	—		
SMP7			—	1	—	—	—	[illegible]	2	B		
SMP8		—	—	—	—	—	—	—	2	—		
SMP9		—	—	1	—		—		—	B		
SMP10			—	—	—	—		—		B		
SMP11		L	—		2		1	—	2	—		

Modified from Alexander and Quinlan, 1992

LEGEND

—	Negative Result	B	Background
1	Very Weakly Postive	B+	Flourescence Significantly above background
2	Weakly Postive	NR	Not Recovered (because of high water or other reason)
3	Moderately Positive	L	Bug Lost or Stolen
4	Strongly Positive	G	New or Extra Gumdrop
5	Very Strongly Positive	P	Significant Precipitation Event on this day
/	Bugs Not Changed		

REMARKS:

FIGURE 3.8
RECORD OF DYE TEST

Radford Army Ammunition Plant

Injection Point: SWMU 17
Tracer: DIRECT YELLOW
Amount:

Injection Date: THURS, SEPT 23, 1993
Injection Time: 1400 hrs
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Detector Location	Date	9/23	9/24	9/25	9/26	9/27	9/28	9/29	9/30	10/67		
	No. Days	0	1	2	3	4	5	6	7	14		
SMP 12/13		L	–	/	2	/	/	2	–	B		
SMP 14		–	–		2	2		–	–	B		
SMP 15		L	–	–	/	/	–	–		–		
SMP 16		–	–	–	/	–	–	–	–	–		
SMP 17			–	–	/	–	–	–	/	–		
SPG 1						/	–			1✓		
SPG 2			–	–	–	–	/	–	–	–		
SPG 3			/	/	2✓	–✓	–✓	–✓	2✓	2✓		
SPG 4			–	/	/		/	/		–		
SPG 5			L	/	–	–	/✓	–	–	–		
SPG 6				–	/	2	2✓	–	2	B		
SPG 7		–		–		2	–	–	–	B		
WMP 1		–	L	–	/	–✓	2✓	–✓	/✓	1✓		
WMP 2		–	–	–	/	– –	2 –			1✓		
WMP 3		–	–	–	L	–✓				1✓		
WMP 4		–			/	–✓	2	–	2✓	1✓		

Modified from Alexander and Quinlan, 1992

LEGEND

–	Negative Result	B	Background
1	Very Weakly Postive	B+	Flourescence Significantly above background
2	Weakly Postive	NR	Not Recovered (because of high water or other reason)
3	Moderately Positive	L	Bug Lost or Stolen
4	Strongly Positive	G	New or Extra Gumdrop
5	Very Strongly Positive	P	Significant Precipitation Event on this day
/	Bugs Not Changed		

REMARKS:

FIGURE 3.8
RECORD OF DYE TEST

Radford Army Ammunition Plant

Injection Point: SWMU 17
Tracer: DIRECT YELLOW
Amount:

Injection Date: Thurs., 23 SEPT 93
Injection Time: 1400
Observer:

Detector Location		Date, number of days since dye injection, and results										
	Date	10/20,21	11/4,5	11/17,18	12/2,3							
	No. Days	28	42	55	70							
RMP 1		—	—	—	—							
RMP 2		B	—	—	—							
RMP 3		—	—	—	—							
RMP 4		—	—	—	—							
RMP 5		B	—	—	—							
RMP 6		L	L	L	L							
RMP 7		—	—	—	—							
RMP 8		B	B	B	B							
RMP 9		B	B	B	—							
SMP 1		B	—	B	—							
SMP 2		—	—	—	—							
SMP 3		L	—	—	—							
SMP 5		1✓	B	1✓	—							
SMP 6		—	—	—	—							
SMP 7		B	B	B	—							
SMP 8		—	—	—	—							
SMP 9		B	—	B	L							
SMP 10		—	B B	—	—							
SMP 11		—	—	—	—							

Modified from Alexander and Quinlan, 1992

LEGEND

—	Negative Result	B	Background
1	Very Weakly Postive	B+	Flourescence Significantly above background
2	Weakly Postive	NR	Not Recovered (because of high water or other reason)
3	Moderately Positive	L	Bug Lost or Stolen
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/	Bugs Not Changed		

REMARKS:

FIGURE 3.8
RECORD OF DYE TEST

Radford Army Ammunition Plant

Injection Point: SWMU 17
Tracer: DIRECT YELLOW
Amount:

Injection Date: Thurs., 23 SEPT 93
Injection Time: 1400
Observer:

Detector Location		Date, number of days since dye injection, and results										
	Date	10/20,21	11/4,5	11/17,18	12/2,3							
	No. Days	28	42	55	70							
SMP 12/13		—	—	B	B							
SMP 14		—	—	B	—							
SMP 15		—	—	—	—							
SMP 16		—	—	—	—							
SMP 17		—	L	—	—							
SPG 1		1✓	1✓	1✓	L							
SPG 2		—	—	—	—							
SPG 3		1✓	—	1✓	—							
SPG 4		—	—	B	B							
SPG 5		—	—	—	—							
SPG 6		1✓	B	B	1✓							
SPG 7		—	—	B	—							
WMP 1		1✓	—	1✓	—							
WMP 2		1✓	1✓	1✓	—							
WMP 3		1✓	—	—	1✓							
WMP 4		—	1✓	1✓	1✓							

Modified from Alexander and Quinlan, 1992 ↑ ↑

LEGEND

–	Negative Result	B	Background
1	Very Weakly Postive	B+	Flourescence Significantly above background
2	Weakly Postive	NR	Not Recovered (because of high water or other reason)
3	Moderately Positive	L	Bug Lost or Stolen
4	Strongly Positive	G	New or Extra Gumdrop
5	Very Strongly Positive	P	Significant Precipitation Event on this day
/	Bugs Not Changed		

REMARKS:

ENGINEERING-SCIENCE, INC.

10521 Rosehaven Street • Fairfax, Virginia 22030 • (703) 591-7575 • Fax: (703) 591-1305

September 12, 1994

Mr. Harry R. Kleiser
Project Manager-Installation Restoration
U.S. Army Environmental Center
Installation Restoration Division
Building E4480
Aberdeen P.G., MD 21010-5401

Re: Radford Army Ammunition Plant, Addenda to the Dye-Tracing Study Report

Dear Mr. Kleiser:

Engineering-Science, Inc. (ES) is pleased to submit these revisions and addenda to the draft report for the Dye-Tracing Study conducted in the vicinity of Solid Waste Management Units 17 and 40 at the Radford Army Ammunition Plant. The attached pages are meant to replace corresponding pages of the Dye-Tracing Study Report submitted by ES on March 9, 1994. These addenda update the report with results from the additional dye-trace study conducted by ES in the spring of 1994. Replacement pages are submitted for the executive summary and Sections 1, 3 and 4. Addenda are provided for Appendices B and C. As required in our statement of work, four copies are provided.

Please call me at (703) 934-2388 with any comments or questions.

Sincerely,

ENGINEERING-SCIENCE, INC.

Alexis L. Fricke, P.E.
Project Manager

SPG:ms
722843/SG42385B.LTR

Attachments

cc: Jeff Titus, ES-Atlanta
Charlie Spiers, ES-Atlanta
File 722843.19

PARSONS

DYE-TRACING STUDY REPORT
RADFORD ARMY AMMUNITION PLANT
CONTRACT NO. DAA1590-D-0008

Prepared For:

U. S. ARMY ENVIRONMENTAL CENTER

ABERDEEN PROVING GROUND, MARYLAND

Prepared By:

ENGINEERING-SCIENCE, INC.

FAIRFAX, VIRGINIA

MARCH 1994
(As Ammended September 1994)

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6

EXECUTIVE SUMMARY

The Radford Army Ammunition Plant (RAAP) was issued a Permit for Corrective Action and Incinerator Operation by the U.S. Environmental Protection Agency (USEPA) requiring RAAP to conduct Verification Investigations (VIs) at sites of suspected contamination, RCRA Facility Investigations (RFIs) at sites of known contamination, and Corrective Measures Studies (CMSs) at sites requiring remediation.

In 1992, RAAP completed several VIs and RFIs at selected solid waste management units (SWMUs) throughout the installation. Specifically, in the south-central section of the Main Manufacturing Area, VIs were conducted at the Sanitary Landfill (NG Area) (SWMU 40), the Flash Burn Parts Area (SWMU 71), and the Waste Oil Underground Storage Tank Area (UST) (South of Oleum Plant) (SWMU 76), and an RFI was conducted at the Contaminated Waste Burning Areas (SWMUs 17A-E). Site hydrogeology could not be fully characterized during these investigations due to the karst geology in this area of the facility. Groundwater flow determination in the vicinity of SWMUs 17 and 40 has been complicated by abundant solution features and numerous zones of intense weathering and fracturing in the limestone and dolostone bedrock.

