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Waterways Experiment
Station

Final Report: RCRA Facility Investigation, Phase II Groundwater Release Assessment, SWMU 06/09 Demolition Area, and Phase III Release Characterization, SWMU 07/09 Old Rifle Range, Naval Surface Warfare Center Crane, Indiana

by William L. Murphy, Roy Wade

WES

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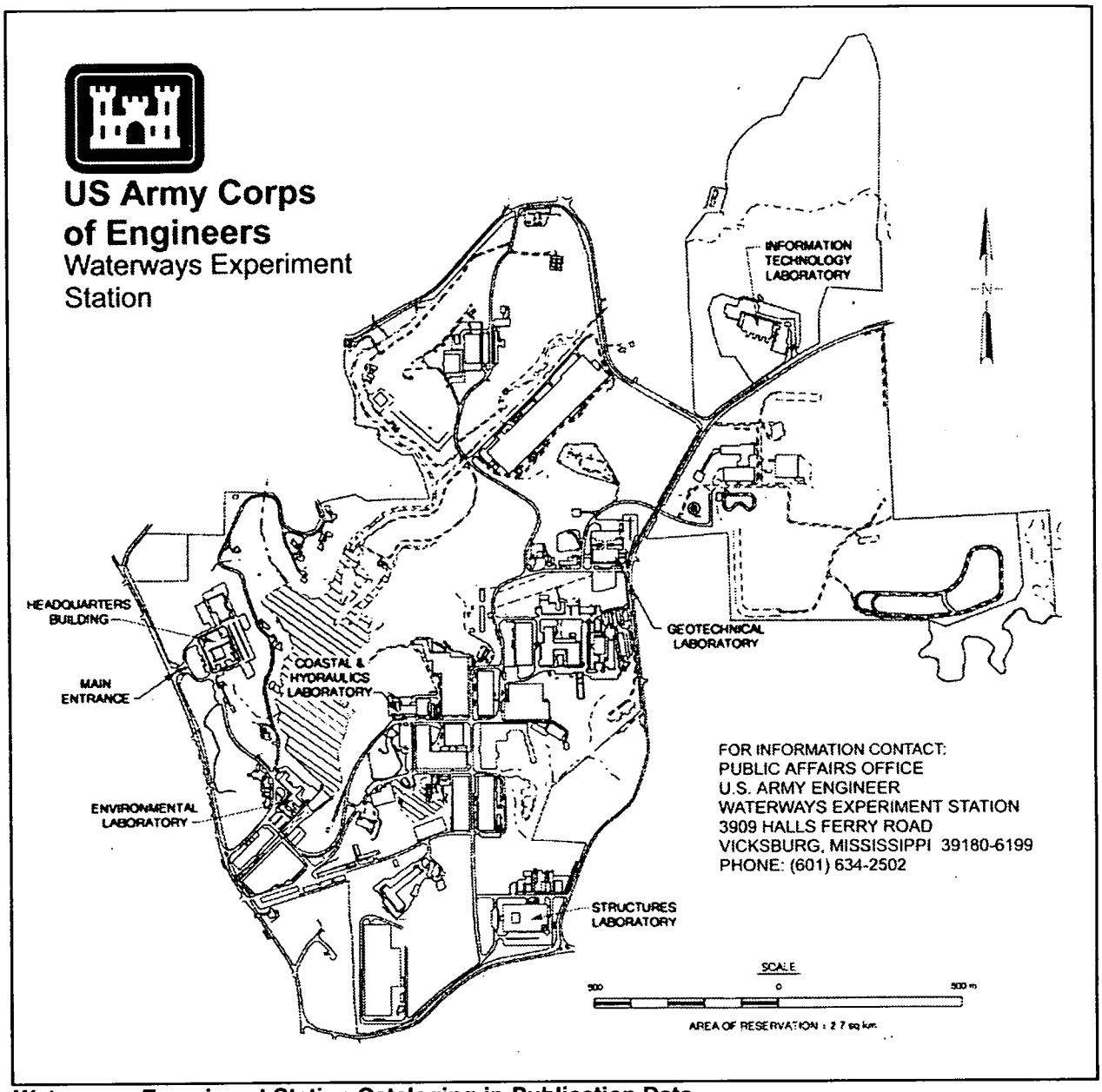

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Preface

This investigation was begun November, 1989 by the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. The Northern Division, Philadelphia, PA, and Southern Division, Charleston, SC, Naval Facilities Engineering Command, provided oversight and management for the Department of the Navy. The work is being performed under authority provided by several Navy Comptroller (NAVCOMPT) documents, funding made available through the Navy's Installation Restoration Program, Defense Environmental Restoration Account.

Much of the geologic field work, including mapping and subsurface exploration by core logging, was performed by Mr. Richard W. Hunt, geologist, Engineering Geology Branch (EGB), Geotechnical Laboratory (GL), WES. Mr. William L. Murphy, GL, provided project management and much of the data analysis. Drilling crews were under the supervision of Mr. Mark Vispi, Chief, In Situ Evaluation Branch, WES. Additional surface geologic mapping was performed by Eric Kvale, Indiana Geological Survey, Indiana University, Bloomington. Mark Barnhill, Indiana Geological Survey, provided additional interpretation of core samples and identification of stratigraphic units. Groundwater quality sampling and data validation were performed by Mr. Roy Wade, Water Supply and Waste Treatment Group, Environmental Laboratory (EL), WES. Chemical analysis of the samples was performed by the Analytical Lab Group, EL, under the direction of Ms. Ann Strong. This report was written by Messrs. Murphy and Wade. Mr. Thomas Brent, Naval Surface Warfare Center Crane (NSWCC), Indiana, Environmental Protection Department, provided logistical and technical assistance. Mr. James Hunsicker was Manager, Environmental Protection Department, NSWCC. Messrs. Jeffrey Ciocco, Byron Brant, and Bill Schrock, Northern Division, and Ms. Adrienne Townsel-Wilson, Southern Division, provided oversight of all Corrective Action work for the Navy.

Dr. William F. Marcuson III was Director, GL, and Dr. John Harrison was Director, EL.

This report is submitted in accordance with the Resource Conservation and Recovery Act (RCRA) Facility Investigation, Phase II Release Assessment Work Plan for Groundwater, Demolition Area, and Phase III Release Characterization Work Plan for Groundwater Old Rifle Range. The

report complies with U. S. Environmental Protection Agency portion of the RCRA Permit for Corrective Action.

Director of WES during the conduct of this study and preparation of the report was Dr. Robert W. Whalin. The Commander was Robin R. Cababa, EN.

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Executive Summary

This report documents the Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI), Phase II Release Assessment for Groundwater, Solid Waste Management Unit (SWMU) 06/09 Demolition Area, and Phase III Release Characterization for Groundwater, SWMU 07/09 Old Rifle Range, at the Naval Surface Warfare Center Crane (NSWCC), Indiana. The investigation was conducted during the period November 1989 to December 1992. Data from earlier investigations were incorporated.

The purpose of the RFIs was to determine the presence or absence, the nature, the rate and extent of migration, and the concentrations of hazardous constituents that may have been released into the groundwater from activities at the Demolition Area and Old Rifle Range. The RFIs fulfill Corrective Action requirements for the two SWMUs established in the RCRA hazardous waste management permit issued to the NSWCC by Region V of the U.S. Environmental Protection Agency in December 1989.

The NSWCC provides materiel, technical, and logistic support to the Navy for equipment, weapons systems, and ordnance. NSWCC is located in southwest Indiana approximately 75 miles southwest of Indianapolis and occupies approximately 100 square miles. It has been in operation since 1941. Certain facility activities, including the Demolition Area and Old Rifle Range, have the potential, primarily from past operations, for releasing contaminants to the groundwater.

The Demolition Area occupies approximately 90 acres atop a ridge in the central portion of the NSWCC. Waste munitions are rendered inoperative by detonation in trenches and pits. The Old Rifle Range occupies approximately 20 acres immediately northeast and downslope of the Demolition Area. The site is used for open burning of explosives in bulk and in loaded projectiles. Both sites have been in operation since the 1940s.

Monitoring of the groundwater for chemical constituents began in 1981 with the installation of monitoring wells at the sites. Twenty-six wells were installed between 1981 and 1983, and an additional thirty-four wells were installed beginning in 1989. Subsurface geological information extracted from logs of the core and other boring samples was used to develop the hydrogeology of the sites. Monitoring wells consisted of polyvinyl chloride (PVC) slotted screens set at depths varying from 19 to 283 ft. Wells have

been sampled by NSWCC semiannually since 1984 for selected contaminants and by WES beginning in 1990 for most Appendix IX constituents and explosives.

Four aquifers or water-bearing zones were monitored at the Demolition Area and Old Rifle Range. The deepest aquifer was in the Big Clifty sandstone and Beech Creek limestone, which are Mississippian units dipping gently to the southwest and which occur consistently beneath much of NSWCC. The deep aquifer was underlain by the Elwren shale aquiclude, which is at least 10 ft thick in the study area. A middle aquifer, of limited extent, was monitored in the Mississippian aged Golconda/Haney limestone. A shallow and poorly defined aquifer was monitored in the Pennsylvanian-aged sandstones atop the ridge at the Demolition Area. A fourth aquifer was monitored at the Old Rifle Range as the uppermost aquifer, which occurred in alluvium and Big Clifty sandstone.

Groundwater flow in the Big Clifty/Beech Creek aquifer is generally to the south and southwest but locally, in the vicinity of the Old Rifle Range, flows to the east toward Turkey Creek, a major north-south flowing stream bordering the Demolition Area and Old Rifle Range on the east. Groundwater in the Golconda/Haney limestone is restricted to the eastern side of the Demolition Area. Flow in the Golconda/Haney is also to the south and southwest with locally southeastward flow near the Old Rifle Range. Groundwater in the shallow aquifer atop the Demolition Area is believed to be confined in perched zones isolated by confining strata of laterally variable lithology.

Metals, cyanides and sulfides, and nitrates and nitrites were detected in significant and verifiable quantities in monitoring wells at the Demolition Area. Certain explosives compounds were found in addition to the above mentioned contaminants at the Old Rifle Range. Organics other than explosives were not present in significant or verifiable quantities in three rounds of sampling and analysis of groundwater from monitoring wells at the Demolition Area and Old Rifle Range.

Conversion Factors, Non-SI to SI Units of Measurement

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

Multiply	By	To Obtain
acres	4,046.873	square meters
feet	0.3048	meters
feet per mile	0.1893935	meters per kilometer
inches	2.54	centimeters
miles (US statute)	1.609347	kilometers

Acronyms and Abbreviations

%D . . . . . percent difference
2,4-DNT 2,4-dinitrotoluene
2,6-DNT 2,6-dinitrotoluene
ANOVA . . . . . analysis of variance
BNA . . . . . base/neutral acid extractable compounds
BFB . . . . . bromofluorobenzene
CAP . . . . . Corrective Action Program
CCV . . . . . continuing calibration verification
CERCLA . . . . . Comprehensive Environmental Response, Compensation and Liability Act
CFR . . . . . Code of Federal Regulations
CL . . . . . clay
CLP . . . . . Contract Lab Program
CMS . . . . . Corrective Measures Study
CRDL . . . . . contract required detection limit
DL . . . . . detection limit
DDD . . . . . dichlorodiphenyldichloroethane
DDE . . . . . dichlorodiphenyldichloroethylene
DDI . . . . . double distilled deionized water
DDT . . . . . dichlorodiphenyltrichloroethane
DFTPP . . . . . decafluorotriphenylphosphine
DOD . . . . . Department of Defense
EL . . . . . Environmental Laboratory
EOD . . . . . Explosive Ordnance Disposal
EPA . . . . . Environmental Protection Agency
GC/MS . . . . . gas chromatograph/mass spectrometer
GL . . . . . Geotechnical Laboratory
GPS . . . . . Global Positioning System
HMX octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine
HSWA . . . . . Hazardous and Solid Waste Amendments
IAS . . . . . Initial Assessment Study
ICP . . . . . inductively coupled plasma
ICV . . . . . initial calibration verification
IDL . . . . . instrumental detection limit
IRP . . . . . Installation Restoration Program
LNAPL . . . . . light nonaqueous phase liquid
MCL . . . . . maximum contaminant limit
MS/MSD . . . . . matrix spike/matrix spike duplicate

NACIP ..... Navy Assessment and Control of Installation Pollutants
NAD ..... North American Datum
NAVCOMPT ..... Navy Comptroller
NBS ..... National Bureau of Standards
NCP ..... National Oil and Hazardous Substances Contingency Plan
NEESA ..... Naval Energy and Environmental Support Activity
NIST ..... National Institute of Standards and Technology
NGVD ..... National Geodetic Vertical Datum
NSWCC ..... Naval Surface Warfare Center Crane
PCB ..... polychlorinated biphenyl
PEP ..... propellants
PVC ..... polyvinyl chloride
QA/QC ..... quality assurance/quality control
RCRA ..... Resource Conservation and Recovery Act
RD/RA ..... Remedial Design/Remedial Action
RDX hexahydro-1,3,5-trinitro-1,3,5-triazine
RFA ..... RCRA Facility Assessment
RFI ..... RCRA Facility Investigation
RI/FS ..... Remedial Investigation/Feasibility Study
RRF ..... relative response factors
RRT ..... relative response time
RSD ..... relative standard deviations
SARA ..... Superfund Amendments and Reauthorization Act
SM ..... silt
SWMU ..... Solid Waste Management Unit
TAL ..... target analyte list
TCL ..... target compound list
TIC ..... tentatively identified compounds
TOC ..... top of casing
TNB 1,3,5-trinitrobenzene
TNT 2,4,6-trinitrotoluene
TSD ..... treatment, storage, or disposal
USAEWES ..... U.S. Army Engineer Waterways Experiment Station
USDA ..... United States Department of Agriculture
USEPA ..... United States Environmental Protection Agency
UXO ..... unexploded ordnance
VOA ..... volatile organic analytes
WES ..... Waterways Experiment Station

1 Introduction

Purpose

This report documents field and laboratory work conducted for the Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI), Phase II Release Assessment for Groundwater, of the Solid Waste Management Unit (SWMU) Demolition Area (SWMU 06/09) and the Phase III Release Characterization for Groundwater, Old Rifle Range (SWMU 07/09), NSWCC Indiana. The two SWMU reports are included in a single document because the SWMUs are contiguous and historically have been investigated jointly. Groundwater investigation borings and wells installed for the RFI provided data applicable to both SWMUs.