Two stages of a dye-trace study were conducted, the first in the fall of 1993 and the second in the spring of 1994, in an effort to better identify groundwater flow paths through the karst limestone in the south-central section of the Main Manufacturing Area at RAAP. On September 23, 1993 two fluorescent dyes, Fluorescein and Direct Yellow 96, were injected into upland sinkholes in which SWMUs 17A and 17B-E occupy, respectively. On April 28, 1994, Rhodamine WT dye was injected into an upland sinkhole which SWMU 17A occupies. This second dye injection was performed to investigate any variations in groundwater flow due to changes in the hydrologic conditions onsite. The injections during the initial stage of this investigation in the fall of 1993 were performed during low flow conditions, while those in the spring of 1994 were performed while the surface water and groundwater were experiencing high flow conditions. A total of 35 locations for the fall 1993 injection and 27 locations for the spring 1994 injection, including on-site and off-site streams, springs, monitoring wells, and locations along the New River were monitored for the appearance of dye for a three month period following each dye injection. Once hydraulic connections were made between the recharge areas at SWMU 17 and their respective discharge areas in and around the facility, the locations were identified for later groundwater, surface water, and sediment sampling activities.

Based on the results of this investigation, one spring (SPG 3), located along the northwest shoreline of the New River, was identified as being hydraulically connected to the sinkhole which SWMU 17A occupies. The flow path identified by the dye trace closely parallels a west-northwest to east-southeast trending fracture trace which can be extended to connect both the dye injection point and the dye resurgence point. This leads to the conclusion that a direct conduit exists between SWMU 17A and SPG 3 which is most likely created by solution opening along a subsurface fracture. The travel time for groundwater flow through this conduit, under low flow conditions in which the initial stage of this trace test was conducted, is calculated to range between 2,095 feet/day and 3,716 feet/day. The travel time for groundwater flow through this conduit under high flow conditions, as were present during the second stage of this investigation, is calculated to average about 4,800 feet/day.

SECTION 1

INTRODUCTION

1.1 INTRODUCTION

This document is the report for the Dye-Tracing Study conducted at the Radford Army Ammunition Plant (RAAP) located in Radford, Virginia. This report has been prepared for the U.S. Army Environmental Center (USAEC) and is submitted under the requirements of Contract No. DAAA15-90-D-0008, Task DA04.

RAAP was issued a Permit for Corrective Action and Incinerator Operation by the U.S. Environmental Protection Agency (USEPA), effective December 13, 1989. Under the criteria of Section 3004(u) of the Resource Conservation and Recovery Act (RCRA), the permit (No. VA-21-002-0730) requires RAAP to conduct Verification Investigations (VIs) at sites of suspected contamination, RCRA Facility Investigations (RFIs) at sites of known contamination, and Corrective Measures Studies (CMSs) at sites requiring remediation.

In 1992, RAAP completed several VIs and RFIs at selected solid waste management units (SWMUs) throughout the installation. Specifically, in the south-central section of the Main Manufacturing Area, VIs were conducted at the Sanitary Landfill (NG Area) (SWMU 40), the Flash Burn Parts Area (SWMU 71), and the Waste Oil Underground Storage Tank Area (UST) (South of Oleum Plant) (SWMU 76), and an RFI was conducted at the Contaminated Waste Burning Areas (SWMUs 17A-E). Site hydrogeology could not be fully characterized during these investigations due to the karst geology in this area of the facility. Groundwater flow determination in the vicinity of SWMUs 17 and 40 has been complicated by abundant solution features and numerous zones of intense weathering and fracturing in the limestone and dolostone bedrock. Therefore, a dye-tracing study was conducted in the south-central section of the Main Manufacturing Area at RAAP to better characterize groundwater flow through the karst aquifer in this vicinity and to identify future sampling locations. The two stages of this study were conducted to characterize groundwater flow at both high-flow (spring 1994) and low-flow (fall 1993) conditions.

1.2 PROJECT OBJECTIVES

The objective of this study was to determine groundwater flow directions through the karst limestone in the south-central section of the Main Manufacturing Area at RAAP by identifying hydrologic connections between areas of groundwater recharge (upland sinkholes near SWMUs 17 and 40) and their respective discharge areas in and around the facility.

This objective was met during the initial stage of this study by the injection of two groundwater dye tracers, specifically Fluorescein and Direct Yellow 96, into two sinkholes at SWMU 17. On September 23, 1993 Fluorescein was introduced into the sinkhole in which SWMU 17A (Stage and Burn Area) is situated and Direct Yellow was introduced into the Runoff Drainage Basin (SWMU 17E) located in the sinkhole adjacent to the Fluorescein injection site. Hydrologic connections between recharge and discharge areas can vary seasonally due to changes in surface and groundwater flow conditions. To investigate this possibility, Rhodamine WT dye was introduced on April 28, 1994, into the sinkhole located in SWMU 17A (stage burning area). Selected monitoring wells, the New River, and springs and streams both on- and off-site were monitored for the appearance of dye for a set period of time after each dye injection. A semi-quantitative, dye-tracing approach was utilized in this investigation.

1.3 REPORT ORGANIZATION

This report consists of six sections and three supporting appendices. Section 1 provides an introduction to the project history and a statement of the project objectives. A detailed description of the current conditions at RAAP, including facility background and environmental setting, is presented in Section 2. Section 3 outlines the dye-trace study field activities including elements such as dye selection rationale, methodologies for dye injection and recovery, and analysis of results. Results of the dye-tracing test are discussed in Section 4. A summary of the conclusions and recommendations for the investigation are presented as Section 5. References are provided in Section 6 and Appendices A through C include well logs, field data sheets, and laboratory analysis sheets.

SECTION 3

DYE-TRACE INVESTIGATION

3.1 DYE SELECTION

Groundwater tracing can be accomplished using a wide variety of tracers, including radioisotopes, chemicals, fluorescent dyes, bacterial tracers, and particulate tracers. Desirable properties in a groundwater tracer include:

- Easily detectable by the researcher(s);
- Not detectable by the public;
- Should not react with the rock or soil matrix;
- Chemically stable over the length of the test;
- Not commonly found in the environment;
- Non-toxic; and,
- Relatively inexpensive.

These criteria are to some extent contradictory. No tracer will meet all of these criteria; however, some will meet most of them. Generally, the fluorescent dyes are the most cost-effective and reliable tracers of the above list.

Four types of fluorescent dyes are commonly used in groundwater tracing in the United States (Quinlan, 1987). These include Sodium Fluorescein, Rhodamine WT, Direct Yellow 96, and a number of compounds within the general category of optical brighteners. From this list, Sodium Fluorescein, Rhodamine WT, and Direct Yellow 96 were chosen for this study.

Fluorescein (CI Acid Yellow 73) is a green fluorescent dye that is recovered on activated coconut charcoal. Sodium Fluorescein is also known and marketed as Uranine. Fluorescein is provided as a powder which must be mixed with water prior to or during injection and is usually cut with fillers such as sodium chloride, sodium sulfate or starch derivatives (Quinlan, 1987). Fluorescein is very susceptible to photochemical decay (Smart and Laidlaw, 1977). Therefore, detectors should be shielded from sunlight and placed at locations where the water has been exposed to as little sunlight as possible. Fluorescein is somewhat resistant to sorption on clays (Quinlan, 1987). Jones (1984) reports that Fluorescein is the most popular dye used in karst studies in the United States.

Direct Yellow 96 is a yellow fluorescent dye recovered on unbleached, unwhitened cotton detectors. It is supplied as a powder that must be mixed with water prior to injection. Direct Yellow is not subject to photochemical decay and is a common dye used in systems where the water has resurgences that allow it to be exposed to the sun (Quinlan, 1987). Reaction with soils and rock matrices is very slight (Jones, 1984). Direct Yellow reacts with cellulose to a greater degree than Fluorescein (Quinlan, 1987). Direct Yellow has been used extensively in groundwater tracing in karst terrains in Kentucky.

Rhodamine WT is a pink fluorescent dye recovered on activated coconut charcoal. Rhodamine WT is provided as a 20 percent solution in water. Rhodamine WT is less susceptible to photochemical decay than fluorescein dye. However, organic matter can effectively mask the pink tint of this dye if the dye is present in small quantities. The stability of Rhodamine WT and its distinct color made it the most feasible dye to use for the second dye injection in the spring of 1994.

3.2 DYE TRACE INVESTIGATION

3.2.1 Well Installation

As part of the dye-tracing study, three bedrock monitoring wells and two temporary dye-injection wells were installed in the study area (Figure 3.1). The bedrock wells range in depth between 120 feet and 190 feet and are designed to intercept the regional water table associated with the New River. The two dye-injection wells, located in the sinkholes comprising SWMUs 17A and 17B-E, were installed to a maximum depth of 23.5 feet and were installed through the fill overburden to the bedrock interface.

All well installation procedures were performed in accordance with the Dye-Tracing Study Work Plan (ES, 1993) or using methods approved by USAEC when unusual conditions were encountered. The boring logs/well completion records for all wells installed as part of this investigation are presented in Appendix A.

Figure 3.1

The bedrock borings were advanced using air-hammer drilling techniques. This drilling method was selected based on the abundant solution features encountered during previous drilling activities in the area to reduce the potential for loss of drilling fluids. Drill cuttings were examined for lithology during the drilling activities and periodically placed into glass jars for further examination, when needed.

Prior to well placement, a color television camera was lowered into each borehole to facilitate examination of structural features (bedding planes and fractures) and physical condition (solution features). The wells were then constructed in the borehole with 4-inch inner diameter, flush-joint, schedule 40 PVC pipe and screened over the lower 20 feet. Each well was developed with a submersible pump following well completion.

The first bedrock well (17MW2) was located between the two dye-injection points at SWMUs 17A and 17E, adjacent to existing piezometer 17PZ1. The well was installed to a depth of 173 feet with a screened interval between 150 feet and 170 feet. Lithology in the 17MW2 boring generally consisted of a hard, massive dolostone interbedded with a soft, highly weathered, argillaceous dolostone. Numerous voids and weathered zones were encountered during drilling activities; between 22 feet and 23 feet, 78 feet and 80 feet, and a major water producing void between 129 feet and 132 feet. The rate of groundwater recharge to 17MW2 was extremely rapid during well installation and development activities.

The second bedrock well (17MW3) was located along the axis of sinkhole alignment in the area to evaluate the influence of structural features and/or solution features on dye transport. Monitoring well 17MW3 was completed at a depth 190 feet and screened between 159 feet and 179 feet. Lithology in the 17MW3 boring was similar to that observed at the 17MW2 location. A large void was encountered between 11 feet and 20 feet requiring the installation of an 8-inch ID, PVC surface casing to 20 feet. Smaller voids (<1 foot) were observed at 52 feet and 73 feet. An intensely weathered zone was encountered between 162 feet and 168 feet across which the well was screened. Recharge to this well was very slow during installation and development.

The third well (40MW3) was located in a downgradient flow direction from SWMUs 17 and 40. Monitoring well 40MW3 was installed to a depth of 120 feet and screened between 97 feet and 117 feet. Approximately 53 feet of soil overburden was encountered at this drilling location. The soil was composed of micaceous silt which graded downward into a micaceous sand and finally into a well to subrounded gravel. Bedrock was encountered at 53 feet below ground surface at this boring location. An 8-inch ID, PVC surface casing was installed to seal off the overburden material at 40MW3. Bedrock lithology was similar to that observed at the previous boring locations. Voids were encountered between 62 feet and 63 feet, 79 feet and 80 feet, 105 feet and 106 feet, and 107 feet to 109 feet. Groundwater recharge to this well was rapid.

Two temporary dye-injection wells (INJ1 and INJ2) were installed in the southwest corner of the Stage and Burn Area (SWMU 17A) and adjacent to the Runoff Drainage Area (SWMU 17E) as shown in Figure 3.2. The wells were installed to facilitate dye injection at these locations. The borings were advanced using either air rotary or hollow stem augers drilling methods and were designed to extend through the soil fill material in the bottom of the sinkhole to the bedrock interface. The injection wells were constructed with an open ended 4-inch, inner diameter PVC pipe.

Lithology in the INJ1 boring consisted of black, sandy, fill material to a depth of 23 feet. Below the fill material, bedrock was encountered consisting of soft, argillaceous dolostone. The overburden lithology was considerably different at the INJ2 location, however. Black sand and gravel was encountered to a depth of 10 feet; underlain by a light brown to gray colored clay extending to bedrock at 23.5 feet. Bedrock lithology was similar to that observed at the INJ2 boring location. Due to the proximity of INJ2 to the ponded water in the runoff drainage basin, water was encountered at a depth of 2 feet in INJ2, suggesting poor drainage in that area.

3.2.2 Field Reconnaissance and Pretest Screening

Prior to injecting the dye for this study, field reconnaissance activities were conducted of the study area between late May, 1993 to early June, 1993. These efforts were conducted to locate and verify dye monitoring points and to locate additional monitoring points not previously identified in the Work Plan. During field reconnaissance for the final selection of dye monitoring locations, dye-detectors 'bugs' were placed in all prospective monitoring locations that were to be utilized during the dye-trace test. They were retrieved prior to dye

Figure 3.2

injection and tested for background levels of Fluorescein and Direct Yellow dyes. A total of 35 monitoring locations were chosen for the initial dye injections that took place in the fall of 1993. Of these, 27 monitoring locations were used for the second dye injection in the spring of 1994. Approximately one week prior to the second injection, dye-detectors "bugs" were placed at each of the prospective monitoring locations. These bugs were retrieved prior to dye injection and tested for background levels of Rhodamine WT dye.

3.2.3 Dye Preparation

Fluorescein and Direct Yellow are supplied in powder form. The Fluorescein was mixed with unchlorinated water at the rate of 1 pound per gallon prior to the test. Direct Yellow was mixed at the rate of 2 pounds per gallon. The dye solutions were stored in 5-gallon plastic jugs and were prepared on the day of injection. Precautions were taken during mixing, storage, and transportation of the dye solutions to minimize the chance of dyes contaminating the detectors. Rhodamine WT is provided in solution, and therefore, does not require any preparation. However, precautions were taken during the storage and transportation of the dye to minimize the chance of it contaminating the detectors.

Quinlan (1987) suggests a dosage of one pound of Fluorescein per mile of travel. The travel distance for the dye was estimated to range between 1 and 2 miles from the injection location; however, a 5 pound dosage was used for this investigation to account for potential losses to organics and/or the soil fill in SWMU 17A.

The appropriate dosage for Direct Yellow is 2 pounds per mile of travel, up to 10 pounds (Quinlan, 1987). The travel distance for the dye was estimated to range between 1 and 2 miles from the injection location. As a result, a dose of approximately 4 pounds of Direct Yellow dye was required. However; because of the restricted inflow at SWMU 17E, an additional 4 pounds of dye was applied to account for adsorption of the dye on leaf litter and other cellulose.

The quantity of Rhodamine required for a dye trace study in karst environments is 0.5 gallons per mile of travel. The travel distance for the dye was estimated to range between 1 and 2 miles from the injection location. Because of the high recharge capacity known to exist at SWMU 17A, a volume of 1 gallon of dye was used for this investigation.

3.2.4 Dye Injection

During the initial stage of this investigation, the dyes were introduced on September 23, 1993 during relatively low flow conditions after a storm event. This ensured that dilution of the dye was minimal and groundwater flow rates would be average. Additionally, the loss of dye due to storage in isolated pools within the karst system matrix would be minimized.

Fluorescein dye was injected into INJ1, located in SWMU 17A. Prior to introduction of the dye, approximately 1,200 gallons of unchlorinated water was pumped into the injection well to saturate the potential flow pathways. The dye was then introduced directly into the well after the slug of water infiltrated into the sinkhole. Following injection, the dye was followed by a chaser of 1,200 gallons of unchlorinated water injected at a moderate and constant rate.

A similar injection method was attempted at INJ2, located in the runoff drainage basin (SWMU 17E). Initially, unchlorinated water was pumped into the injection well; however, the water did not infiltrate into the surrounding formation. The remaining 1,150 gallons of water was pumped onto the ground surrounding the injection well in an effort to saturate the entire area. The Direct Yellow dye introduced into the well and also poured into the ponded water in the runoff basin. Another 1,200 gallons of unchlorinated water were pumped on the ground at the runoff drainage basin to further saturate the soil overburden and to speed up dye infiltration.

During the second stage of this investigation, Rhodamine WT dye was introduced on April 18, 1994 during relatively high flow conditions. This was done to investigate variations in the karst hydrologic conditions that would result in changing the groundwater flow paths in the vicinity of SWMU 17.