The purpose of the RFIs was to determine the presence or absence, the nature, the rate and extent of migration, and the concentrations of hazardous wastes or hazardous constituents released into the groundwater. The Phase II RFI for groundwater characterized the hydrogeology, evaluated groundwater flow patterns, and determined the presence or absence of a release to groundwater at the Demolition Area. The Phase III RFI for groundwater further evaluated groundwater flow patterns, determined the extent of the release to groundwater and the horizontal and vertical distribution of contaminants, and predicted the long term disposition of contaminants at the Old Rifle Range.

Background

The NSWCC is located in southwest Indiana approximately 75 miles southwest of Indianapolis and 71 miles northwest of Louisville, Kentucky (Figure 1). The NSWCC occupies 62,463 acres (approximately 100 square miles) of the northern portion of Martin County and small portions of neighboring Greene, Daviess, and Lawrence Counties. NSWCC provides materiel, technical, and logistic support to the Navy for equipment, weapons systems and expendable and nonexpendable ordnance items. The facility was opened in 1941 as the Naval Ammunition Depot, Burns City to serve as an inland munition production and storage center. The name became Naval Weapons Support Center in 1975 and was changed to Naval Surface Warfare Center in 1992. The Department of Defense (DOD) ammunition

procurement responsibility was transferred to the Army in 1977. The Army has assumed ordnance production, storage, and related responsibilities under the single service management directive. All environmental activities on the installation, including permitting activities, remained the responsibility of the Navy.

A sequence of remedial investigations and remedial actions has been performed at the NSWCC. Investigations began after the initial discovery in early 1981 of a potential hazardous substance release from the Center. The investigations have proceeded since 1981 and continue at the time of this writing. In April 1981 the U.S. Navy implemented the Navy Assessment and Control of Installation Pollutants (NACIP), now known as the Installation Restoration Program (IRP), to identify and control environmental contamination from past use and treatment of hazardous substances at the NSWCC and other Naval facilities. The IRP program is designed to conform to the scope and purposes of the National Oil and Hazardous Substances Contingency Plan (NCP) established by the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980, and amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986.

An Initial Assessment Study (IAS) for the NSWCC began in April 1981 and was completed in May 1983 by the Naval Energy and Environmental Support Agency (NEESA). Assistance was provided by the Ordnance and Environmental Support Agency and the U.S. Army Corps of Engineers Waterways Experiment Station (WES). The IAS recommended site inspections be performed at 14 sites: 9 ordnance sites and 5 non-ordnance sites. The IAS identified the Demolition Area as a site requiring investigation because of past and present munitions treatment operations with the potential to introduce explosive contaminants to the groundwater and to surface water. The Old Rifle Range was included in the area assessed for the Demolition Area because of open burning of explosives that occurred there.

On 19 May 1980, the United States Environmental Protection Agency (USEPA) finalized Phase I of the RCRA hazardous waste regulatory program, which became effective 19 November 1980. By this date the NSWCC had to comply with the codified regulatory sections of the RCRA. In October 1980 the NSWCC filed a RCRA Section 3010 notification and a Part A permit application to operate as a treatment, storage or disposal (TSD) facility. The NSWCC was qualified for and obtained Part A "interim status," which allowed the facility to legally operate as though it had a permit. The Demolition Area and Old Rifle Range then became subject to 40 CFR Part 265 (interim status standards). Part 265 and Parts 260 through 280 are divided into Subparts which address the general operating requirements for hazardous waste management facilities and the technical standards applicable to specific units.

A groundwater monitoring program (confirmation study) began at the NSWCC in 1981. Through a Military Interservice Procurement Request, the Navy contracted the WES to conduct hydrogeologic investigations at ten sites, eight identified in the IAS and two new sites. The work was performed

under authority provided by NAVCOMPT Document Number N00164-IMP-04575, dated June 1981 and amended October 1981. The WES installed monitoring wells from September to December 1981 at the Demolition Area/ Old Rifle Range (both sites identified as Site 06) and provided a report in April 1982 (Dunbar 1982). The Dunbar report was not published, but the text of the report pertaining to the Demolition Area and Old Rifle Range, the accompanying well logs and the well installation diagrams are included as Appendix A of this report (the appendices are to be published under a separate cover). Results of the monitoring program suggested the presence of groundwater contamination at the Demolition Area/Old Rifle Range. Five exploratory borings and three additional monitoring wells were installed at the Old Rifle Range in May and August-September of 1983, respectively, to provide data for the construction of a hazardous waste flashing facility. Results of the 1983 work were reported in Dunbar, 1984, also unpublished and included in this report as Appendix B. Funding was provided by an Order for Work and Services, NAVCOMPT No. N0016483WR0G185, dated May 1983 and amended September 1983.

The Northern Division, Naval Facilities Engineering Command (NORTHDIV), pursuant to the IRP, contracted the Hazardous Materials Technical Center (HMTC) to perform Confirmation Studies at several sites at the NSWCC in November 1984. The ABG was included in the investigation. The Hazardous and Solid Waste Amendments (HSWA) of RCRA (Section 3004) established corrective actions programs (CAP) at TSD facilities. The provision required the NSWCC to address past releases of hazardous waste or hazardous constituents at solid waste management units (SWMUs) and regulated units. The first step of the CAP required the NSWCC to submit a Hazardous Waste Management Report (known as the SWMU report) to the USEPA. The SWMU report listed the ABG and all of the IAS-identified hazardous waste sites as SWMUs, and was submitted to the USEPA in January 1985 (Hazardous Materials Technical Center 1985).

The next step of the CAP, a RCRA Facility Assessment (RFA), was conducted by A. T. Kearney, an USEPA contractor. The contractor conducted a file search of the facility and a site visitation and prepared a report in 1987 which characterized possible releases from 100 SWMUs. On 22 June 1987 the USEPA promulgated amendments to allow the information related to detailed corrective action planning to be developed by USEPA Regional Administrators after the issuance of a RCRA permit through the use of compliance schedules included in the permit (see paragraph 10 for a description of the NSWCC permit).

The WES Geotechnical Laboratory (GL) began RFI Phase II groundwater assessment at the Demolition Area and Phase III groundwater characterization at the Old Rifle Range in November 1989 by installing 18 additional monitoring well clusters (34 wells) at and near the SWMUs. Well sampling and analysis for water quality began in November 1981 for selected compounds and in November 1990 for Appendix IX compounds and explosives. Sampling for selected compounds also has been conducted for NSWCC by contractors under other permitting requirements. The WES Environmental Laboratory (EL) provided groundwater sampling, laboratory analysis and

data validation for the RFI (Appendix IX) work. Continuous sampling (coring) of the deep well boring at each cluster provided subsurface data for a hydrogeological assessment of the area.

A joint RCRA hazardous waste management permit was issued to the U.S. Navy by the USEPA and the State of Indiana on 20 December 1989. The Federal portion of the RCRA Permit established the HSWA Corrective Action Requirements and Compliance Schedules (RCRA Section 3004). A copy of the Permit cover letter is included as Appendix C. The compliance schedules obligated the NSWCC to perform RCRA Facility Investigations (RFI) at 30 SWMUs, and if contamination were found, to conduct Corrective Measures Studies (CMS) and implement Corrective Measures if needed. The State of Indiana obtained pre-HSWA authorization and issued the state portion of the permit which authorized the NSWCC to operate the Central Hazardous Waste Storage Facility, Building No. 2993. The Permit's RFI compliance schedule for the Demolition Area established a submittal date for the Phase II Release Assessment (Groundwater) Work Plan. The Permit established for the Old Rifle Range a submittal date for a Phase III Release Characterization (Groundwater) Work Plan and a Phase II Release Assessment(Soil) Work Plan. The Work Plan for the Phase II Release Assessment for Soil was submitted to USEPA in July 1990 and approved after revision in August 1990. A draft report of the soils investigation was submitted in April 1991 (U.S. Army Corps of Engineers 1991).

The RCRA Section 3004 Corrective Action Requirements of the Permit have incorporated the IRP. RCRA will be the primary vehicle to further investigate and provide remediation of the IRP sites. The NSWCC is also pursuing a USEPA, RCRA operating permit for thermal treatment (open burning/open detonation) of pyrotechnics, explosives, and propellants (PEP) at the following Subpart X units: the ABG, the Demolition Area, and the Old Rifle Range.

Scope

The information and discussion in this report pertain to the facilities known as the Demolition Area and the Old Rifle Range, SWMUs 06/09 and 07/09, respectively, of the NSWCC, Indiana. Field data acquisition methods discussed are applicable to other military facilities requiring similar evaluation and assessment, with modifications to meet specific site and regulatory requirements. Laboratory chemical analysis methods discussed generally followed USEPA protocol for RFIs and are applicable to other RFIs with modification for site-specific requirements.

Operational History and Description of the Demolition Area

The Demolition Area is in the central portion of the NSWCC east of Crane Highway 45 and south of Crane Highway 58 (Figure 2). The restricted zone for the Demolition Area occupies approximately 1,250 acres of Sections 26, 27, 34 and 35 of T5N, R4W of the Indian Springs, Indiana topographic quadrangle (U.S. Geological Survey 1978). The operations area for the Demolition Area occupies a much smaller area (roughly 90 acres) atop a topographic ridge bounded on the west, south and east by major surface streams, Boggs Creek and Turkey Creek (see Plate 1). Figure 3 is a May 1988 aerial photograph of the site. The cleared area at the center of the photograph is the active demolition area. The dark areas are trees. Craters from a recent demolition event are visible in the cleared area. The cleared, bright area jutting to the east (Figure 3) on the ridge top has been used by the Navy Explosive Ordnance Disposal (EOD) Detachment to detonate ordnance (Haliburton NUS 1993).

High-explosives waste munitions have been disposed of by detonation at the Demolition Area since the 1940s. Explosives products included hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), trinitrotoluene (TNT), octahydro-1,3,5,7-tetranitro-1,2,5,7-tetrazocine (HMX) and ammonium picrate. Bundles of explosives are placed in trenches excavated in the bare ground, covered with soil and detonated. As much as 10 tons per day were disposed of at the Demolition Area from 1956 to 1960. Approximately 35 shots per day are fired. The limit per detonation is 500 lb. Unexploded ordnance (UXO) has occasionally been found on site.

The blast zone has been denuded of vegetation (Figure 3), causing enhanced surface runoff during precipitation events. The primary avenues for contamination of groundwater by waste products from the demolition activities were presumed to be direct infiltration (percolation) of leached wastes and transport of waste materials off-site to streams and recharge areas by surface runoff. Four sedimentation ponds have been constructed downslope of the demolition area to intercept and collect most of the runoff. Three ponds are shown on Figure 3. A fourth is in place northeast of the Demolition Area (Plate 2). The ponds have been sampled for solids content and pH.

Water from monitoring wells installed by Dunbar in 1981-82 was sampled quarterly from November 1981 through July 1983 as part of a base-wide confirmation study. Possible groundwater contamination was indicated in the relatively shallow wells at the Demolition Area. Detected contaminants or indicators included certain metals, fluoride, and low (acidic) pH. Explosives were not detected in Demolition Area wells (but were detected in a well at the Old Rifle Range) in the 1981-83 monitoring. Demolition Area wells have been sampled by NSWCC approximately semiannually to the present under contract beginning in 1984 for selected groups of parameters including drinking water quality, groundwater quality, and indicator parameters and selected explosives and organics. An explosive (RDX) was detected in two of the

semiannual sampling events (February 1984 and January 1986) in well 06-08. No explosives have been detected in Demolition Area wells (excluding the Old Rifle Range) in the WES sampling which began in November 1990. Certain metals have been detected in all sampling events to the present.

Seventeen wells were originally installed at the Demolition Area by WES (Dunbar) in 1981. The activities at the site have resulted in the loss or disruption of several wells, and only eight of the original 17 can now be sampled. Wells installed by WES for the RFI work beginning in 1989 have provided additional monitoring. The locations of Demolition Area monitoring wells are shown in Plate 1.

Operational History and Description of the Old Rifle Range

The Old Rifle Range occupies approximately 20 acres (10 active) within the restricted zone of the Demolition Area (see Plate 1 and Figure 2). The site is immediately west of NSWCC Highway 8 in the flat-lying floodplain of Turkey Creek, immediately downslope of the Demolition Area. The site is the roughly rectangular cleared area immediately northeast of the Demolition Area in the aerial photograph of Figure 3. The Old Rifle Range is located in Sections 26 and 35 of T5N, R4W on the Indian Springs, Indiana topographic quadrangle (U.S. Geological Survey 1978).

The Old Rifle Range acquired its name when it served as the Marine rifle range at NSWCC. The site began destruction of explosives by open burning and open detonation in the 1940s and was used for bomb "cook-off" tests. Current operations consist of open burning, or "flashing," of the explosive "Yellow-D" (ammonium picrate, 2,4,6-trinitrophenol ammonium salt) in bulk and in loaded projectiles in three burning pits. Prior to 1986 the burning was conducted on bare ground. Burning is now done in clay-lined steel pans.

Ten monitoring wells were installed at the Old Rifle Range in 1981 and 1983 for the early confirmation work. They were wells 06-14 through 06-23 (see well logs in Appendix A and Appendix B). The locations of the early wells, ten RFI well clusters emplaced by WES in 1990, and an additional RFI well cluster emplaced in 1994, are shown in Figure 4, a map of the Old Rifle Range proper[1]. The wells were screened in the uppermost aquifer, which for the Old Rifle Range is the Big Clifty sandstone and residual, colluvial and alluvial soils overlying the sandstone. Quarterly sampling of the Old Rifle Range wells 06-14A through 06-23 from November 1981 through July 1983 detected nitrates and nitrites in well 06-18 on several events and the explosive

[1] Two additional wells in one cluster, designated 06C19 and 06C19P2, were added in November of 1994. The two additional wells, which have not yet been surveyed, were placed downgradient, east of Highway 8, between the Old Rifle Range and Turkey Creek (see Plate 1 for approximate location).

HMX once in well 06-16. Semi-annual sampling of the wells beginning in 1984 detected certain metals and other inorganics in several wells, the explosives RDX and TNT in well 06-18 on two events, and RDX and TNT once in well 06-22. Wells 06-16, 06-18 and 06-22 are in the center of the Old Rifle Range near the flashing operations. The presence of specific explosives compounds and explosives indicators (nitrates) in the wells was evidence of groundwater contamination resulting from disposal operations at the Old Rifle Range.