Rhodamine WT dye was injected into INJ1, located in SWMU 17A. Prior to introducing the dye, approximately 1,250 gallons of unchlorinated water was pumped into the injection well to saturate the potential flow pathways. The dye was poured directly into the well, after the slug of water infiltrated the sinkhole. Following the injection of the dye, an additional 1,250 gallons of unchlorinated water was pumped into the injection well at a moderate and constant rate.

3.2.5 Dye Monitoring

3.2.5.1 Dye Detection

Passive detectors, or "bugs," were used to accumulate dyes for visual examination during this investigation. Fluorometric techniques were used to detect the dye and to provide qualitative and/or semi-quantitative measures of the dye concentration. Visual examination was chosen for this study in order to reduce the complexity of the detector processing while still meeting the objectives of the study. Activated charcoal was used to adsorb Fluorescein and Rhodamine WT dye for detection and Direct Yellow was detected on cotton bugs.

The detectors used to detect Fluorescein and Rhodamine WT were composed of three to four tablespoons of 6 to 14 mesh-activated coconut charcoal enclosed in a pouch of nylon window screen. Surgical cotton pads, enclosed in a screen pouch similar to the charcoal, were used to detect Direct Yellow. Both the charcoal and cotton detectors were prepared daily. In addition each new roll of cotton was checked with an ultraviolet light for the presence of optical brighteners or other fluorescence that might interfere with detection of the dye prior to being used for this investigation.

During both stages of this investigation, both a cotton and a charcoal bug were placed at each monitoring location. Although no dyes were injected in the spring of 1994 that would be detected on a cotton bug, these were used to examine if residual direct yellow dye remained in the groundwater. The bugs were suspended above the stream bed using a weighted, stable stand known as a "gumdrop." Typical gumdrop construction is illustrated in Figure 3.3. A laminated tag was affixed to each gumdrop to identify the monitoring location and to discourage removal by unauthorized personnel. The detectors were placed within the main channel of flow in an effort to maximize the amount of water passing through the bug and secured to an immovable object on-shore to insure that a sudden rise in the current would not wash the detectors away. Detectors installed in wells were suspended below the water table by a piece of weighted polypropylene rope.

Figure 3.3

3.2.5.2 Monitoring Locations

A total of 35 locations were monitored for the resurgence of dye during the initial stage of this investigation (15 stream locations, 9 river locations, 7 spring locations, and 4 well locations). A total of 27 locations were monitored for the resurgence of dye during the second stage of this investigation. Seven river monitoring points (RMP 1, RMP 3, RMP 4, RMP 5, RMP 6, RMP 7, and RMP 8) and one stream monitoring point (SMP 17) were dropped for the second stage of this investigation. These points were dropped based on findings of the initial dye injection which indicated that these were improbable discharge points. The monitoring locations are shown in Figure 3.4.

Fifteen monitoring points were located in streams on and off site. Primarily, Stroubles Creek and several unnamed tributaries flowing into the creek were monitored for transport of dye east from the injection area (SMPs 4-15, and 17). An unnamed tributary flowing into the New River, located northeast of the Rolled Powder Area, was also monitored for dye (SMP16). Spring fed Pepper Creek and its two tributaries, located south of RAAP, was monitored in three locations (SMPs 1-3) to determine if groundwater is discharging south from the dye injection site.

Seven springs were located during the field reconnaissance activities and subsequently monitored for dye during this investigation. The springs were primarily located along the northwestern shoreline of the New River (SPG 2 through SPG 7) with the exception of SPG 1, which was located at the base of the bluff along the Norfolk & Western Rail Road (RAAP southwest property boundary).

Four monitoring wells were monitored for dye (WMPs 1-4). These wells include piezometer 17PZ1 (WMP1), and newly installed bedrock wells 17MW2 (WMP2), 40MW3 (WMP3), and 17MW3 (WMP4).

Ten monitoring points (RMPs 1-10) were placed along the southern shore of the New River and used during the initial stage of this investigation. The monitoring points extend from the confluence of Pepper Creek, near the Route 114 bridge, to the Rolled Powder Area near the northeastern RAAP boundary. The monitoring locations were spaced at approximately 3,000-foot intervals. Where possible, the monitoring points were sighted

Figure 3.4

offshore from structural lineaments at the facility, such as fracture traces and sinkhole alignments. The New River monitoring points were selected to determine the most likely area where groundwater in the karst flow system is discharging into the New River. The resurgences may be either from surface water flow, diffuse flow through the river alluvium, springs and seeps below the water line, springs in the river bottom, or any combination of the above. Because no dye was observed at the river monitoring points during the initial stage of this investigation, only one upstream (RMP 2) and one downstream (RMP 9) river monitoring points were utilized for the second stage of this investigation.

3.2.5.3 Monitoring Schedule

During the field reconnaissance phase and prior to each dye injection, detectors were placed at each of the monitoring locations and tested for background levels of the dyes.

During the tracing study, the bugs were collected from each monitoring location and analyzed for dye on a daily basis during the first week after dye injection. A biweekly monitoring schedule was implemented during weeks two through twelve of the initial stage of this study. A monthly monitoring schedule was implemented for weeks two through twelve during the second stage of this study. Both the charcoal and cotton bugs were collected from all locations during the monitoring program and daily tasks associated with the test were recorded on a field data sheets shown in Appendix B.

Each pair of bugs (one charcoal, one cotton) were drained of water and placed in labeled whirl-pac plastic bags immediately upon retrieval. Each bag was labeled with the detector location and the date and time of retrieval. If the bugs could not be processed within 12 hours of retrieval, they were air dried to minimize microbial activity that may mask a positive detection.

3.2.5.4 Detector Analysis

Charcoal Detectors - Approximately one-third of the charcoal in the detector was placed into a glass jar labeled with the same number as the sample. The unused portion of the charcoal detector was returned to the plastic bag and retained for later confirmation if required.

Fluoresein dye collected on the charcoal was eluted using a basic potassium hydroxide (KOH) and 70 percent propanol (common rubbing alcohol) solution that was prepared daily. A distinctive kelly-green color would develop if dye was present on the charcoal and a muted green color would develop due to the extraction of algae and organic matter. Practice in eluting weak positive spike samples was performed to reduce the chance of confusion resulting in false positives. Rhodamine WT dye collected on the charcoal bugs was eluted using a 5:2:3 mixture of 1-propanol, concentrated NH_4OH, and distilled water. This mixture is known as a Smart solution. A distinctive hot-pink color would develop if dye was present on the charcoal. Organic matter produces a light brown turbid appearance in this solution. Practice in eluting weak positive spike samples was performed to reduce the possibility of reading false positives. During each stage of this investigation, the degree of positiveness was judged based upon the following scheme taken from Aley and Fletcher (1976):

1. Very Strongly Positive: 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: Same as above, but after 15 minutes and before 3 hours.
3. Moderately Positive: 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: 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: 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.

The results of the bug analysis were recorded on the data sheets shown in Appendix C.

Cotton Detectors - The cotton detectors were examined for the presence of Direct Yellow using a long-wave ultraviolet lamp. The detector was removed from the screen pouch and placed in a view box under the ultraviolet lamp. A positive test was indicated by a uniform yellow color. After examination, the detector was returned to the plastic bag and retained for later confirmation if required. The results of the bug analysis were recorded on the data sheets shown in Appendix C.

3.2.5.5 Quality Assurance

Quality assurance samples were analyzed both before and during the tracer test. These samples included detectors spiked with varying concentrations of the dyes, detectors that have not been exposed to dyes. The spiked detectors were used to confirm that the detectors and analysis techniques will detect the dye. In addition, by using spikes of varying concentration, information on the range of detection was obtained. The blank samples insured that there was no dye or material that would interfere with the detection of dye in the unexposed detectors. The background samples were used to identify algal growths or organics that may interfere with detection of dye, or be confused with the presence of dye. Pretest screening of the monitoring sites has been previously discussed. Duplicate detectors on separate holders were placed at two of the monitoring sites.

SECTION 4

DYE-TRACING STUDY RESULTS

The objective of this study was to determine groundwater flow directions during both high and low flow conditions through the karst limestone in the south-central section of the Main Manufacturing Area at RAAP. This was done by identifying hydrologic connections between areas of groundwater recharge (upland sinkholes near SWMUs 17 and 40) and their respective discharge areas in and around the facility.

This objective was met by the injection of groundwater tracer dyes during two episodes, the first during low flow conditions in the fall of 1993 and the second during high flow conditions in the spring of 1994. In the fall of 1993, two dyes (Fluorescein and Direct Yellow 96) were injected into two sinkholes at SWMU 17. On September 23, 1993 Fluorescein was introduced into the sinkhole in which SWMU 17A (Stage and Burn Area) is situated and Direct Yellow was introduced into the Runoff Drainage Basin (SWMU 17E) located in the sinkhole adjacent to the Fluorescein injection site. On April 28, 1994, Rhodamine WT was injected into the sinkhole in which SWMU 17A is located. The following section describes the results of the dye-trace test.

4.1 FLUORESCEIN AND RHODAMINE WT TRACE RESULTS

Three monitoring locations sampled during the initial stage of this investigation (SPG 3, RMP 4, and RMP 5) showed a positive trace for Fluorescein. The dye was injected into INJ 1 at approximately 1400 hours on September 23, 1993. Analyses of the charcoal samples for all monitoring points collected on September 24 were negative. By 0900 hours on September 25, Fluorescein dye was visibly noticeable in the groundwater discharging from SPG 3. By 0900 hours on September 26, a 10-foot wide band of green colored water extended along the shoreline from the discharge point at SPG 3 to the RAAP water intake, located approximately 0.4 miles downstream (Figure 3.4). This area encompasses the locations for sampling points RMP 4 and RMP 5, thus explaining the positive trace results observed at these points. This pattern was observed until September 30, 1993.

Visible detection of dye in the water discharging from SPG 3 decreased until September 30,1993 when dye was no longer visible. One additional sighting of Fluorescein dye issuing from SPG 3 was reported by Hercules personnel to have occurred after a significant precipitation event during the week of October 4, 1993 (Pers. Comm., 1993a). The most likely explanation of continued detection of dye at SPG 3 is due to recharge events flushing out residual dye trapped in isolated pools in the karst matrix. Laboratory analysis of the SPG 3 charcoal samples, however, showed continued high concentrations of Fluorescein dye throughout the duration of this stage of the test.

Only one monitoring location (SPG 3) showed a positive trace for Rhodamine WT during the second stage of this investigation. The dye was injected into INJ 1 at 1045 hours on April 28, 1994. By 1500 hours on April 29, a 5- to 10-foot wide band of pink colored water extended into the New River along the shoreline from the discharge point SPG 3. Visible detection of Rhodamine WT dye in the water discharging from SPG 3 decreased until May 2, 1994 when dye was no longer visible. Laboratory analysis of charcoal samples from SPG 3 displayed continued high concentrations of Rhodamine WT dye throughout the duration of this stage of the investigation.

Based on the field observations and laboratory analyses for monitoring point SPG 3, groundwater travel times were calculated for the flow path originating from SWMU 17A and discharging to SPG 3. The distance between INJ 1 and SPG 3 is approximately 4,800 feet (0.9 miles). During the initial stage of this test, the fist appearance of dye is estimated to have occurred around 2100 hours on September 24, 1993 (31 hours after injection) and the peak concentration is estimated to have reached SPG 3 around 2100 hours on September 25, 1993 (55 hours after injection) as shown in Figure 4.1. Using these times and the approximate travel distance, groundwater travel times during low flow conditions for water originating at SWMU 17A and discharging to SPG 3 is calculated to range between 2,095 feet/day and 3,716 feet/day. However, the groundwater travel times appear to be higher during periods of high flow. During the second stage of this test, dye was first observed at SPG 3 27 hours after it was injected at INJ 1. The first appearance of dye is estimated to have occurred at around 1100 hours on April 29 (24 hours after injection) and the peak concentration was observed by 1400 hours on the same day. Using these times and the

Figure 4.1

approximate travel distance, groundwater travel times during high flow conditions for water originating at SWMU 17A and discharging to SPG 3 is calculated to average at about 4,800 feet/day.

Figure 4.1 shows the results of the Fluorescein dye-trace test. The red arrow in the figure denotes approximate flow route from recharge area in SWMU 17A and the discharge point at SPG 3. Also shown in Figure 4.2 are the fracture traces (shown as red hatched lines) and sinkholes (in black) described in the EPIC (USEPA, 1992) report. This figure clearly shows an alignment of the SWMU 17 sinkholes, SPG 3, and a west-northwest to east-southeast trending fracture trace connecting the two points. Solutionization along this fracture has most likely created a direct conduit for groundwater flow and contaminant transport from SWMU 17A and explains the extremely rapid travel times calculated for this test.

4.2 DIRECT YELLOW TRACE RESULTS

No Direct Yellow dye has been observed to date during this test. This can be explained in three ways. First, the dye may have infiltrated into the bedrock and is traveling at a slow enough rate that it has yet to reach any of the dye monitoring points. The second explanation is that the dye has infiltrated into the bedrock and has discharged at one or more locations that were not monitored during this investigation. Lastly, the dye may not have infiltrated into the bedrock aquifer and is still located in the SWMU 17E sinkhole and fill material.

The most probable explanation for the lack of Direct Yellow detection at the dye monitoring points is that the dye is still sitting in the sinkhole where it was injected. This explanation is likely do to the clay fill material in observed during installation of INJ 2 in SWMU 17E and the slow infiltration rate observed during dye injection activities.

4.3 BACKGROUND DYE OBSERVATIONS

A common class of fluorometric dye, known as optical brighteners, was detected at several dye monitoring locations during this investigation. Cotton bugs, after having come into contact with optical brighteners, will fluoresce a blue color under examination with a

Figure 4.2

long-wave ultraviolet lamp. Optical brighteners are commonly used as whitening agents in laundry detergents and are thus extremely common in sanitary sewer water and in septic tank water.

New River monitoring points RPM 8 and RMP 9 showed high concentrations of optical brighteners in the water. These two monitoring locations are immediately downstream of RAAP outfall number 026 and Hercules personnel indicate that this outfall receives discharges from various processes including the RAAP laundry facility (Pers. Comm., 1993b). The observed concentrations of optical brighteners at the RMP 8 and RMP 9 can therefore be explained by the effluent from RAAP outfall number 026. Optical brighteners were occasionally detected at low concentrations in several other monitoring points including SMP 1, RMP 1 through RMP 7, SMP 12/13, SMP 14, SMP 7, SMP 9, and SMP 10. These observations are most likely the result of sanitary sewer effluent from the cities of Radford and Blacksburg, other RAAP outfalls, or area home septic discharges.

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The dye-trace test conducted between September 23, 1993 and July 8, 1994 was designed to determine groundwater flow directions through the karst limestone in the south-central section of the Main Manufacturing Area at RAAP by identifying hydrologic connections between areas of groundwater recharge (upland sinkholes near SWMUs 17 and 40) and their respective discharge areas in and around the facility. Based on the results of this investigation, one spring, SPG 3, was identified as being hydraulically connected to the sinkhole which SWMU 17A occupies. Furthermore, the flow path identified by the dye trace closely parallels a west-northwest to east-southeast trending fracture trace which can be extended to connect both the dye injection point and the dye resurgence point. This leads to the conclusion that a direct conduit exists between SWMU 17A and SPG 3 which is most likely created by solution opening along a subsurface fracture. The travel time for groundwater flow through this conduit, under low flow conditions, is calculated to range between 2,095 feet/day and 3,716 feet/day and under high flow conditions is calculated to average about 4,800 feet/day.

5.2 RECOMMENDATIONS

The dye-trace study conducted in the south-central section of the Main Manufacturing Area at RAAP was successful in identifying one dye monitoring location (SPG 3) to be hydraulically connected to SWMU 17A. As a result of the positive trace at this spring, groundwater, surface water, and sediments at this location should be sampled during future RFI sampling activities being conducted at SWMU 17.