An RFI Phase II Release Assessment for Soils was conducted at the Old Rifle Range in July-December 1990 as required by the RCRA permit. Samples from 13 soil borings emplaced within the Old Rifle Range were analyzed for the presence of metals and other inorganics, volatile and semi-volatile organics, and selected explosives. The Draft Report of the soils work (U.S. Army CE 1991), submitted to USEPA in April, 1991, concluded that contamination of soil was limited to the surface soils in the immediate vicinity of the flashing pits by specific explosives compounds. Contamination of the soil by organic compounds could not be confirmed. The presence of metals and other inorganic compounds in the soil at the Old Rifle Range could not confidently be attributed to disposal operations at the site. The report recommended that no further action on soils (i.e., a Phase III study) be taken at the Old Rifle Range.

2 Action Levels

Background

The USEPA's goal in RCRA corrective action is to eliminate significant releases from SWMUs that pose threats to human health and the environment, and to clean up contaminated media to a level consistent with reasonably expected and current uses. Section 264.521 of the Code of Federal Regulations, Title 40 was proposed in the Federal Register, July 27, 1990 to establish the general principles by which action levels would be determined for each medium (Federal Register 1990). Where contamination is identified during the facility investigation, EPA or an authorized State will have to make a decision on whether further analysis is appropriate or whether the contamination is at an insignificant level. The proposed rule incorporates the concept of "action levels" - levels of contamination that will typically trigger a Corrective Measure Study (CMS). The following discussion is an excerpt from the proposed Section 264.521 with particular emphasis on its application to groundwater.

Use of Action Levels

Action levels are health- and environmental-based levels of contamination determined by the EPA to be indicators for protection of human health and the environment. The EPA proposes action levels for hazardous constituents, a subset of hazardous wastes. Where appropriate, action levels are based on promulgated (published) standards (e.g. maximum contaminant levels (MCL) established under the Safe Drinking Water Act). In other cases, action levels are established by the Regional Administrator on the basis of general criteria. Table 1 provides examples of concentrations derived by EPA according to these criteria for some Appendix VIII and IX constituents. Table 2 presents current and proposed MCLs as of April, 1992.

The EPA is proposing the use of action levels because active remediation may not be necessary at all facilities required to perform a remedial investigation. For instance, a remedial investigation may indicate that a suspected release identified in the RFA had, in fact, not occurred, or may indicate that levels of contamination from a past release are unlikely to present a threat to

human health and the environment. Therefore, the EPA believes it should establish a trigger that will indicate the need for a CMS and below which a CMS would not ordinarily be required.

A determination that action levels have been exceeded may occur at any point during the RFI, or may not become evident until the RFI is completed. In either case, when such data become available, the permit schedule of compliance will provide for notification of the permittee that the action levels specified in the schedule have been exceeded. The notification would specify which hazardous constituents exceed action levels, for which media, and when initiation of a CMS is required. It is the EPA's intention that the action level "trigger" approach serves to identify early in the process the need for initiating a CMS. Such studies should typically not be delayed pending completion of all remedial investigation. In many instances it will be appropriate to conduct simultaneously the RFI and CMS for the facility.

Action levels should be distinguished from cleanup standards, which are determined later in the corrective action process. Contamination exceeding action levels indicates a potential threat to human health or the environment which may require further study. Action levels also inform the permittee of the levels below which the EPA is unlikely to require active remediation of releases, and provide a point of reference for suggesting and supporting alternative remedial levels. In some cases, the permittee may rebut the presumption that a CMS is required when action levels are exceeded. For example, the permittee may establish that the contamination is not due to releases from SWMUs at the facility. In other instances, the permittee may demonstrate that a CMS is not required if the release is confined to a Class III aquifer (an aquifer not considered a potential source of drinking water) or to groundwater other than Class III for which the uses do not merit further action. The "rebuttal" of the need for a CMS would generally be made through the process for determination of no further action. Conversely, the fact that no contaminants are found to exceed action levels does not preclude the Regional Administrator from requiring a CMS. A CMS could be required if concentrations below action levels may pose a threat to human health or the environment due to site-specific exposure conditions.

Criteria for Determining Action Levels

In several cases, the EPA has promulgated health-based standards appropriate for action levels for specific media. Where these standards are available, the EPA intends to use them as action levels. The most obvious of these are MCLs. The EPA will use these standards to set action levels for groundwater, and, in some cases, for surface water. Usually, however, promulgated standards will not be available. Nevertheless, health-based levels that have undergone extensive scientific review, but which have not been formally promulgated, are available for many chemicals. Section 264.521 proposes criteria which enable the Regional Administrator to use such non-promulgated health-based levels to derive action levels.

Guidance levels based on carcinogenicity and systemic toxicity are available for many chemicals as presented in Table 1. Classes A, B, and C of Table 1 represent carcinogens (cancer-causing substances); class D represents systemic toxicants (toxic chemicals that cause effects other than cancer or mutations). EPA established these concentrations by an assessment process which evaluated the quality and weight-of-evidence of supporting toxicological, epidemiological, and clinical studies.

Action Levels in Groundwater

Section 264.521 establishes action levels for groundwater in aquifers. By specifying the term "aquifer" in this context, the EPA intends to define broadly the type of groundwater contamination situations that may require a CMS, while triggering such studies only in situations where actual groundwater cleanup is a reasonable remedial approach. The EPA considered using the term "uppermost aquifer" but decided that the use of the term would limit its flexibility in addressing contamination in lower aquifers that are not hydraulically connected with the uppermost aquifer. The wording of the proposed rule will allow the EPA to address any instances where SWMUs have contaminated groundwater that is not in an "uppermost" aquifer.

The MCLs are among the most important of the standards and criteria promulgated by EPA for protection of environmental media. As of April, 1992 there were 82 primary MCLs promulgated for organic and inorganic contaminants (Table 2). Secondary Maximum Contaminant Levels (taste, odor appearance) for inorganics are listed at the bottom of Table 2. Where MCLs are available for a particular constituent but the groundwater at a site is not currently used for a drinking water supply, and is unsuitable for use as a drinking water supply in the future, MCLs will still ordinarily be used as action levels. However, cleanup to the MCL might not be required. In cases where groundwater is contaminated at levels above action levels, further study is necessary to make sure that sources of releases are controlled.

Where MCLs have not been promulgated for hazardous constituents, EPA would develop levels according to criteria described above (Table 1). The EPA would use the standard exposure assumptions of two liters per day for a 70 kg (154 lb) adult over a 70 year lifetime, assumptions that are used extensively throughout EPA and other agencies.

3 Investigation Methods and Rationale

Exploratory Drilling and Well Installation Methods

Monitoring well history and emplacement rationale

The WES installed 23 wells in 1981 in the Demolition Area and Old Rifle Range and three in 1983 at the Old Rifle Range for the Confirmation Study (Dunbar 1982, 1984). Well borings were made with hollow-stem or solid augers in soil and with a 5-5/8 in. outside diameter (O.D.) rock bit or 5-1/2 in. O.D. core barrel in rock. Four well borings were cored (06-02, 06-07, 06-15 and 06-17). The other borings were logged from rock bit drill cuttings. Borings were advanced using air or water to return cuttings. The well string consisted of 2-in., Schedule 40 PVC solid (unslotted) pipe, a 10-ft long section of slotted PVC with 0.020-in. wide slots, a five-foot capped silt trap beneath the slotted screen, and a 3-ft PVC riser above the ground surface fitted with a vented cap. All PVC joints for the confirmation wells were attached using PVC cement. Wells placed in a saturated zone less than 12.5 ft thick were sealed at the bottom using bentonite. Wells placed in rock or in a saturated zone greater than 12.5 ft thick were not sealed, but had filter sand placed around the trap and screen. The annulus (approximately 1-3/4-in.) of all wells was filled with washed filter sand to 2 ft above the top of the screen, then 2 ft of bentonite, and then sealed with cement-bentonite grout to the surface. Well logs and well installation diagrams for all of the confirmation study wells are included in Appendices A and B.

Locations of 18 monitoring well clusters installed by WES in 1989-90 for the RFI groundwater assessment and characterization at the Demolition Area and Old Rifle Range are shown on Plate 1 and for the Rifle Range proper in Figure 4. WES installed an additional cluster (06C19 and 06C19P2) in November 1994 west of Highway 8, between the Old Rifle Range and Turkey Creek. The RFI well numbers are designated by "06" followed by a "C" to distinguish them from the confirmation wells placed in 1981 and 1983. The deepest well (deepest intake screen placement) of a cluster is designated with a "C" followed by the cluster number (for example "06C05"). Progressively shallower wells of the cluster are designated by a "C" followed by the well number followed by "P2" or "P3," "P3" being the

uppermost well of the cluster (for example "06C16P3"). Because of the proximity of wells in a cluster, only the deep well is shown on the location maps.

Most of the clusters consist of paired wells, one deep and one shallow well. Two are 3-well clusters and four are single wells. The first and deepest well of each cluster was logged by a geologist on-site by examination of continuous rock cores retrieved by wireline core barrel. The overburden soil was logged by examination of cuttings from a flight auger. The well locations were surveyed via Global Positioning System (GPS) operated by the Survey Branch of the U.S. Army Engineer District, Louisville. The X, Y (Easting, Northing, respectively) coordinates were reported in Indiana State Plane Coordinates, North American Datum (NAD) 1927, which allowed plotting the well locations on standard USGS topographic quadrangle maps. Elevations of the top of casing (TOC) of each well, including all wells of a cluster, were surveyed to a hundredth of a foot NGVD (National Geodetic Vertical Datum). Table 3 lists available well data for all Demolition Area/ Old Rifle Range wells, including the earlier (1981-83) wells. Table 4 presents the survey data for those wells that could be found.

Well cluster locations were selected to provide sufficient areal coverage to characterize the subsurface hydrogeology at and around the sites and sufficient depth to determine vertical extent of potential contamination. The disruptive nature of the disposal operations, particularly in the detonation zone atop the ridge, prevented emplacement of monitoring wells or exploratory borings in the center of the Demolition Area (several of the original confirmation wells emplaced in 1981 had been lost to subsequent demolition activities). Well clusters 06C01 and 06C08 were sited atop the ridge but all remaining clusters were positioned downslope along the periphery of the site beside the paved roads 333 and 8. After determination of the local groundwater slope from data from wells 06C01 through 06C07, well 06C08 was placed upgradient, north of the active demolition zone, to serve as a background well. Wells were placed in greater density at the Old Rifle Range to provide the amount of data needed for the Phase III groundwater characterization of the site.

The general stratigraphy and hydrologic characteristics of the geologic formations at the site were known from previous investigations at other NSWCC SWMUs. The positions of water-bearing strata (aquifers) at the Demolition Area/Old Rifle Range were confirmed by logging of the boring for the first deep well, 06C01. Decisions on the positions of well screens for monitoring purposes were based on the data from the first well boring and refined with subsequent drilling and logging of other wells.

Drilling and sampling of rock and soil

Well borings were drilled with a Failing 1500 rotary drilling rig. In the first and deepest boring of each cluster, soil overburden was penetrated and sampled to refusal depth (top of rock) using a 7-in. flight auger. Rock was

then drilled and sampled using an HQ wireline core barrel. If the depth to refusal was less than 11 ft (the depth needed to insert the HQ barrel), a 2-ft long NX core barrel, which retrieves a 2-1/8-in. diameter core, was used to sample the rock to the 11-ft depth. The HQ wireline core barrel retrieves a 2-1/2 in. diameter core and produces a 3 25/32 in. diameter borehole. The remaining well borings of the cluster were drilled with a 4-in. O.D. roller rock bit with no samples retrieved (i.e. they were unlogged). The core samples were placed, in order of removal, into plywood boxes for future reference, and detailed geologic logs were prepared. Copies of the field boring logs are presented as Appendix D.

Prior to the start of drilling and between set-ups at each of the boring sites thereafter, the drill rig and drilling tools were steam-cleaned to prevent cross-contamination of monitoring well borings. Drilling was conducted with clean water obtained from the water treatment plant at NSWCC. No other drilling fluids or additives were used. The drill cuttings were removed by circulating clean water in a steel mud pan sealed around the boring top. During drilling operations the mud pan was cleaned and refilled with new water whenever conditions became necessary. In most borings the drilling water was lost in the more porous and jointed aquifer zones. When water loss occurred, the mud pan was replenished with a continuous flow of clean water. Where more than one aquifer zone was penetrated in a particular boring, the upper zone or zones were sealed off before advancing the boring deeper.

PVC casing was grouted 3 to 5 ft into the relatively impervious shale beds that underlie each aquifer and allowed to set overnight. The procedure used in casing the higher aquifers was to set 6-in. diameter casing in the upper zone (8-in. casing in the two deep borings), followed by 4-in. diameter casing in the middle zone (6-in. casing followed by 4-in. casing in deep well 06C08 and 6-in. followed by open hole in 06C01). Each casing was grouted up through the higher, previously set casing. Where there was no upper aquifer, the 6-in. casing was used to seal off surface soils. In all borings where drilling water had been lost in the aquifer zones, the water circulation returned after the casing was set. In most of the borings the circulation was again lost in the next lower aquifer zone.

The drilling for deep well 06C01 typified the procedures for progressive casing and sealing of deep borings that penetrated more than two aquifers (refer to Figure 5). After coring to a depth of 59 ft and penetrating the uppermost water-producing zone, the boring was reamed out to 10-in. diameter with a roller-rock bit. Twenty-five gallons (a depth of approximately 6 ft) of cement-bentonite grout were then tremied into the hole through the drill rods. An 8-in. diameter PVC casing was then set in the hole to 59 ft, bottoming in the grout. Another 25 gal of grout was poured into the hole in the annulus around the casing and allowed to set for 24 hr. Grouting was completed by filling the remaining annulus with grout to the surface. Drilling to the next aquifer then commenced through the hardened grout within the casing.

After completion of each boring a bailer was attached to the drill cable hoist and the drilling fluids were bailed out until the water became relatively

clear. The bailing operation usually lasted 1 to 2 hr using a 2-1/2-in. diameter, 10 ft long stainless steel bailer. In most borings the water flow into the boring was adequate to maintain a regulated steady pace of bailing. In a few borings, the aquifer was tighter (less productive) and there were slight delays in bailing operations to allow the inflow of additional water. After the bailing operations, monitoring well screens and riser pipes were installed in each boring.

The bottom of each deep-well boring extended 5 to 10 ft into the Elwren shale below the Beech Creek limestone, the lowermost aquifer monitored at the Demolition Area/Old Rifle Range. Drilling at least 5 ft into the Elwren shale in all deep wells at the site established that the Elwren was consistently and uniformly present beneath the deep aquifer as a thick aquiclude.

Monitoring well installation procedures

Two-inch diameter PVC pipe was used for the screens and risers of the monitoring wells. The PVC screens have three vertical columns of horizontal slots .020-in. wide and spaced approximately a quarter of an inch apart. The riser pipe extends upward to approximately 2.5 ft above the ground surface. Sediment traps were not placed at the base of the well screen in the RFI wells. In some borings placed in the Beech Creek aquifer, however, the bottom of the boring extended 1 or more feet below the base of the well screen to assure that the Elwren shale was sufficiently thick. The space between the bottom of the boring and the base of the screen was backfilled with bentonite and sand. The top of each well was fitted with a vented PVC cap. The riser pipe was protected at the surface by a 3-in. diameter steel pipe fitted with a locking cap and grouted 3-1/2 ft inside the 4-in. and 6-in. diameter PVC surface casing. Well installations for the 06C01 cluster illustrate the installation procedures for the Demolition Area/Old Rifle Range RFI (see Figure 5).

Three aquifers are shown screened by the 06C01 cluster wells in Figure 5. The Big Clifty-Beech Creek aquifer is screened by well 06C01 from depth 192 ft to 232 ft (40 ft). A forty-foot screened interval was deemed necessary in 06C01 and in the other deep well, 06C08, because it was not clear during drilling and logging of the boring where groundwater was entering the well boring from the formations. It was decided to install a continuous screen through most of the saturated intervals in the Big Clifty-Beech Creek of the two wells to ensure intercepting flow zones. The Big Clifty-Beech Creek in all other wells was screened with 10- or 20-ft screens. A 7-ft plug of bentonite pellets was placed in the bottom of the deep boring for well 06C01 as a precaution because it was not known at this early stage of exploratory drilling how consistently thick the Elwren shale aquiclude was at the study area. Subsequent wells did not require the bentonite plug.

The middle well of the cluster, 06C01P2 (Figure 5) screened a 10-ft section of a sandstone and coal water-producing zone at depth 107 ft to 117 ft in the Pennsylvanian rock. The particular formation or zone screened in each

well of a cluster was specific to the well; i.e. the middle-depth well of a cluster was not necessarily screened in the same formation as the middle-depth well of another cluster. The Golconda formation of well cluster 06C01, normally a water producing, and screened, formation, was dry and showed no potential for producing water in the 06C01 boring and therefore was not screened in 06C01. The uppermost well of the cluster (06C01P3) screened a 10-ft section of a shaley sandstone of the Pennsylvanian.

Once the pipe system was installed in the boring, the screened section and the entire aquifer zone were packed with a siliceous sand filter material (purchased in prepackaged bags and certified free of clay or deleterious materials by seller). The filter material had the following grain size analysis: 2.4 percent retained on the No. 8 sieve, 58.8 percent retained on the No. 10 sieve, 33.8 percent retained on the No. 12 sieve, 5.0 percent retained on the No. 16 sieve with none passing. The analysis corresponds to a USCS well-sorted, medium- to coarse-grained sand, all grains larger than the 0.020 screen slot size. The filter material was poured in from the top slowly by hand and checked for depth periodically with a tape measure. The filter pack was brought up to the next higher shale zone in order to obtain a good seal above the aquifer and to prevent clogging of the aquifer by annular grout. A 3- to 5-ft thickness of bentonite pellets was poured in from the top to secure a seal above the filter pack in each well. The bentonite was allowed to set 30 min to 1 hr for swelling time, and the well was grouted to the surface above the bentonite. The grout consisted of a cement-bentonite mixture and was pumped in from the bottom through a 3/4-in. diameter pipe.

Well development

The procedure for developing the wells consisted of bailing well water, alternating with periods of surging. The surge tool consisted of an 18-in.-long, 1-1/4-in.-diam stainless steel rod with rubber washers attached at each end. The washers were cut slightly smaller than the inside diameter of the well pipe. The surge tool was lowered into the well with 1/8-in.-diam stainless steel cable and pulled briskly up and down in the slotted zone to create a pumping/pushing action. The processes were repeated for several hours in each well or until the water forced out at the top became relatively clear. The same stainless steel cable used for surging was used to lower and raise a 1-1/8-in. diam, 5 ft long stainless steel bailer. To increase speed and efficiency of the bailing operation, a frame was constructed on a small trailer in conjunction with a portable wireline winch to run the tools in and out of the wells. The wells were bailed until the water became clear. The developing tools were flushed with clean water between each well setup.

Water level measurements

The depth to groundwater in all monitored wells was measured by the water-quality sampling crew during each sampling event. Measurement of depth was made by lowering a stainless steel electrical probe attached to a plastic cable marked in increments of feet, tenths and two-hundredths of a

foot. Measurements were made from the lip of the PVC well casing, from the same position on the lip at each measurement period. Water surface elevations were then computed by subtracting the depth to water from the surveyed top-of-casing (TOC) elevation. The water level in the well casing represented the piezometric surface of the water in the aquifer.

Water levels in Demolition Area/Old Rifle Range wells were recorded for May-June 1991, November 1991 and March-April 1992. Water level measurements for all wells for the available sampling periods are presented in Table 5. Water level measurements were used to construct groundwater surface contour maps, which are discussed later in this report.

Groundwater Sampling

Selection of background wells

Demolition Area. Well 06C08, located atop the Demolition Area ridge due north of the active operations zone, was initially selected as the background well for the Big Clifty/Beech Creek aquifer for the Demolition Area. The well is upgradient from the active zone and is relatively free of monitored compounds. Well 06C07 subsequently replaced 06C08 as background well for statistical evaluation of well contaminants. The selection of background for the Demolition Area is discussed further in Part 6 of this report.

Old Rifle Range. Well cluster 06C16, comprised of wells 06C16, 06C16P2 and 06C16P3 was selected as background for qualitative comparisons between wells at the Old Rifle Range. Wells 06C16 and 06C16P2 screen the lower and upper Big Clifty/Beech Creek aquifer, respectively. Well 06C16P3 screens the Golconda/Haney limestone. All three wells are upgradient of the Old Rifle Range Operations area in their respective aquifers and are relatively free of monitored compounds. Well 06C07 was used as background for the statistical evaluations at the Old Rifle Range.

Selection of groundwater contamination parameters

An extensive list of contamination parameters was developed for the RFI work at the two SWMUs from the Appendix IX groundwater monitoring list suggested for RFI Corrective Action under Section 40 Code of Federal Regulations (CFR), Part 264, Standards for Owners and Operators of Hazardous Waste Treatment, Storage and Disposal Facilities (USEPA 1990). The parameter list was amended to include explosives compounds. Five rounds of sampling were originally scheduled for the two SWMUs. After three rounds it was apparent that certain groups of parameters were not present at quantifiable levels. Round four was subsequently reduced in scope through a letter request from Northern Division, NAVFAC to RCRA Permitting Branch, EPA Region V Chicago dated 12 March, 1992 and letter reply dated 27 March, 1992. The fourth round of sampling was limited to metals, cya-

nides and sulfides, and nitrates/nitrites at the Demolition Area and to metals, cyanides and sulfides, nitrates/nitrites, and explosives at the Old Rifle Range. Explosives had been detected regularly in two wells within the Old Rifle Range.

A list of the modified Appendix IX groundwater quality parameters monitored at the Demolition Area and Old Rifle Range and detection limits is provided in Table 6. The sampling history for each well is tabulated in Table 7.

Sampling procedures

Overview. The goal of the groundwater sampling program was to obtain samples representative of the sample matrix. The locations and number of samples were selected to optimize the identification of sources of contaminants and pathways of contaminant migration. External sources to the samples were eliminated through the use of good sampling techniques.

The following sections describe the field sampling procedures followed for groundwater sampling at the Demolition and Old Rifle Range sites.

Groundwater sampling. All groundwater sampling occurred no earlier than 14 days after newly constructed wells were developed. This procedure allowed the natural groundwater system to return to chemical equilibrium.

Field measurements prior to purging. Prior to purging a well, organic vapor measurement of the well headspace was checked using an HNU brand photoionization organic vapor meter. The well headspace was checked to ensure the safety of the sampling personnel and to indicate the presence of light nonaqueous phase liquid (LNAPL) within the well casing. The well was unlocked and the well cap was lifted high enough for the meter's probe to be inserted into the well casing. Upon indication that organic vapor levels were in the permissible range, the well cap was removed. The photoionization meter indicated no volatiles in the well headspace of any of the sampled Demolition Area/Old Rifle Range wells.

The water level and the well depth of each well were taken using a water level indicator incremented in hundredths of a foot (see Appendix E for field measurements of well parameters). The water level measurements were taken by lowering the stainless-steel probe until the unit indicated contact with the piezometric surface. The well depth measurements were taken by lowering the probe to the bottom of the well, measuring from the well bottom to the top of well casing. The difference between the well total depth and water level depth was used to determine the volume of water to be purged. All depth measurements were measured from the top of the well casing, not the protective casing. Depth data were recorded in a field sampling log book. The sampling crew also measured and recorded the pH and electrical conductivity of the water in each well prior to purging and sampling. Field measurements of pH and conductivity for the four sampling rounds are presented in Appendix E.

Purging of groundwater wells. A primary consideration in obtaining a representative groundwater sample was to prevent the inclusion in the sample of stagnant water in the well casing. Since there is little or no mixing of the volume of water above the screened interval, stratification can occur. To ensure representative sampling of the aquifer, parameters such as electrical conductivity, pH, and temperature must be stable. However, stable measurements of these parameters may be difficult and time demanding due to the variety of contaminants present. Therefore, purging of three well volumes was recommended. The purged volume of water was determined by calculating three volumes of water in the well (see Appendix E). The equations used for calculating purged volumes of water in a 2-in. diam well are as follows:

$$A \text{ (cu ft)} = 0.8 \circ d^2 \circ h$$
$$B \text{ (gals)} = A \circ 7.48 \text{ gal/ft}^3$$
$$3 \text{ volumes (gals)} = 3 \circ B$$

where

A = volume of water in well, cu ft
B = volume of water in well, gal
d = diameter of the well, ft
h = height of water in well, ft

After the volume of water to be purged was determined, the water was removed by pumping or bailing depending on the well information obtained from well development or prior sampling activity. If the well recharged rapidly and/or had 20 gal or more of water to be purged, the well water was purged with a pump. If the well had a slow recharge and/or had less than 20 gal of water to be purged, the well water was bailed with a Teflon bailer.

If the well went dry during pumping or bailing, removal of all water that had prolonged contact with the well casing or air was assured. If the well recovery rate was rapid, the well was allowed to recover to its original level and purged a second time before sampling. If the recovery rate was slow (e.g., more than 2 hr), samples were obtained as soon as sufficient water became available.

Sampling of monitoring wells. The sample was obtained immediately after the well was purged. For a slow-recovering well, the sample was collected immediately after a sufficient volume became available. Sampling was accomplished by filling a Teflon bailer lowered into the well with a spool of Teflon coated cable or by immersing a 2-in. submersible pump with flow adjustment, which had effectively obtained samples from wells at other NSWCC SWMUs. The 2-in. submersible pump exterior was made of stainless steel with interior components of Teflon and stainless steel.

Clean plastic sheeting spread around each well helped prevent ground-surface contamination of the sample. Sampling equipment was never placed

on the bare ground or any object that might contribute to ground-surface contamination.

Before sampling of groundwater wells began, equipment rinsates were collected to be analyzed for the monitored contaminants. Rinsates permitted the qualification of analytical results as suspect if equipment contaminant levels were comparable to groundwater contaminant levels.

A minimum of one rinsate was collected for each parameter of interest in the field on each day of sampling. The equipment rinsate was obtained by pouring double distilled deionized (DDI) water through the Teflon bailer. For metals analysis, which required filtering, the rinsate was poured into the filtering apparatus from the Teflon bailer.

Volatile samples were collected first. Extra care was exercised to prevent analyte loss by volatilization. Precautionary measures included avoiding aeration or agitation of the sample, taking care that no air bubbles were trapped in the vial by tapping the vial lightly in the palm of the hand, and never allowing the volatile sample to freeze. If the submersible pump was used, volatile samples were collected at a flow rate of 100 ml/min. Extra care was exercised when pumping to prevent analyte loss by volatilization.

Samples for metals analysis were filtered in the field using a 0.45 micron filter under positive pressure. The metals sample was poured into the filtering apparatus from the Teflon bailer. Samples for organics analysis were not filtered.

After obtaining samples for analysis, a sample was collected for immediate temperature, conductivity, and pH measurements. These measurements were measured and recorded in the field (Appendix E).

The appropriate preservative was added to the collected sample and the container cap was securely fastened. Samples were labeled for facility, well number and date of sampling. The sample bottles were placed in an ice chest immediately after sampling and delivered to the laboratory as soon as possible so that specified holding times were not exceeded.

Equipment decontamination

All equipment used to measure, purge, filter, and sample groundwater wells (e.g., bailers, submersible pump, and water level indicator) were cleaned to prevent cross-contamination between wells. The water level indicator was rinsed thoroughly with distilled water. Equipment used for purging and sampling wells (e.g., the Teflon bailer and/or submersible pump) was decontaminated by rinsing thoroughly with distilled water. Sampling and measuring equipment was scrubbed, if necessary, to remove sediment adhering to it after withdrawal from the well. Filtering equipment was decontaminated and 0.45 micron filters were cleaned with a nitric acid solution and rinsed thoroughly several times with copious amounts of distilled water.

Water used for rinsing field equipment was distilled water from NSWCC or retail merchants. At least one field blank, a sample of the water used for decon, was submitted to the laboratory and analyzed for all analytes of interest per sampling event.

Sample preservation

The purpose of sample preservation was to prevent or retard the degradation/modification of chemicals in samples during transit and storage. Efforts to preserve the integrity of the samples were initiated at the time of sampling and continued until analyses were performed. Preservatives and holding times for the monitored parameters are presented in Table 8.

All water samples were kept cool at 4°C.

Quality control procedures

Field chain-of-custody. A chain-of-custody procedure was used to maintain the integrity of the sample after collection. The samples were locked up when unattended. When the samples were being shipped by parcel delivery (Federal Express), a signed chain-of-custody sheet and seal were placed inside and on the shipping container, respectively. Once the samples reached the analytical laboratory, the samples were signed over to the lab recipient for analysis.

A sample was considered to be in someone's custody if:

a. It was in the person's actual possession.

b. It was in the person's view, immediately after being in the person's possession.

c. It was placed in an ice chest that remained in view, after being in someone's possession.

d. It was placed in a secured area, restricted to authorized personnel only.

Examples of chain-of-custody forms and tags are shown in Figures 6 and 7, respectively.