ADDENDA TO APPENDIX B

FIGURE 3.7
DAILY FIELD DATA SHEET

Dye – Tracing Study
Radford Army Ammunition Plant

TEST: DYE TRACE II
RUN BY: S. Glennie - B. Walker
DATE: 4/21/94

Jar ID	AY73 Flour. Charcoal	DY 96 Cotton	Site Code	Location	Pull Gum Drop	Pull All Bugs	Hang Charcoal	Hang Cotton	Rig Gum Drop
				RMP 2			✓	✓	
				RMP 9			✓	✓	
				SMP 1			✓	✓	
				SMP 2			✓	✓	
				SMP 3			✓	✓	
				SMP 5			✓	✓	
				SMP 6			✓	✓	
				SMP 7			✓	✓	
				SMP 8			✓	✓	
				SMP 9			✓	✓	
				SMP 10			✓	✓	
				SMP 11			✓	✓	
				SMP 12/13			✓	✓	
				SMP 14			✓	✓	
				SMP 15			✓	✓	
				SMP 16			✓	✓	
				SPG 1			✓	✓	
				SPG 2			✓	✓	
				SPG 3			✓	✓	
				SPG 4			✓	✓	
				SPG 5			✓	✓	
				SPG 6			✓	✓	
				SPG 7			✓	✓	
				WMP 1			✓	✓	
				WMP 2			✓	✓	
				WMP 3			✓	✓	
				WMP 4			✓	✓	

Modified from Alexander and Quinlan, 1992

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FIGURE 3.7
DAILY FIELD DATA SHEET

Dye – Tracing Study
Radford Army Ammunition Plant

TEST: Dye Trace II
RUN BY: J. Titus + Steve Glennie
DATE: 4/27/94, 4/28/94

Note: Collection of Background samples prior to injection of Dye on 4/28/94

	Jar ID	AY73 Flour. Charcoal	DY 96 Cotton	Site Code	Location	Pull Gum Drop	Pull All Bugs	Hang Charcoal	Hang Cotton	Rig Gum Drop
4/27 →					SMP 10		✓	✓	✓	
					SMP 3		✓	✓	✓	
					SPG 1		✓	✓	✓	
					RMP 2		✓	✓	✓	
					SMP 8		✓	✓	✓	
					SMP 14		✓	✓	✓	
					SMP 7		✓	✓	✓	
					SMP 6		✓	✓	✓	
					SMP 12/13		✓	✓	✓	
					SMP 11		✓	✓	✓	
					SMP 9		✓	✓	✓	
					WMP 4		✓	✓	✓	
					SMP 5		✓	✓	✓	
(					SMP 16		✓	✓	✓	
4/28 AM					RMP 9		✓	✓	✓	
					SMP 1		✓	✓	✓	
					SMP 2		✓	✓	✓	
→					WMP 1		✓	✓	✓	
					WMP 2		✓	✓	✓	
					WMP 3		✓	✓	✓	
PM After injection					SPG 2		✓	✓	✓	
					SPG 7		✓	✓	✓	
		Flowing	Now	Visible.	SPG 3 (Gate 6)		✓	✓	✓	
				NA —	RMP4 NA					
					SPG4		✓	✓	✓	
					SPG 5		✓	✓	✓	
					SPG 6		✓	✓	✓	
					SMP 15		✓	✓	✓	

Modified from Alexander and Quinlan, 1992

28 Total Monitoring points

18 + 18A

NA. Not Analysed

76

FIGURE 3.7
DAILY FIELD DATA SHEET

Dye – Tracing Study
Radford Army Ammunition Plant

TEST: DYE TRACE II
RUN BY: STEVE GLENNIE
DATE: 4/29/94

Jar ID	AY73 Flour. Charcoal	DY 96 Cotton	Site Code	Location	Pull Gum Drop	Pull All Bugs	Hang Charcoal	Hang Cotton	Rig Gum Drop
				SMP 10		✓	✓	✓	
				SPG 1		✓	✓	✓	
				RMP 2		✓	✓	✓	
				SMP 3		✓	✓	✓	
				SMP 1		✓	✓	✓	
				SMP 2		✓	✓	✓	
				SMP 8		✓	✓	✓	
				SMP 14		✓	✓	✓	
				SMP 7		✓	✓	✓	
				SMP 6		✓	✓	✓	
				SMP 12/13		✓	✓	✓	
				SMP 11		✓	✓	✓	
				SMP 9		✓	✓	✓	
				SMP 5		✓	✓	✓	
				SMP 16		✓	✓	✓	
				RMP 9		✓	✓	✓	
				WMP 4 →		✓	✓	✓	
				WMP 1		✓	✓	✓	
				WMP 2		✓	✓	✓	
				WMP 3		✓	✓	✓	
				SPG 2		✓	✓	✓	
				SPG 7		✓	✓	✓	
	- STRONG COLOR IN H2O -			SPG 3		✓	✓	✓	
				NA ~~RMP 4~~ NA					
				SPG 4		✓	✓	✓	
				SPG 5		✓	✓	✓	
				SPG 6		✓	✓	✓	
				SMP-15		✓	✓	✓	

(Left margin, beside rows SMP 9 through WMP 4:) NOT IN LIMITED AREA

(Left margin, beside rows WMP 1 through SPG 2:) IN LIMITED AREA

Modified from Alexander and Quinlan, 1992

* NA: Not Analysed

FIGURE 3.7
DAILY FIELD DATA SHEET

Dye – Tracing Study
Radford Army Ammunition Plant

TEST: DYE TRACE II
RUN BY: SPG, SMB
DATE: 4/30/94

Jar ID	AY73 Flour. Charcoal	DY 96 Cotton	Site Code	Location	Pull Gum Drop	Pull All Bugs	Hang Charcoal	Hang Cotton	Rig Gum Drop
				RMP 2		✓	✓	✓	
				RMP 9		✓	✓	✓	
				SMP 1		✓	✓	✓	
				SMP 2		✓	✓	✓	
				SMP 3		✓	✓	✓	
				SMP 5		✓	✓	✓	
				SMP 6		✓	✓	✓	
				SMP 7		✓	✓	✓	
				SMP 8		✓	✓	✓	
				SMP 9		✓	✓	✓	
				SMP 10		✓	✓	✓	
				SMP 11		✓	✓	✓	
				SMP 12/13		✓	✓	✓	
				SMP 14		✓	✓	✓	
				SMP 15	Rope	Broke	- Gum	Drop	Lost
				SMP 16		✓	✓	✓	
				SPG 1		✓	✓	✓	
				SPG 2		✓	✓	✓	
				SPG 3		✓	✓	✓	
				SPG 4		✓	✓	✓	
				SPG 5		✓	✓	✓	
				SPG 6		✓	✓	✓	
				SPG 7		✓	✓	✓	
				WMP 1		✓	✓	✓	
				WMP 2		✓	✓	✓	
				WMP 3		✓	✓	✓	
				WMP 4		✓	✓	✓	

Modified from Alexander and Quinlan, 1992

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FIGURE 3.7
DAILY FIELD DATA SHEET

Dye – Tracing Study
Radford Army Ammunition Plant

TEST: DYE TRACE II
RUN BY: SPG + SMB
DATE: 5/1/94

Jar ID	AY73 Flour. Charcoal	DY 96 Cotton	Site Code	Location	Pull Gum Drop	Pull All Bugs	Hang Charcoal	Hang Cotton	Rig Gum Drop
				RMP 2		✓	✓	✓	
				RMP 9		✓	✓	✓	
				SMP 1		✓	✓	✓	
				SMP 2		✓	✓	✓	
				SMP 3		✓	✓	✓	
				SMP 5		✓	✓	✓	
				SMP 6		✓	✓	✓	
				SMP 7		✓	✓	✓	
				SMP 8		✓	✓	✓	
				SMP 9		✓	✓	✓	
				SMP 10		✓	✓	✓	
				SMP 11		✓	✓	✓	
				SMP 12/13		✓	✓	✓	
				SMP 14		✓	✓	✓	
				SMP 15 ADDED	NEW	Drop	✓	✓	
				SMP 16		✓	✓	✓	
				SPG 1		✓	✓	✓	
				SPG 2		✓	✓	✓	
				SPG 3		✓	✓	✓	
				SPG 4		✓	✓	✓	
				SPG 5		✓	✓	✓	
				SPG 6		✓	✓	✓	
				SPG 7		✓	✓	✓	
				WMP 1		✓	✓	✓	
				WMP 2		✓	✓	✓	
				WMP 3		✓	✓	✓	
				WMP 4		✓	✓	✓	

Modified from Alexander and Quinlan, 1992

FIGURE 3.7
DAILY FIELD DATA SHEET

Dye – Tracing Study
Radford Army Ammunition Plant

TEST: DYE TRACE II
RUN BY: S. GLENNIE / S. Buckley
DATE: 5/2/94

Jar ID	AY73 Flour. Charcoal	DY 96 Cotton	Site Code	Location	Pull Gum Drop	Pull All Bugs	Hang Charcoal	Hang Cotton	Rig Gum Drop
				SMP 10		✓	✓	✓	
				SPG 1		✓	✓	✓	
				RMP2		✓	✓	✓	
				SMP1		✓	✓	✓	
				SMP2		✓	✓	✓	
				SMP3		✓	✓	✓	
				SMP8		✓	✓	✓	
				SMP 14		✓	✓	✓	
				SMP 7		✓	✓	✓	
				SMP 6		✓	✓	✓	
				SMP 12/13		✓	✓	✓	
				SMP 11		✓	✓	✓	
				SMP 9		✓	✓	✓	
				SMP 16		✓	✓	✓	
				RMP 9		✓	✓	✓	
				WMP4		✓	✓	✓	
				WMP1		✓	✓	✓	
				WMP 2		✓	✓	✓	
				WMP3		✓	✓	✓	
				SPG ~~WMP4~~ SPG3		✓	✓	✓	
				SPG 4		✓	✓	✓	
				SPG 5		✓	✓	✓	
				SPG 6		✓	✓	✓	
				SMP 15		✓	✓	✓	
				SPG 2		✓	✓	✓	
				SPG 7		✓	✓	✓	
				SMP 5		✓	✓	✓	