Sample containers. The sample containers were compatible with the analyte(s) of interest. The following containers were used for all sample matrixes except where noted:

a. Septum-sealed glass vials for volatiles.

b. Amber glass bottles with Teflon-lined lids for Target Compound List (TCL) organics other than volatiles.

c. Polyethylene bottles for Target Analyte List (TAL) metals and other inorganics.

To ensure the integrity of the samples, steps were taken to minimize contamination from the containers in which they were stored. If the analyte(s) were organic, the container was an amber glass bottle. If the analyte(s) were inorganic, the container was a polyethylene bottle. Since organic and inorganic substances were expected to be present, separate samples were taken. Reuse of sample containers was prohibited. Commercially certified cleaned containers were used.

Documentation from the container manufacturer consisted of the results of bottle blank analysis. Quality Control results from the supplier of commercially cleaned containers demonstrated that the bottles were "clean." Validation was provided for each batch or "lot" of bottles cleaned.

Field quality control samples. Although the number of Quality Control (QC) samples varied for each sampling event, the types of field QC (e.g., trip blank, equipment rinsate, field blank, field duplicates, and referee duplicates) remained the same.

Trip blanks were samples that originated from analyte-free water taken from the laboratory to the sampling site and returned to the laboratory with the volatiles organic analytes (VOA) samples. One set of trip blanks accompanied each cooler containing VOAs. Trip blanks were analyzed only for VOAs.

Equipment rinsates were the water rinses from equipment cleaning collected daily during a sampling event. A sampling event was considered to be from the time the sampling personnel arrived at the site until they left for more than one day. The results from the blanks were used to flag or assess the levels of analytes in the samples. The comparison of levels in blanks to levels in samples was made during data validation. The rinsates were analyzed for the same parameters as the samples collected from the wells.

Field blanks consisted of the source water used in decontamination. At a minimum, one field blank from each event and each source of water was collected and analyzed for the same parameters as the well samples.

Field duplicates were collected simultaneously with the water samples at a frequency of one duplicate per 10 samples per matrix.[1] All the duplicates were sent to the primary laboratory responsible for analysis. The same samples used for field duplicates was split by the laboratory and used as the laboratory duplicate or matrix spike. This means that for the duplicate sample, there were analyses of the normal sample, the field duplicate, and the laboratory matrix spike/duplicate.

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[1] The matrix is the suite of all analytes being sampled (metals, VOAs, etc.).

Blind samples were collected simultaneously with the water sample at a frequency of 1 blind sample per 10 samples per matrix, as appropriate. The blind samples were used to check the analytical laboratory accuracy. The analytical laboratory had no knowledge of the identity of the blind samples. Table 9 lists well numbers from which blind samples were collected for the four sampling rounds. Well numbers assigned to blind samples were fictitious (e.g., well 06C14P3 of Round 4, Table 9, did not exist).

Sample coordination. Prior to and during sampling activities, there was coordination between the sampler and the analytical laboratory. The laboratory provided the sampler information on the quantity of sample to collect, preservatives to be used, chain-of-custody sheets and seals, sample containers, and ice chests. The laboratory informed the sampler whether any sample containers containing samples were broken in transit. The sampler informed the laboratory when to expect a shipment, whether any empty glass containers were broken in transit, and any other irregular events that occurred (e.g., limited sample collection, etc.).

4 Hydrogeology of Demolition Area/Old Rifle Range

Technical Approach

The evaluation of the hydrogeology (the surface and subsurface geology and its associated groundwater hydrology) was accomplished primarily by analyzing data from the 36 RFI and the 26 confirmation borings and wells emplaced at the Demolition Area and Old Rifle Range. The lithology, stratigraphy and geologic structure of the study area were defined from the extensive continuous rock core recovered in the deep well of each RFI well cluster and in a few of the confirmation borings, and from well logs of cuttings where core was not taken. Geologic cross sections and contour maps of selected geologic surfaces (structure maps) were constructed from boring data. Groundwater piezometric surface contour maps were constructed from water level measurements taken in the monitoring wells. Additional geologic data was provided by surface mapping of geological contacts by the Indiana State Geological Survey in the spring of 1992.

The confirmation work performed in 1981 through 1984 emplaced relatively shallow borings and wells in or near the operations areas of the Demolition Area and Old Rifle Range. Confirmation borings were generally less than 50 ft deep. The RFI expanded on the earlier effort by exploratory boring through the entire thickness of the Demolition Area ridge, bottoming in the Elwren shale. RFI borings were as deep as 283 ft. The Elwren shale had been shown to be a persistent, thick shale aquiclude at other SWMUs at NSWCC. Borings at the Demolition Area were driven far enough into the Elwren to confirm its presence and thickness. Confirmation of the integrity of the Elwren permitted selecting the Beech Creek limestone, overlying the Elwren, as the deepest aquifer to be monitored at the SWMUs. Several confirmation wells placed in or near the active zone of the Demolition Area had been destroyed or damaged when planning started for the RFI work. The RFI wells were located outside the active zone to prevent their destruction. Well cluster 06C01 was placed atop the ridge to the northeast of the active zone and cluster 06C08 was placed considerably to the north and upgradient to serve as background. Other Demolition area wells were placed below the ridge on the periphery of the site and primarily within the Big Clifty/Beech Creek aquifer because the aquifer was a potential receptor of surface and subsurface waters migrating from the active zone.

The Big Clifty/Beech Creek aquifer is shallow at the Old Rifle Range and is hydraulically continuous with the alluvial (water table) aquifer there. RFI wells were set in the upper and lower portions of the Big Clifty/Beech Creek at the Old Rifle Range throughout (upgradient and downgradient of) the operations area. Well clusters were positioned to provide sufficient areal information to describe the subsurface geology and to monitor potential groundwater flow paths. Well screens were placed in the upper and lower portions of the aquifer to discern segregation or preferential migration routes of groundwater contaminants and to evaluate hydraulic connectivity of the alluvial-upper rock groundwater to the deeper groundwater.

Regional Geology and Hydrogeology

Physiography

The physiographic divisions of the state of Indiana, the limits of Pleistocene glaciation and the location of the NSWCC are shown in Figure 8. The NSWCC lies in an unglaciated area of the Crawford Upland, a rugged, dissected plateau bounded on the east by the Mitchell Plain and on the west by the Wabash Lowland. The Mitchell Plain is a low, dissected limestone plateau characterized by sinkhole topography and other karst features. The boundary between the Crawford Upland and the Mitchell Plain is called the Chester Escarpment, a highly irregular east-facing cuesta. The escarpment trends northwest-southeast and passes just east of the NSWCC. Numerous springs, cavern passages and caves occur along the Chester Escarpment and in the eastern part of the Crawford Upland. Some of these solution features are found in the eastern portion of the NSWCC. The Crawford Upland grades into the Wabash Lowland near the western NSWCC boundary. Elevations on the Crawford Upland at the NSWCC range from less than 500 ft NGVD to greater than 850 ft NGVD. Relief on the upland varies from about 100 ft to 350 ft, with higher elevations and greater relief occurring generally in the eastern part of the NSWCC. Surface drainage in the upland is to the south and southwest.

The surface drainage along major streams in Indiana is shown in Figure 9. With the exception of the extreme northeast corner of Indiana, all the surface drainage is to the southwest and south. Approximately two-thirds of the state drains into the Wabash River which in turn empties into the Ohio River. Surface drainage at the NSWCC eventually flows into the White River and thence to the Wabash to the southwest. The major drainage at the NSWCC is divided into five basins as shown in Figure 10. The Demolition Area/Old Rifle Range site is located in Basin IV near the confluence of Boggs and Turkey Creeks.

Groundwater in the unglaciated southwest portion of Indiana in general is contained in joint openings of limestone and sandstone aquifers. In the area of the Crawford Upland (Figure 8), aquifers are essentially isolated from each other vertically by interlayered shale units which act as aquicludes.

Groundwater enters the aquifers through outcrops and flows by gravity down the dip of the strata or locally in directions controlled by the piezometric gradient.

Regional geologic structure

The state of Indiana and NSWCC lie in the midwestern region of the United States where stresses within the earth's crust have been relatively mild throughout geologic time. The crustal deformation that has occurred has produced structural arches and basins of regional proportions where the sedimentary rocks are gently tilted and faulting has been minimal. The major structural provinces of the region are shown in relation to the state of Indiana in Figure 11. The Kankakee and Cincinnati Arches join and extend diagonally across Indiana from the southeast to the northwest. The combined arches form a structural divide from which sedimentary rocks dip northeast into the Michigan Basin and southwest into the Illinois Basin. The sedimentary rocks were deposited in cyclic seas and coastal plains that fluctuated across the region between 280 and 500 million years ago.

Geologic time periods extending from the Pennsylvanian through the Cambrian (nearly all of the Paleozoic Era) are represented in the sedimentary sequence underlying the region. Total accumulations of the sedimentary rocks range from 3,500 ft thick across the Kankakee and Cincinnati Arches to over 13,000 ft thick near the center of the Illinois Basin. Surface rocks are older and thinner across the arches and become progressively thicker and deeper in the subsurface as the strata dip into the basins. Consequently, the surface rocks become progressively younger in a direction outward from the arches toward the basins. In Indiana, the youngest sedimentary rocks associated with the regional geologic structural features are Pennsylvanian in age. The NSWCC is on the eastern flank of the Illinois Basin where the underlying sedimentary rocks dip west-southwest at approximately 50 ft per mile.

The structure of the geologic formations underlying the NSWCC was described in Hunt (1988) as gently sloping units dipping approximately 50 ft per mile to the west-southwest (striking north-northwest). Recent mapping of the base of the Beech Creek limestone in Martin County by the Indiana Geological Survey (1980, revised 1991) indicates the dip is approximately 30 ft per mile. Figure 12 is a rendition of the northern half of the Indiana Geological Survey map, which includes the NSWCC. The structure contours are on the base of the Beech Creek limestone. Local structural anomalies such as small scale flexures and folds exist.

Two faults or proposed faults have been mapped in the NSWCC general area. The closest mapped major fault, known as the Mt. Carmel fault, trends NW-SE and passes approximately 20 miles east of the NSWCC. A possible fault trending approximately N-S has been mapped in a railroad cut on NSWCC property in Sec 31, T5N, R3W (Ault et al. 1985). The NSWCC fault is inferred from an apparent 30 ft displacement of Mississippian Glen Dean Limestone above strata of the stratigraphically higher Pennsylvanian Mansfield Formation. The inferred fault is approximately 2-1/2 miles east of

the Demolition Area/Old Rifle Range. The Indiana State Geological Survey recently investigated the reported presence of the fault during geologic mapping at NSWCC (Kvale 1992). Kvale reported that the area of the fault has been covered by mass wasting. Geologic units projected toward the reported position of the fault conceivably could have been displaced at least 10 ft by faulting. No other evidence of the fault was found.

Stratigraphy

The surface rocks underlying the NSWCC are in the Lower Pennsylvanian and Upper Mississippian geologic time periods (about 300 to 330 million years old). A generalized stratigraphic column at the NSWCC is presented in Figure 13. Mississippian rocks of the Chester Series are extensively exposed in the valley walls and hollows along the eastern portions of the NSWCC and in the lower zones of deeper valleys toward the west. Pennsylvanian rocks of the Pottsville series cap most of the hills and ridges along the eastern side of the NSWCC and become the predominant surface rocks toward the west boundary of the NSWCC. The stratigraphic units in the Pottsville series consist of interfingered sandstones, shales, claystones and clastic siltstones with occasional, relatively thin interbeds of coal that were deposited in cyclic seas and swamps. The stratigraphic units in the Chester Series consist of alternating and repetitive sequences of limestones, shales, and sandstones that were deposited in shallow seas. Several hundred feet of continuous limestone, Middle Mississippian in age, underlie the Chester rocks but remain in the subsurface at the NSWC. The contact between the Mississippian and the Pennsylvanian rocks is an unconformity where erosional processes operating over a long period of time removed upper portions of the Chester Series prior to Pottsville deposition. Local relief along the unconformity may be as much as 150 ft in some areas.

Hydrogeology of the Study Area

Local physiography

The Demolition Area occupies the crest of a north-south trending topographic ridge bounded on the east by the south-flowing Turkey Creek, on the west by the south-flowing Boggs Creek, and on the south by the confluence of the two creeks (see Plate 2). The ridge is 500 to 1,000 ft wide at its crest and slopes steeply to the east, south and west at approximately a 23 percent grade. Maximum elevation on the ridge crest at the Demolition Area is approximately 685 ft NGVD. The peripheral NSWCC Roads 333 and 8 follow the base of the ridge at an elevation of about 500 ft NGVD. The minimum elevation in Turkey and Boggs Creeks is about 475 ft NGVD. Maximum topographic relief at the site is approximately 210 ft.

The Demolition Area active zone is surface-drained by four gullies, two of which drain to the southwest and two to the east (Plate 1). All four drainage

ways now discharge into sediment retention ponds near the foot of the slope (Plate 2). Other drainages exist farther up the ridge, north of the active zone, but all surface runoff is ultimately to Boggs or Turkey Creeks. Boggs and Turkey Creeks, which are permanent streams, become Boggs Creek at their confluence at the base of the Demolition Area ridge. Boggs Creek flows due south and discharges into the White River approximately 5 miles south of the NSWCC boundary.

The Old Rifle Range extends from the foot of the ridge below the Demolition Area 1,200 to 1,500 ft east to NSWCC Road 8 (Figure 4). Maximum elevation within the Old Rifle Range is about 530 ft NGVD at the base of the ridge and the minimum elevation is about 500 ft NGVD near the road, for a total relief of about 30 ft. The area east of the Old Rifle Range continues to slope to the east toward Turkey Creek, where the minimum elevation is approximately 485 ft NGVD. Mean slope from the west side of the Old Rifle Range to Turkey Creek is about 2 percent. The northern end of the Old Rifle Range is drained by a perennial stream that flows southeast and east into Turkey Creek.

Surface and near-surface geology

The surface exposure (with soil overburden disregarded) of mappable geologic units at the NSWCC was provided in a map constructed by Erik Kvale of the Indiana Geological Survey (Kvale 1992). The map, a portion of which is presented as Plate 3, was constructed from field reconnaissance of outcrops within NSWCC, which included the vicinity of the Demolition Area/Old Rifle Range. Recognizable formation contacts and formation exposures were plotted on the Indian Springs, Indiana 7-1/2 min topographic quadrangle. Four units were mapped, as indicated on Plate 3 and described below.

The Quaternary alluvium is shown by the large cross-hatch pattern. The alluvium is characterized by graded sequences of thin gravels that are typically well rounded and that fine upwards to silty loams. Only alluvial sequences at least 7 ft thick were mapped. The Quaternary sequences generally correspond to the Haymond or Wakeland silt loams of the U.S.D.A soils map for Martin Co.