Modified from Alexander and Quinlan, 1992

FIGURE 3.7
DAILY FIELD DATA SHEET

Dye – Tracing Study
Radford Army Ammunition Plant

TEST: Dye Trace II
RUN BY: G. Gilcanic, J. Daugherty
DATE: 5/3/94

Jar ID	AY73 Flour. Charcoal	DY 96 Cotton	Site Code	Location	Pull Gum Drop	Pull All Bugs	Hang Charcoal	Hang Cotton	Rig Gum Drop
				SMP 10		✓	✓	✓	
				SPG 1		✓	✓	✓	
				RMP 2		✓	✓	✓	
				SMP 1		✓	✓	✓	
				SMP 2		✓	✓	✓	
				SMP 3		✓	✓	✓	
				SMP 8		✓	✓	✓	
				SMP 14		✓	✓	✓	
				SMP 7		✓	✓	✓	
				~~SMP 6~~		✓	✓	✓	
				SMP 12/13		✓	✓	✓	
				SMP 11		✓	✓	✓	
				SMP 9		✓	✓	✓	
				SMP 16		✓	✓	✓	
				RMP 9		✓	✓	✓	
				WMP 4		✓	✓	✓	
				WMP 1		✓	✓	✓	
				WMP 2		✓	✓	✓	
				WMP 3		✓	✓	✓	
				SMP 3		✓	✓	✓	
				SPG 4		✓	✓	✓	
				SPG 5		✓	✓	✓	
				SPG 6		✓	✓	✓	
				SMP 15		✓	✓	✓	
				SPG 2		✓	✓	✓	
				SPG 7		✓	✓	✓	
				SMP 5		✓	✓	✓	

Modified from Alexander and Quinlan, 1992

FIGURE 3.7
DAILY FIELD DATA SHEET

Dye – Tracing Study
Radford Army Ammunition Plant

TEST: Dye - TRACE II
RUN BY: S. Gleanic, J. Dougherty
DATE: 5/4/94

Jar ID	AY73 Flour. Charcoal	DY 96 Cotton	Site Code	Location	Pull Gum Drop	Pull All Bugs	Hang Charcoal	Hang Cotton	Rig Gum Drop
				SMP10		✓	✓	✓	
				SPG 1		✓	✓	✓	
				RMP2		✓	✓	✓	
				SMP1		✓	✓	✓	
				SMP 2		✓	✓	✓	
				SMP3		✓	✓	✓	
				SMP 8		✓	✓	✓	
				SMP 14		✓	✓	✓	
				SMP 7		✓	✓	✓	
				SMP 6		✓	✓	✓	
				SMP 12/13		✓	✓	✓	
				SMP 11		✓	✓	✓	
				SMP 9		✓	✓	✓	
				SMP 16		✓	✓	✓	
				RMP 9		✓	✓	✓	
				WMP 4		✓	✓	✓	
				WMP 1		✓	✓	✓	
				WMP 2		✓	✓	✓	
				WMP 3		✓	✓	✓	
				SPG 4		✓	✓	✓	
				SPG 5		✓	✓	✓	
				SPG 6		✓	✓	✓	
				SMP 15		✓	✓	✓	
				SPG 2		✓	✓	✓	
				SPG 7		✓	✓	✓	
				SMP 5		✓	✓	✓	

Modified from Alexander and Quinlan, 1992

FIGURE 3.7
DAILY FIELD DATA SHEET

Dye – Tracing Study
Radford Army Ammunition Plant

TEST: Dye Trace II
RUN BY: S. Glennie, J. Daugherty
DATE: 5/5/94

Jar ID	AY73 Flour. Charcoal	DY 96 Cotton	Site Code	Location	Pull Gum Drop	Pull All Bugs	Hang Charcoal	Hang Cotton	Rig Gum Drop
				SMP 10		✓	✓	✓	
				SPG 1		✓	✓	✓	
				RMP 2		✓	✓	✓	
				SMP 1		✓	✓	✓	
				SMP 2		✓	✓	✓	
				SMP 3		✓	✓	✓	
				SMP 8		✓	✓	✓	
				SMP 14		✓	✓	✓	
				SMP 7		✓	✓	✓	
				SMP 6		✓	✓	✓	
				SMP 12/13		✓	✓	✓	
				SMP 11		✓	✓	✓	
				SMP 9		✓	✓	✓	
				SMP 16		✓	✓	✓	
				RMP 9		✓	✓	✓	
				WMP 4		✓	✓	✓	
				WMP 1		✓	✓	✓	
				WMP 2		✓	✓	✓	
				WMP 3		✓	✓	✓	
				SMP 3		✓	✓	✓	
				SPG 4		✓	✓	✓	
				~~SMP~~ SPG 5		✓	✓	✓	
				SPG 6		✓	✓	✓	
				SMP 15		✓	✓	✓	
				SPG 2		✓	✓	✓	
				SPG 7		✓	✓	✓	
				SMP 5		✓	✓	✓	

Modified from Alexander and Quinlan, 1992

FIGURE 3.7
DAILY FIELD DATA SHEET

Dye – Tracing Study
Radford Army Ammunition Plant

TEST: Dye Trace II
RUN BY: Steve Glennie / Sean Buckley
DATE: 6/2/94 - 6/3/94

Jar ID	AY73 Flour. Charcoal	DY 96 Cotton	Site Code	Location	Pull Gum Drop	Pull All Bugs	Hang Charcoal	Hang Cotton	Rig Gum Drop
				SMP 10		✓	✓	✓	
				SMP 3		✓	✓	✓	
				SPG 1		✓	✓	✓	
				RMP 2		✓	✓	✓	
				SMP 8		✓	✓	✓	
				SMP 14		✓	✓	✓	
				SMP 7		✓	✓	✓	
				SMP 6		✓	✓	✓	
				SMP 12/13		✓	✓	✓	
				SMP 11		✓	✓	✓	
				SMP 9		✓	✓	✓	
				WMP 4		✓	✓	✓	
				SMP 5		✓	✓	✓	
				SMP 16		✓	✓	✓	
				RMP 9		✓	✓	✓	
				SMP 1		✓	✓	✓	
				SMP 2		✓	✓	✓	
				WMP 1		✓	✓	✓	
				WMP 2		✓	✓	✓	
				WMP 3		✓	✓	✓	
				SPG 2		✓	✓	✓	
				SPG 7		✓	✓	✓	
				SPG 3		✓	✓	✓	
				SPG 4		✓	✓	✓	
				SPG 5		✓	✓	✓	
				SPG 6		✓	✓	✓	
				SMP 15 Cotton Missing		✓	✓	✓	

Modified from Alexander and Quinlan, 1992

FIGURE 3.7
DAILY FIELD DATA SHEET

Dye – Tracing Study
Radford Army Ammunition Plant

TEST: DYE TRACE II
RUN BY: S. Buckley, B. Wallen
DATE: 7/7/94, 7/8/94

Jar ID	AY73 Flour. Charcoal	DY 96 Cotton	Site Code	Location	Pull Gum Drop	Pull All Bugs	Hang Charcoal	Hang Cotton	Rig Gum Drop
				RMP 2 dry		✓	✓	✓	
				RMP 9		✓	✓	✓	
				SMP 1		✓	✓	✓	
				SMP 2		✓	✓	✓	
				SMP 3 charcoal missing		✓	✓	✓	
				SMP 5		✓	✓	✓	
				SMP 6		✓	✓	✓	
				SMP 7		✓	✓	✓	
				SMP 8 out of water		✓	✓	✓	
				SMP 9		✓	✓	✓	
				SMP 10		✓	✓	✓	
				SMP 11 cotton missing		✓	✓	✓	
				SMP 12/13 charcoal missing		✓	✓	✓	
				SMP 14		✓	✓	✓	
				SMP 15 Cotton missing		✓	✓	✓	
				SMP 16		✓	✓	✓	
				SPG 1 dry		✓	✓	✓	
				SPG 2		✓	✓	✓	
				SPG 3		✓	✓	✓	
				SPG 4 cotton missing		✓	✓	✓	
				SPG 5 Cotton missing		✓	✓	✓	
				SPG 6		✓	✓	✓	
				SPG 7		✓	✓	✓	
				WMP 1		✓	✓	✓	
				WMP 2		✓	✓	✓	
				WMP 3		✓	✓	✓	
				WMP 4		✓	✓	✓	

Modified from Alexander and Quinlan, 1992

ADDENDA TO APPENDIX C

FIGURE 3.8
RECORD OF DYE TEST

Radford Army Ammunition Plant

Injection Point: SWMU 17
Tracer: RHODAMINE WT
Amount:

Injection Date: THURS, April 28, 1994
Injection Time: 1045 hrs.
Observer: STEVEN GLENNIE

Detector Location	Date, number of days since dye injection, and results										
	Date	4/27	4/29	4/30	5/1	5/2	5/3	5/4	5/5	6/2	7/7	
	No. Days	0	1	2	3	4	5	6	7	35	70	
RMP 2		–	–	–	–	–	–	–	–	–	–	
RMP 9		–	–	–	–	–	–	–	–	–	–	
SMP 1		–	–	–	–	–	–	–	–	–	–	
SMP 2		–	–	–	–	–	–	–	–	–	–	
SMP 3		–	–	–	–	–	–	–	–	–	L	
SMP 5		–	–	–	–	–	–	–	–	–	–	
SMP 6		–	–	–	–	–	–	–	–	–	–	
SMP 7		–	–	–	–	–	–	–	–	–	–	
SMP 8		–	–	–	–	–	–	–	–	–	–	
SMP 9		–	–	–	–	–	–	–	–	–	–	
SMP 10		–	–	–	–	–	–	–	–	–	–	
SMP 11		–	–	–	–	–	–	–	–	–	–	
SMP 12/13		–	–	–	–	–	–	–	–	–	L	
SMP 14		–	–	–	–	–	–	–	–	–	–	
SMP 15		–	–	L	G	–	–	–	–	–	–	
SMP 16		–	–	–	–	–	–	–	–	–	–	

Modified from Alexander and Quinlan, 1992

LEGEND

–	Negative Result	B	Background
1	Very Weakly Postive	B+	Flourescence Significantly above background
2	Weakly Postive	NR	Not Recovered (because of high water or other reason)
3	Moderately Positive	L	Bug Lost or Stolen
4	Strongly Positive	G	New or Extra Gumdrop
5	Very Strongly Positive	P	Significant Precipitation Event on this day
/	Bugs Not Changed		

REMARKS:

FIGURE 3.8
RECORD OF DYE TEST

Radford Army Ammunition Plant

Injection Point: SWMU 17
Tracer: RHODAMINE WT
Amount:

Injection Date: Thurs, April 28, 1994
Injection Time: 1045
Observer: STEVEN GLENNIE

Detector Location		Date, number of days since dye injection, and results										
	Date	4/27	4/29	4/30	5/1	5/2	5/3	5/4	5/5	6/2	7/7	
	No. Days	0	1	2	3	4	5	6	7	35	70	
SPG 1		–	–	–	–	–	–	–	–	–	–	
SPG 2		–	–	–	–	–	–	–	–	–	–	
SPG 3		–	5	5	5	5	5	5	5	5	5	
SPG 4		–	–	–	–	–	–	–	–	–	–	
SPG 5		–	–	–	–	–	–	–	–	–	–	
SPG 6		–	–	–	–	–	–	–	–	–	–	
SPG 7		–	–	–	–	–	–	–	–	–	–	
WMP 1		–	–	–	–	–	–	–	–	–	–	
WMP 2		–	–	–	–	–	–	–	–	–	–	
WMP 3		–	–	–	–	–	–	–	–	–	–	
WMP 4		–	–	–	–	–	–	–	–	–	–	

Modified from Alexander and Quinlan, 1992

LEGEND

–	Negative Result	B	Background
1	Very Weakly Postive	B+	Flourescence Significantly above background
2	Weakly Postive	NR	Not Recovered (because of high water or other reason)
3	Moderately Positive	L	Bug Lost or Stolen
4	Strongly Positive	G	New or Extra Gumdrop
5	Very Strongly Positive	P	Significant Precipitation Event on this day
/	Bugs Not Changed		

REMARKS:

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FIGURE 3.8
RECORD OF DYE TEST

Radford Army Ammunition Plant

Injection Point: SWMU 17
Tracer: DIRECT YELLOW
Amount:

Injection Date: Thurs, Sept 23, 1993
Injection Time: 1400 hrs
Observer: S. GLENNIE

Detector Location	Date, number of days since dye injection, and results										
Date	4/27	4/29	4/30	5/1	5/2	5/3	5/4	5/5	6/2	7/7	← 1994
No. Days	125	126	127	128	129	130	131	132	160	195	
RMP 2	–	–	–	–	–	–	–	–	–	–	
RMP 9	–	–	–	–	–	–	–	–	–	–	
SMP 1	–	–	–	–	–	–	–	–	2	–	
SMP 2	–	–	–	–	–	–	–	–	–	–	
SMP 3	–	–	–	–	–	–	–	–	–	–	
SMP 5	–	–	–	–	–	–	–	–	–	–	
SMP 6	–	–	–	–	–	–	–	–	–	–	
SMP 7	–	–	–	–	1	1	–	–	–	2	
SMP 8	–	–	–	–	–	L	–	–	–	–	
SMP 9	–	–	–	L	–	–	1	–	–	–	
SMP 10	–	–	–	–	–	–	–	–	–	–	
SMP 11	–	–	–	–	–	–	–	–	–	L	
SMP 12/13	–	–	–	1	–	–	–	–	L	–	
SMP 14	–	–	–	–	–	–	1	–	–	2	
SMP 15	–	–	L	L	–	–	–	–	L	L	
SMP 16	–	–	–	–	–	–	–	–	2	–	

Modified from Alexander and Quinlan, 1992

LEGEND

–	Negative Result	B	Background
1	Very Weakly Postive	B+	Flourescence Significantly above background
2	Weakly Postive	NR	Not Recovered (because of high water or other reason)
3	Moderately Positive	L	Bug Lost or Stolen
4	Strongly Positive	G	New or Extra Gumdrop
5	Very Strongly Positive	P	Significant Precipitation Event on this day
/	Bugs Not Changed		

REMARKS: 1: Faint yellow to yellow/green Fluorescence Around Edge of cotton
2: Faint yellow fluorescent spots throughout cotton
3: Faint yellow Fluorescence throughout cotton

FIGURE 3.8
RECORD OF DYE TEST

Radford Army Ammunition Plant

Injection Point: SWMU 17
Tracer: DIRECT YELLOW
Amount:

Injection Date: Thurs, Sept 23, 1993
Injection Time: 1400 hrs
Observer: S. GLENNIE

Detector Location	Date, number of days since dye injection, and results											
	Date	4/27	4/29	4/30	5/1	5/2	5/3	5/4	5/5	6/2	7/7	1994
	No. Days	125	126	127	128	129	130	131	132	160	195	
SPG 1		–	–	–	–	1	1	–	–	2	–	
SPG 2		–	–	1	–	–	–	–	–	L	–	
SPG 3		–	–	–	–	–	–	–	–	3	–	
SPG 4		–	–	–	–	–	–	–	–	–	L	
SPG 5		–	–	–	1	–	1	–	–	–	L	
SPG 6		–	–	–	–	–	–	–	–	–	–	
SPG 7		–	–	–	–	–	–	–	–	–	–	
WMP 1		–	–	–	–	–	–	–	–	1	–	
WMP 2		–	–	–	–	–	–	–	–	–	–	
WMP 3		–	–	–	–	–	–	–	–	–	–	
WMP 4		–	–	–	–	–	–	–	–	1	–	

Modified from Alexander and Quinlan, 1992

LEGEND

–	Negative Result	B	Background
1	Very Weakly Postive	B+	Flourescence Significantly above background
2	Weakly Postive	NR	Not Recovered (because of high water or other reason)
3	Moderately Positive	L	Bug Lost or Stolen
4	Strongly Positive	G	New or Extra Gumdrop
5	Very Strongly Positive	P	Significant Precipitation Event on this day
/	Bugs Not Changed		

REMARKS: 1: Faint yellow to yellow/green fluorescence around edge of cotton
2: Faint yellow fluorescent spots throughout cotton
3: Faint yellow fluorescence throughout cotton