The unpatterned unit comprising the bulk of the map is the Pennsylvanian Mansfield formation. The Pennsylvanian may be as thick as 220 ft in the NSWCC. A major paleovalley (ancient stream valley) trending north-northeast to south-southwest across the center of the map and beneath the Demolition Area has cut out much of the Mississippian section (Golconda/Haney limestone, Indian Springs shale, and Big Clifty sandstone) and replaced it with Pennsylvanian sandstones and shales. Data from monitoring well borings indicate as much as 100 ft of relief on the paleovalley beneath the Demolition Area.

The diagonally ruled unit corresponds to the interval from the top of the Big Clifty sandstone to the base of the Pennsylvanian. The unit includes the

Indian Springs shale, the Golconda/Haney limestone, the Hardinsburg formation and the Glen Dean limestone. These units were included as one because the contacts between them are not usually discernible in outcrops.

The small cross-hatch unit corresponds to the thick Big Clifty sandstone member. It varies in thickness from about 30 to 40 ft across the NSWCC and forms prominent cliffs in outcrop.

The walls of the valley of Turkey Creek are in Mississippian limestones, sandstones and shales (Plate 3). The valley of Boggs Creek is bordered by Pennsylvanian units. No exposures of Beech Creek limestone were found in the mapped area.

Subsurface geology

The structure, stratigraphy, lithology and hydrologic characteristics of the geologic units underlying the Demolition Area and Old Rifle Range were evaluated and described with data obtained from the 26 original confirmation well borings in 1981-83 and the 34 RFI well borings emplaced in 1989-90.

The geologic units discussed below are described briefly in the stratigraphic column presented in Figure 13. The general stratigraphy (sequence of depositional units) was known from previous hydrogeological investigations at other NSWCC sites. The geologic units encountered at the Demolition Area/Old Rifle Range are, in descending order (youngest and overlying first), the Pennsylvanian Mansfield formation of the Raccoon Creek Group, the unconformity surface separating the Pennsylvanian from the Mississippian units, the Hardinsburg shale, the Golconda/Haney limestone, the Indian Springs shale member of the Big Clifty formation, the Big Clifty sandstone member, the Beech Creek limestone and the Elwren shale. The Elwren shale was the deepest geologic unit encountered for the investigation. Not all of the units were encountered in every boring. For example, well 06C03, situated at the base of the ridge, encountered only Golconda/Haney and deeper units, because the higher formations have been removed by erosion. Well 06C01, atop the ridge, encountered all of the above-mentioned geologic units.

Local stratigraphic units. The geologic formations encountered by borings in the study area are described in the following paragraphs, with younger units first.

a. *Mansfield formation (Pennsylvanian Raccoon Creek Group)*. The Mansfield formation comprises most of the ridge on which the Demolition Area is situated, attaining a maximum bored thickness of 220 ft in well boring 06C08. The formation was absent in the Old Rifle Range. The Mansfield consisted of alternating beds or lenses of fine to medium-grained, cross-bedded, friable sandstones; shaly sandstone to sandy shale; thinly bedded to laminated, fissile to blocky shale; thinly bedded carbonaceous shale; claystone or clayshale; and thin (1 to 2 ft)

coal seams. Well screens were emplaced in certain sandstone and coal units of the Mansfield for monitoring as aquifers beneath the Demolition Area.

b. *Hardinsburg shale formation (Mississippian Stephensport Group).* The Hardinsburg shale occurred in only one boring, 06C01, at elevation 126 to 130 ft, immediately below the Pennsylvanian-Mississippian unconformity. It was absent by erosion in all other borings. The formation consisted of green, very hard shale.

c. *Golconda/Haney limestone formation (Stephensport Group).* The Golconda/Haney limestone was encountered in several borings at the Demolition Area/Old Rifle Range. Maximum bored thickness was 32 ft in 06C01. The base of the formation was above 482 ft NGVD in all borings emplaced for the Demolition Area/Old Rifle Range study. The Golconda/Haney variably was a fossiliferous, dark green to brown shaley limestone; green-brown hard crystalline limestone; or, more rarely, beds of limey shale. The site geologist noted solution zones up to 1/2 ft thick in the Golconda/Haney in two borings (06C03 and 06C04), in both of which the formation was near the ground surface (shallow) and was weathered. The Golconda/Haney was screened as an aquifer in three RFI wells (06C03, 06C04 and 06C16P3) at the foot of the Demolition Area ridge, on the east side, and in confirmation well 06-21, slightly upslope and west of the Old Rifle Range. The Golconda/Haney was dry in other well borings in which it was encountered. The boring log for well 06C01 noted that the formation displayed negligible porosity (no jointing or other openings) and did not lose the drilling water even after standing overnight.

d. *Indian Springs shale member, Big Clifty formation (Stephensport Group).* The Indian Springs shale was encountered in many of the RFI borings drilled for the Demolition Area/Old Rifle Range study. Bored thickness ranged from 1.6 ft in 06C01 to 16.1 ft in 06C04. The unit was absent by erosion or by unconformity in several wells. The 1.6 ft thickness in boring 06C01 was a depositional thinning of the unit, not a result of the unconformity or erosion. The Indian Springs was an olive green to gray, hard, fissile shale to massive claystone with occasional softer zones.

e. *Big Clifty sandstone member, Big Clifty formation (Stephensport Group).* The Big Clifty sandstone was encountered in all RFI deep borings except 06C06 and 06C07, west of the Demolition Area where it was absent because of the unconformity. The unit was uniformly about 40 ft thick throughout the study area. It was a tan to green-gray, massive to thick-bedded, rippled, fine to very fine-grained, well sorted, rounded, friable sandstone with occasional shaly partings. Boring log information indicated that jointing in the Big Clifty was sparse in some borings to numerous in others. Numerous joints noted in two wells were interpreted to be drilling-induced breaks along incipient parting planes. The Big Clifty produced water from several zones and was screened at various depths for monitoring.

f. Beech Creek limestone formation (Stephensport Group). The Beech Creek limestone was encountered in all RFI deep borings. The unit was typically 17 ft thick in the Demolition Area/Old Rifle Range study area, but the thickness ranged from 15 ft in 06C08 and 06C09 to 22-1/2 ft in 06C07. The Beech Creek consisted of fossiliferous, hard, dense limestone. The upper 5 to 10 ft were gray to gray-brown, crystalline limestone with occasional stylolites. The lower portion was dark gray, crystalline limestone with occasional to numerous shaly partings. Joints in the limestone were sparse to numerous in core recovered from the 18 well borings penetrating the Beech Creek. Drilling water loss through the formation was greatest in borings at the Old Rifle Range, where the Beech Creek is shallow (see Figure 4). Borings 06C12, 06C14, 06C15 and 06C17 each had an open joint, up to 0.2 ft wide, within 3 ft of the top of the Beech Creek, near the contact with the overlying Big Clifty sandstone. Considerable water loss occurred through the open joints. Those borings also exhibited numerous other joints in the Beech Creek. The Beech Creek displayed moderate to extensive solution-enlarged jointing at another site within NSWCC (see Hunt 1989). At the Demolition Area/Old Rifle Range, however, the only solution feature noted was in the open joints in two of the four borings listed above. Apparently, the Beech Creek was sufficiently below the level of incision by surface streams that extensive solution of open joints had not occurred in the study area.

g. Elwren shale (West Baden Group). The Elwren shale was encountered in all of the deep borings of the 18 well clusters emplaced for the Demolition Area/Old Rifle Range RFI. The Elwren was a hard, dark green to occasionally red-mottled, occasionally fissile shale. Slickensides were evident in some borings. Occasional sandy partings occurred in some borings. The maximum depth penetrated in the Elwren shale was 10 ft in boring 06C01.

Aquifer assignments for Demolition Area/Old Rifle Range wells are presented in Table 10.

Geologic structure in the study area. Figure 12 presented the structural contour map of the top of the Elwren shale at NSWCC. The base of the Beech Creek limestone (top of the Elwren shale) was contoured for the Demolition Area/Old Rifle Range study area using elevations from the logs of all borings penetrating the Elwren shale. Figure 14 presents the structure contour map. Elevation contours were plotted on a five-foot interval. The regionally dominant southwest dip is preserved in the local contours with the highest elevations in the northeast corner of the map (top of Elwren is 463 ft in 06C14). A local anomaly is evident, however, as a saddle-shaped ridge trending northeast-southwest. The saddle structure produces local anomalous dips of geologic units to the northwest and southeast beneath the Demolition Area. The contour map is somewhat biased because of a lack of geologic information in the center of the mapped area, where no borings could be emplaced because of active demolition activities. The map represents a computer-drawn, gridding algorithm interpretation of available data. The

structural anomaly at the Demolition Area is also evident on the regional structure map presented in Figure 12.

Geologic cross-sections. Several geologic cross-sections were constructed using graphic boring logs prepared for the Demolition Area/Old Rifle Range. Most of the boring data were from the RFI cored borings emplaced after 1989. Data from the earlier, predominantly uncored, confirmation borings were used in a few instances to augment the cross-section construction. Two sets of cross sections were constructed: sections A-A through F-F (Plates 4 through 9) for the Demolition Area and sections G-G through M-M Plates 10 through 12) for the Old Rifle Range. The locations of cross sections A-A through F-F are shown in Figure 15. The locations of cross sections G-G through M-M are shown in Figure 16. The sections were constructed with a vertical enhancement of ten to one for the Demolition Area and five to one for the Old Rifle Range. The sections display the projected formation contacts between borings for the Mississippian units, the projection of the unconformity contact between Mississippian and Pennsylvanian units, and the lithologic contacts in borings penetrating the Pennsylvanian units. Other information provided on the sections includes the positions of well screens, positions of groundwater levels for each screened interval, interpolated piezometric surface for selected aquifers, and pertinent geologic or hydrologic features. Contacts of Mississippian units were projected between borings confidently because of the relatively uniform stratigraphy of the Mississippian formations. The Pennsylvanian units vary considerably laterally and were projected only short distances from the borings, if at all. Appropriate cross sections are referred to in the following discussion of the geology of the Demolition Area and Old Rifle Range.

Geology of the Demolition Area

The active zone of the Demolition Area is underlain by 0 to 9 ft of sandy clay (CL) or silt (SM) as characterized in the 13 confirmation borings and one RFI cored boring emplaced in or near the active the zone (see Plate 1). Bare rock is at the surface near the eastern side of the active zone and at the edge of the ridge. The rock underlying the active demolition area is sandstone and shale of the Pennsylvanian Mansfield formation. Geologic cross-sections A-A (Plate 4) and A-AA (Plate 5) portray the subsurface between ridge-top boring 06C08 and borings in the Old Rifle Range to the east and southeast. The 220-ft thick sequence of Pennsylvanian sediments and the position of the Pennsylvanian-Mississippian unconformity beneath the ridge are evident in borings 06C08 and 06-21. The abundance of shale units, as much as 55 ft thick, beneath the ridge inhibits vertical infiltration of surface contaminants to the Mississippian aquifers at depth.

Sections B-B (Plate 6) and C-C (Plate 7) cut the north and south portions, respectively, of the Demolition Area active zone (see Figure 15). Section D-D (Plate 7) cuts the south end of the ridge. The entire ridge is underlain by Pennsylvanian sandstones and shales because the Pennsylvanian paleovalley has cut out the underlying Mississippian units. The sections illustrate the relative uniformity and continuity of the Mississippian sequence.

Sections E-E (Plate 8) and F-F (Plate 9) cut north-south along the west and east sides, respectively, of the Demolition Area. Section F-F extends north through the eastern side of the Old Rifle Range. Note that the Mississippian aquifers, the Big Clifty sandstone and the Beech Creek limestone, are exposed to surface infiltration in the valley of Turkey Creek north of boring 06C10. The section beneath the Old Rifle Range is presented in more detail below.

Sections A-A through F-F reflect the existence of the saddle structure beneath the Demolition Area. Components of dip vary considerably from section to section. The general, regional trend of south to southwest dip is preserved somewhat in section F-F.

The Big Clifty sandstone/Beech Creek limestone aquifer underlies most of the study area and is the most extensive monitored aquifer present. The thickness of the aquifer penetrated by exploration borings 06C01 through 06C18 is shown by the isochore (drilled thickness) map of Figure 17. The contours are in feet of vertically drilled thickness of the combined Big Clifty sandstone and Beech Creek formations (base of Beech Creek to top of Big Clifty sandstone). The decreasing thickness at the upper right of the figure reflects surface erosion by the modern and ancestral Turkey Creek. The decreasing thickness on the left (west) reflects the increasing depth to the Pennsylvanian erosional surface (the unconformity) to the west. On the west side, the Pennsylvanian thickness increases at the expense of the underlying Mississippian formations.

The Golconda/Haney limestone formation produces water as an aquifer in much of the Demolition Area study area. Its position in the subsurface beneath the study area is illustrated in Figure 18. The Golconda/Haney's position was plotted by projecting the base of the formation along dip from borings to the nearest erosional surface, either the ground surface or the buried Pennsylvanian-Mississippian unconformity. The shaded area of Figure 16 implies that the Golconda/Haney would be encountered in sufficiently deep borings placed within the shading. The Golconda/Haney is projected not to exist outside the shaded area (bounded by the heavy solid line in Figure 18), having been removed by erosion.

Geology of the Old Rifle Range

The subsurface of the Old Rifle Range is characterized by a greater and more variable thickness of soil than that of the Demolition Area active zone. A mixture of colluvial (slope debris), alluvial (stream-deposited) and residual soils typify the section. Soils range in thickness from less than 2 ft at the northwest corner of the Old Rifle Range to about 28 ft along the eastern boundary (near NSWCC Highway 8). Rock underlying the soil is Mississippian, predominantly Big Clifty sandstone.

A contour map showing the distribution of the thickness of soil in the Old Rifle Range is presented in Figure 19. The contour values represent

thickness of soil, which is also the depth from the ground surface to the top of rock. Contours on the top of rock (elevations in feet NGVD) are shown in Figure 20. Data for the two maps were obtained from logs of monitoring well borings and soil borings emplaced for the soil RFI. The thicker soils east of the dashed line of Figure 19 were interpreted to be alluvial deposits of the ancestral channel of Turkey Creek. The alluvial soils are clays, sands and gravels with the coarser deposits near the base of the soil column. The thick soil area west of the dashed line of Figure 19 was interpreted to be colluvial soils derived by mass wasting of the slopes above the Old Rifle Range to the west. The thick colluvial soils correspond to the deep top-of-rock anomaly west of boring 06C09 in Figure 20. The area resembles a region of slope failure that might have been caused by erosion of the toe of the slope by lateral cutting of the ancestral Turkey Creek channel. The soil and top-of-rock maps are presented because the presence of thick permeable soils affects the movement of surface and groundwater within the Old Rifle Range. Soils are discussed further with the presentation of geologic cross sections below.

Geologic cross sections G-G through M-M (Plates 10 through 12) provide information on the soils, rock and hydrogeologic features beneath the Old Rifle Range. The locations of the cross sections were shown in Figure 16. Sections G-G, H-H and J-J run roughly east-west; sections K-K through M-M run roughly north-south through the area. The six sections show the relatively flat-lying, uniformly thick, continuous Mississippian units beneath the Old Rifle Range. The Big Clifty sandstone underlies the active area (the area with flashing operations, see Section L-L and Figure 4). The Beech Creek limestone is beneath the Big Clifty and is within 12 ft of the base of the soil in boring 06C13 (Section H-H). The Indian Springs shale and Golconda/Haney limestone underlie the western slopes of the Old Rifle Range but are absent by erosion generally east of the position of Section L-L. Figure 21 shows the eastern subcrop extent of the Indian Springs and Golconda/Haney at the Old Rifle Range, as plotted on the top-of-rock contour map. Over most of the Old Rifle Range, the Big Clifty-Beech Creek aquifer is open to direct infiltration of surface water penetrating the soil cover.

The base of the uppermost oxidation zone within the Big Clifty sandstone is shown by "xxxx" on the cross sections (for example see boring log 06C17, Section H-H, Plate 10). The geologist logging the core at the drill site noted, when possible, the depth at which the rock ceased to show signs of oxidation (such as prominent limonite[1] staining). The position of the base of oxidation is interpreted to be the deepest historical position of the water table, or aeration.

The Big Clifty and Beech Creek formations beneath the Old Rifle Range were noted to contain more open fractures (joints or bedding planes) than the same formations elsewhere in the Demolition Area/Old Rifle Range study area. All nine core borings emplaced for the Old Rifle Range assessment

[1] Limonite (primarily the mineral goethite) is an oxide of iron formed by oxidation (weathering) of iron-bearing sediment or rock.

recorded many low-angle and some high-angle joints. The abundant low-angle joints are probably bedding plane relief joints caused by unloading of the rock by erosional processes in the Turkey Creek system. A recurrent open discontinuity or fracture zone with accompanying loss of water return during drilling occurred at or near the top of the Beech Creek limestone in five of the nine cored borings. The presence of the open fractures can be expected to make the formations more transmissive of groundwater.

Groundwater hydrology of the Demolition Area

Aquifers and aquicludes. Wells were installed in three Mississippian formations and the Pennsylvanian Mansfield formation to monitor water quality and groundwater flow at the Demolition Area. The Big Clifty sandstone and Beech Creek limestone were treated as a single aquifer, a practice established at other SWMUs at NSWCC in previous RFI investigations. The Big Clifty and Beech Creek represented the deepest aquifer monitored for the study. Forty-foot screens were placed in the deep wells 06C01 and 06C08, for reasons discussed above (see Part II). Ten and twenty-foot screens were placed in other Big Clifty-Beech Creek wells. An upper and a lower interval in the aquifer were screened in some well clusters, especially northeast of the Demolition Area in the vicinity of the Old Rifle Range. The underlying Elwren shale was determined during the drilling program to be consistently at least five feet thick. The probable total thickness of the Elwren shale is 16 to 20 ft, based on information from borings penetrating the Elwren at the Ammunition Burning Ground east of the Demolition Area. The Elwren thus provides ample retardation of infiltration of groundwater to deeper aquifers.

The Mississippian Golconda/Haney formation, a limestone and limey shale in the Demolition Area study area, was monitored with wells in four borings, 06C03P2 and 06C04P2, both at the foot of the ridge southeast of the Demolition Area, 06C16P3 at the northwest end of the Old Rifle Range (also monitored for the Demolition Area) and confirmation well 06-21 in the slope west of the Old Rifle Range. The greatest thickness of Golconda/Haney penetrated in the study area was 31 ft in deep boring 06C01 (see Section F-F, Plate 9). However, no well was installed there because there were no indications that the formation was producing water or that there was any usable porosity present (see remarks column of page 9 of the drilling log for boring 06C01 in Appendix D).

The Golconda/Haney is separated from the underlying Big Clifty sandstone by the Indian Springs shale, a persistent but variably thick aquiclude. The Indian springs increases from a few feet thick in borings on the north end of the Demolition area to 16 ft thick in borings 06C04 and 06C05 on the south. A 6 to 9 ft head difference between cluster wells in the Golconda/Haney and Big Clifty indicates the Indian Springs shale provides hydraulic separation.

Wells were installed in sandstones at several intervals or depths in the Pennsylvanian Mansfield formation. Of the RFI (1989-90) wells, 06C01P2,

06C01P3, 06C08P2, and 06C06P2 screened the Pennsylvanian. The earlier confirmation borings 06-01 through 06-13 screened the Pennsylvanian. Because the Pennsylvanian sediments are so difficult to map (correlate) in the subsurface, monitoring of the Pennsylvanian is at best random. It is unlikely that bodies of groundwater in the sediments persist for more than a few hundred feet areally because of the likelihood of encountering occluding shales within that distance. Estimates of hydraulic conductivity of two samples of a cross-bedded sandstone recovered at depths of 25 and 45 ft from core boring 06C08 were made from laboratory gas permeability tests performed on the two samples (Fisher 1994). Values of hydraulic conductivity for the two samples were 4.97×10^{-5} and 1.8×10^{-4} cm/sec, respectively, with corresponding porosities of 23 and 24 percent, respectively. These values indicate poor Darcian conductivity. Groundwater movement is less likely to occur within and from the Pennsylvanian sediments than in the more uniform and persistent Mississippian aquifers. The Pennsylvanian contact with the underlying Mississippian is "daylighted" (intercepts the ground surface) on the east and south flank of the Demolition Area ridge, and consequently would discharge any migrating groundwaters to the surface. The Mississippian-Pennsylvanian contact is buried (i.e., not exposed) on the west side of the ridge (see Plate 3). Any migration of contaminated Pennsylvanian groundwaters to the west would be more likely than eastward-moving water to escape detection by the monitoring program.

Hydraulic characteristics. Groundwater transmission through the limestone aquifers (Beech Creek and Golconda/Haney) is through systems of connected joints. Flow within the Big Clifty sandstone is believed to be both through joints (secondary porosity) and through intergranular pores (primary porosity). It was not possible to isolate specific joints or zones of groundwater flow in the Big Clifty-Beech Creek aquifer. Long screens were necessary in some wells to assure intercepting all flow zones.

A simple, non-rigorous laboratory test was performed on an unjointed section of sandstone core from the Big Clifty formation of well boring 06C01 to verify that there was effective porosity (intergranular permeability) in the sandstone. Two pieces of the core were weighed air-dry, submerged in water under equal heads for two days, and then weighed wet. The difference in weight in grams, representing the weight (and volume in cc) of water absorbed by the rock, was divided by the volume of each piece to yield an estimate of the effective porosity of the rock. A value of 18 percent effective porosity was obtained for both samples of the sandstone. Effective porosity is a measure of specific yield of an aquifer and is also called the drainable porosity or the percentage of interconnected pore space. The Big Clifty likely can yield groundwater even where it is not particularly well-jointed.

Groundwater flow patterns. Groundwater flow patterns could be described only for the two Mississippian aquifers, the Golconda/Haney and the Big Clifty-Beech Creek system. Groundwater zones in the Pennsylvanian rock were not sufficiently uniform nor persistent to permit mapping of the piezometric surface. The piezometric profiles for the two aquifers are plotted on the geologic sections of Plates 4 through 9. Contours of the piezometric surface (groundwater elevations) of the Big Clifty-Beech Creek and

Golconda/Haney aquifers were plotted for two dates of well readings. Figures 22 and 23 are water level contour maps of the Big Clifty-Beech Creek aquifer in the Demolition Area study area for May/June and November 1991, respectively. Water levels in the wells decreased by about 5 ft between the two measurement periods, but the overall shape of the piezometric surface was unchanged. Groundwater levels are highest in the north and decrease to the south. Flow in the Big Clifty-Beech Creek is generally to the south and southwest, but locally flows southeast toward Turkey Creek near the Old Rifle Range at the upper right of the map. The hydraulic gradient from the vicinity of wells 06C01 and 06C08 to well 06C05 to the southwest averaged 0.002 or about 10 ft/mile. Locally the gradient was as high as 0.004 (21 ft/mile). The shape of the piezometric surface in the northeast corner of the map is distorted from the regional trend. The distortion is caused by drainage of the Big Clifty-Beech Creek aquifer through that portion of the aquifer that is exposed to near-surface flow through the alluvial soils at the Old Rifle Range. Flow through the Old Rifle Range is discussed further, below.

The piezometric surface of the Big Clifty-Beech Creek aquifer was above the top of the Big Clifty (within the overlying shale) beneath most of the Demolition area, indicating the aquifer was in a confined flow condition (see Plates 4, 7, 8 and 9). Northeast and below the Demolition Area, however, the piezometric surface was below the top of the aquifer and the aquifer became unconfined as it drained toward Turkey Creek through the more permeable soil and rock beneath the Old Rifle Range. In its unconfined state the aquifer is a water-table aquifer.

The Golconda/Haney limestone was unconfined in all wells placed in it. The Golconda/Haney is "daylighted" in most of the study area and is allowed to free-drain, resulting in the unconfined condition. Water levels in the Golconda/Haney aquifer were also plotted for May-June and November of 1991. There were only about 0.5 to 2.5 ft of fall in water levels between the two dates, however, and the corresponding piezometric surface contour maps showed little variation from one date to the other. Only the map for May-June, 1991 is shown (Figure 24). There were only four data points (wells) with which to plot the surface, with all of the points on the east side of the Demolition Area. The direction of groundwater flow in the Golconda/Haney is similar to that in the Big Clifty-Beech Creek: south and southwest with local southeastward flow in the vicinity of the Old Rifle Range (the upper right quadrant of the map in Figure 24). The hydraulic gradient to the southwest across the central portion of the map is 0.012, or about 63 ft/mile.

The distribution of well-screened intervals in the Pennsylvanian rocks was insufficient to permit mapping of the piezometric surface(s).

Potential groundwater receptors. Potential receptors of contaminated groundwaters originating at the Demolition Area include the Big Clifty-Beech Creek aquifer, the Golconda/Haney limestone aquifer, water-bearing units of the Pennsylvanian sediments, the alluvial/rock water table aquifer in the valleys of Turkey and Boggs Creeks, the surface waters of Turkey and Boggs creeks, and the sedimentation ponds at the foot of the ridge below the Demo-

lition Area. The Big Clifty and Beech Creek formations extend in all directions away from the Demolition Area. Much of the Big Clifty has been removed by erosion, and the formation "daylighted," by Turkey Creek to the east of the Demolition Area (see east side of section A-A, Plate 4). South, north and west of the Demolition Area, however, the Big Clifty and Beech Creek are intact and can transport groundwater from beneath the ridge for an undetermined distance down-gradient (see section D-D, Plate 7). Monitoring wells 06C03, 06C04, 06C05, 06C06 and 06C07 were placed to detect contaminants migrating away from the Demolition Area.

The distribution of alluvial sediments in the valleys of Turkey and Boggs Creeks is shown in Plate 3 (large cross-hatch). The water table aquifer of the valleys is presumed to be at about the position of the water in the permanent streams that flow within the valleys. No monitoring wells were installed in the alluvial aquifer for this study except those in the Old Rifle Range on the west side of the alluvial valley of Turkey Creek (see sections F-F, Plate 9 and A-A, Plate 4, well 06C13). On the Boggs Creek, or west, side of the ridge the stream valley is in Pennsylvanian rocks (see sections B-B, Plate 6 and C-C, Plate 7). Near the south end of the ridge, the valley is probably in, and the stream flows on, the Indian Springs shale (see section D-D, Plate 7). The alluvial groundwater west of the ridge is subject to contact with groundwater issuing from the Pennsylvanian and Golconda-Haney aquifers, but probably not with groundwater from the Big Clifty-Beech Creek aquifer.

East of the ridge, the valley of Turkey Creek is in Big Clifty sandstone from north of the Demolition Area to approximately just south of the line of cross section B-B (see Figure 15 for cross section location). South-north geologic section F-F, Plate 9 and Figure 15, shows that the updip-north component of the Mississippian formations causes the Big Clifty sandstone to be exposed in the stream valley (east of section F-F) where the ground surface drops below about elevation 490 ft (also see topographic contours of Plate 3). The Turkey Creek alluvial aquifer is especially subject to contact with groundwater issuing from the Big Clifty Beech Creek aquifer north of the line of section B-B at well 06C01. South of the line (well 06C01), the alluvial aquifer is more subject to contact with water from the Golconda/Haney because the Big Clifty dips below the level of the alluvial valley floor. Infiltration of surface runoff from the Demolition Area into the alluvial aquifers has probably decreased significantly since the construction of the four retention ponds on the slopes of the ridge. The water of Turkey and Boggs Creeks flows southward around the Demolition Area ridge to their confluence south of the ridge. The surface water in the creeks is subject to potential contamination issuing from the formations in the creek valleys, in a manner similar to that discussed in the preceding paragraph. The stream water is also susceptible to airborne contaminants and surface runoff, but that discussion is beyond the scope of this report.

The four sedimentation ponds below the Demolition Area intercept surface runoff through four main drainage ways (Plate 2). The two ponds on the west side of the ridge receive water flowing over Pennsylvanian sediments (see sections B-B, Plate 6 and C-C, Plate 7). Any groundwater that seeps from the Pennsylvanian where it intercepts the ground surface above the

levels of the ponds and within their drainage basins can collect in the ponds. The two ponds on the east side of the ridge receive water flowing over Pennsylvanian rocks and the Golconda/Haney limestone (see sections A-AA, Plate 5 and F-F, Plate 9). Any groundwater seeping into the pond drainage basins from the base of the Pennsylvanian, for example along the unconformity, or from the Golconda/Haney limestone, can collect in the ponds. No seeps have yet been identified in the slopes above the ponds. The sedimentation pond water is currently monitored under another program.

Groundwater hydrology of the Old Rifle Range

Aquifers and aquicludes. The Big Clifty sandstone and Beech Creek limestone were monitored as one aquifer at the Old Rifle Range as they were for the Demolition Area. The Beech Creek limestone was the deepest formation monitored at the Old Rifle Range. Well screens were placed at two levels within the Big Clifty-Beech Creek. Ten or twenty-foot screens were installed near the base of the aquifer and 10-ft screens near the top. The upper screens monitor the uppermost or water table aquifer at the Old Rifle Range. Many of the upper screens partially screen the deep soil zone which exists at the Old Rifle Range. The maximum thickness of Big Clifty-Beech Creek penetrated was 58 ft in boring 06C16. The least penetrated was 26 ft in 06C13. The deeper wells bottom in the Elwren shale aquiclude, which is persistent beneath the entire Old Rifle Range.

Two wells were installed in the Golconda/Haney limestone. Confirmation well 06-21 was installed in 1983 and RFI well 06C16P3 in 1990 (two other wells in the Demolition Area study area also screened the Golconda/Haney). The Golconda/Haney well positions are shown in Figure 4 and on sections G-G and H-H of Plate 10. The Golconda/Haney is absent beneath most of the Old Rifle Range. The wells are set in or near the Indian Springs shale aquiclude. The greatest thickness of Golconda/Haney encountered was 10 ft in boring 06C16.

The thick alluvial soils that occur over much of the Old Rifle Range constitute part of the uppermost aquifer. The similarity in water levels in wells installed solely in the soil column and wells installed in the upper Big Clifty sandstone indicate that the soils are hydraulically connected with the Big Clifty-Beech Creek aquifer.

Hydraulic characteristics. Groundwater flow through the limestones is through systems of connected joints. Flow within the Big Clifty sandstone at the Old Rifle Range is believed to be both through joints (secondary porosity) and through intergranular pores (primary porosity). As mentioned earlier, the Big Clifty and Beech Creek formations beneath the Old Rifle Range contained more open discontinuities (joints and bedding planes) than the same formations elsewhere in the study area. Abundant low-angle joints and the prominent open discontinuity near the top of the Beech Creek were expected to increase the aquifer's groundwater transmissibility.

The open discontinuity in the Beech Creek limestone is identified in boring logs of borings 06C12, 06C13, 06C14, 06C15 and 06C17 of Plates 10, 11 and 12. A loss of drilling water return was experienced in the zone in most of the borings, indicating it transmits water rapidly through the formation.

The thick alluvial deposits, which generally occur in the eastern half of the Old Rifle Range (see Figure 19) contain basal gravels expected to have high permeability. Geologic sections H-H (Plate 10), J-J (Plate 11), and L-L and M-M (Plate 12), show the distribution of the basal alluvial soil unit, designated GM (USCS classification silty gravel) or SM (silty sand) at the Old Rifle Range. The gravel unit is as much as 11 ft thick in borings. Groundwater contours indicate some of the colluvial soils near the center of the site (see section H-H), Plate 10) may also be more permeable to water. The lower gravel unit is extrapolated from boring 06C09 to be in contact with the flashing pits, as shown in section L-L of Plate 12. The flashing pits are a potential source of groundwater contamination. Contaminants would be expected to migrate toward down-gradient wells monitoring the sand and gravel unit, possibly wells 06-19, 06C09, 06C13 and 06C18. The statistical and qualitative evaluation of contamination presented in Part III, below, confirmed that those four wells were among the contaminated wells identified (see Figure 75).

Cross-section LL (Plate 12) also shows that the top-of-rock (the Big Clifty sandstone) is near the base of the flashing pits and susceptible to infiltration by contaminated runoff. Monitoring well 06-20 of Plate 12 and well 06-22, east and down-gradient of section LL, are both screened in the Big Clifty sandstone and are the only wells in which explosives contamination has been detected.

Groundwater flow patterns. Groundwater flow patterns were determined for the uppermost aquifer (the Big Clifty sandstone and the soils) and the lower Big Clifty-Beech Creek aquifer at the Old Rifle Range. The piezometric surfaces are within the Big Clifty and overlying soils over the entire Old Rifle Range (see Plates 10, 11 and 12). The aquifer is thus an unconfined, or water table, aquifer and is free to drain under gravity toward lower elevation, in this case toward the local base level represented by Turkey Creek to the east. Water level contour maps for two sampling periods, May-June and November, 1991, were constructed for the uppermost aquifer at the Old Rifle Range and are presented in Figures 25 and 26, respectively There were about 5 ft of fall in the water table between May-June and November because of low rainfall in the late summer and Fall. The general shape of the water table is the same for the two dates, with east and southeast flow and flow concentrated in a trough in the southeast quadrant. The gradient within the uppermost aquifer, however, is considerably lower in November under low-flow conditions. The average gradient from the northwest to the southeast for May-June is 0.0033 or 17 ft/mile. The average gradient for November is 0.0022 or 11 ft/mile. Contour intervals are the same for the two maps.

The piezometric surface for both the uppermost aquifer and lower Big Clifty-Beech Creek were plotted as dashed lines on the geologic sections of Plates 10 through 12. The lower screens and corresponding water level were designated "1" and the upper screens and corresponding water level, "2." The lower and upper levels were essentially identical over most of the Old Rifle Range, indicating good hydraulic continuity and horizontal flow within the aquifer. On the north (section G-G) and west (section K-K), the uppermost level was 3 to 4 ft higher than the lower level. There is no discernible difference in lithology or hydraulic characteristic of the aquifer materials across the area. The head difference must be caused by local non-horizontal flow through the aquifer on the north and east, probably by local recharge of the aquifer from waters draining from within the slopes and by contribution from an eastward flowing tributary stream near wells 06C14, 06C15 and 06C16 (see Plate 1). Locally non-horizontal flow, with equipotential lines inclined from the vertical, is not uncommon in water table aquifers.

The most striking feature of the water table maps of Figures 25 and 26 is the trough with axis centered on well 06-18 and oriented northwest-southeast. Flow paths (selected flow lines drawn perpendicular to the equipotential contour lines) are shown by arrows. Groundwater flow is directed toward the trough from surrounding areas of the Old Rifle Range and channeled away to the east-southeast toward Turkey Creek. The trough corresponds to the area of thick alluvial soil containing the more permeable basal sands and gravels (SM and GM) discussed above. The water table contour trough supports the conclusion that the alluvial soils and the underlying jointed rock convey groundwater more rapidly through the Old Rifle Range. The more subdued extension of the trough northwest of well 06C09 indicates that the thick colluvial soils may also enhance movement of uppermost groundwaters.

The water level contour maps for the lower Big Clifty-Beech Creek aquifer at the Old Rifle Range for the two dates are presented as Figures 27 and 28. The lower aquifer at the Old Rifle Range is the deep aquifer of the Demolition Area, discussed earlier. The hydraulic gradient through the lower aquifer is much flatter (little difference in levels between wells) than in the uppermost aquifer (note that the contour interval is only 0.2 ft). The ultimate direction of flow is similar: generally to the southeast. The highest levels are in the southwest quadrant of the map area near well 06C12, reflecting local dewatering of the Big Clifty-Beech Creek aquifer from beneath the Demolition Area ridge as the aquifer becomes unconfined and free-draining (see discussion under "Groundwater flow patterns" of the Demolition Area, above). The hydraulic gradient computed for a lower aquifer flow path from the vicinity of well 06C12 toward the center of the area and out to the southeast was 0.0010 for May-June (Figure 26) and 0.0008 for November (Figure 27). Flow paths are shown by arrows.

5 Validation of Analytical Data

Background

USEPA Type II data validation was performed on all of the laboratory analytical results and raw data. Data validation included a thorough review of chemical data from the laboratory using a set of standard criteria in a systematic manner. The primary objective of data validation was to assess data quality with respect to pre-determined criteria. Type II data validation applied specifically to Contract Lab Program (CLP) data. Type II validation was done under the following protocol:

a. CLP data were reviewed according to the criteria in the latest versions of the following USEPA Contract Laboratory Program documents: "Laboratory Data Validation: Functional Guidelines for Evaluating Organics Analyses," February, 1988; "Laboratory Data Validation: Functional Guidelines for Evaluating Inorganics Analyses," July, 1988; and "National Functional Guidelines for Organic Data Review: Multi-Media-Concentration (OLM01.0) and Low Concentration Water (OLC01.0)," June, 1991 revision.

b. Summary tables of data that underwent independent quality assurance review were generated. Data points are "flagged" to convey qualitative and quantitative quality assessments.

c. The data validator initially screened data packages for completeness (e.g., frequency of quality control samples).

The validation findings for each analytical method are discussed in the following subsections. The findings offered in this report are based upon a general review of all available data including the following:

a. Holding times.

b. GC/MS tuning and calibration data.

c. ICP interference check sample.

d. Furnace atomic absorption QC.

e. Laboratory and field blank results.

f. ICP serial dilution.

g. Surrogate spike recoveries.

h. Matrix spike/matrix spike duplicate results.

i. Internal standards performance.

j. Field duplicate precision.

k. Compound identification and quantitation.

l. Tentatively Identified Compound (TIC) evaluation.

Laboratory QA/QC data sheets for CLP validation were completed by the analytical laboratory but are not included in this report.

A summary of analytical procedures used in the groundwater analyses is presented in Table 11.

The data qualifiers ("J," "R," etc.) described in the following sections apply to the data validation procedures and the accompanying data validation tables presented in Appendix F.

Organic Analytes

Holding time

The holding time validation was based on the holding time of the sample from time of collection to time of analysis or sample preparation, as appropriate. The unpreserved aromatic volatiles and non-aromatic volatiles must be analyzed within 14 days. Pesticide/PCB, explosive, herbicide, and BNA samples must be extracted within 7 days and the extract must be analyzed within 40 days. Table 8 shows the permissible holding time for each analyte. If holding time was exceeded, all positive results were flagged as estimated (J). If holding times were grossly exceeded, professional judgment was used to determine the reliability of the data and the effects of additional storage on the sample results. The non-detected data may be determined unusable (R).

GC/MS tuning

Tuning and performance criteria were established to ensure mass resolution, identification, and sensitivity. The ion abundance criteria of

decafluorotriphenylphosphine (DFTPP) and bromofluorobenzene (BFB) were used to evaluate the results. The ion abundance criteria were met. The mass calibration was performed correctly. The samples were analyzed each 12-hr period. Neither transcription errors nor calculation errors were made by the laboratory.

Pesticides instrument performance

The pesticides instrument performance criteria were established to ensure that adequate chromatographic resolution and instrument sensitivity were achieved by the chromatographic system.

The raw data were evaluated by verifying that DDT retention time was greater than 12 min on the standard chromatogram and that there was adequate resolution between peaks. If the retention time was less than 12 min, the chromatography was examined closer for adequate separation of individual components. If adequate separation was not achieved, the compound data were flagged unusable (R). The raw data were also checked to verify that the percent breakdown for endrin and 4,4-DDT or the combined percent breakdown did not exceed 20 percent. If DDT breakdown was greater than 20 percent, all quantitative results for DDT were flagged as estimated (J). If DDT was not detected, but DDD and DDE were positive, the quantitation limit was flagged for DDT as unusable (R). DDD and DDE results were flagged as presumptively present at an estimated quantity (NJ).

If endrin breakdown was greater than 20 percent, all quantitative results were flagged as estimated (J). If endrin was not detected, but endrin aldehyde and endrin ketone were detected, the quantitation limit was flagged as unusable (R). The endrin ketone results were flagged as presumptively present at an estimated quantity (NJ).

Calibration

Instrument calibration ensures that the instrument is capable of producing acceptable quantitative data. Initial calibration demonstrates that the instrument is capable of acceptable performance in the beginning. Continuing calibration checks document satisfactory maintenance and adjustment of the instrument on a day-to-day basis. All average relative response factors (RRF) for TCL (target compound list) compounds must be greater than or equal to 0.05. All percent relative standard deviations (% RSD) must be less than or equal to 30 percent for initial calibration and less than or equal to 25 percent for continuing calibration. Pesticide %RSD must be less than or equal to 10 percent for each 72-hr period for initial calibration and percent difference less than 15 percent for continuing calibration.

All TCL organic compounds were checked and properly calculated. Since no calculation errors were detected, a more comprehensive recalculation was not warranted.

For TCL organic compounds with RRF less than or equal to 0.05 or %RSD greater than or equal to 30 percent or 25 percent for initial calibration and continuing calibration, respectively, positive results were flagged as estimated (J). Non-detects were flagged as unusable (R).

For pesticide compounds with %RSD greater than or equal to 10 percent for initial calibration and percent difference greater than or equal to 15 percent for continuing calibration, positive results were flagged as estimated (J).

Blanks

Results of blank analysis determined the existence and magnitude of possible contamination problems. The criteria for evaluation of blanks applied to any blank associated with the samples. If problems with any blank existed, all associated data were carefully evaluated to determine whether or not there was an inherent variability in the data, or if the problem was an isolated occurrence not affecting other data. No contamination should be present in the blank(s). The results were not corrected by subtracting possible blank value.

Contaminants such as methylene chloride, acetone, toluene, 2-butanone, and common phthalate esters are common lab contaminants. If the concentration of any of the five compounds detected in the sample was greater than ten times the blank concentration, which was also detected in any associated blank, the result was reported as submitted. If the concentration of other TCL organic and pesticide compounds detected in the sample was greater than five times the blank concentration, which was also detected in any associated blank, the result was reported as submitted. If gross contamination was determined, all compounds affected were flagged as unusable (R), due to interference, in all appropriate samples.

Surrogate recovery

Laboratory performance on individual samples was established by means of spiking the samples. All samples were spiked with surrogate compounds prior to sample preparation. The evaluation of the results of these surrogate spikes was not necessarily straightforward. The sample may produce effects from such factors as interferences and high concentrations of analytes.

If at least two surrogates in a base/neutral or acid fraction or one surrogate in the volatile fraction were out of specification, but had recoveries greater than 10 percent, detects for that fraction were flagged as estimated (J). Non-detects for that fraction were flagged with the sample quantitation limit as estimated (UJ). If any surrogate in a fraction was less than 10 percent, the detects were flagged as estimated (J). The non-detects were flagged as unusable (R). No qualification with respect to surrogate recovery was placed on data unless at least two surrogates were out of specification in the base/neutral or acid fraction, or one in the volatile fraction, or unless any surrogate had a less than 10 percent recovery.

If pesticide surrogate recoveries were outside of advisory windows, low recoveries of positive results and quantitation limits were flagged as estimated (J). If the surrogate was not present, all negative results were flagged unusable (R).

Matrix spike/matrix spike duplicate

Matrix spike and matrix spike duplicate (MS/MSD) were generated to determine accuracy of the analytical methods on various matrices and long-term precision. MS/MSD data alone were not used to evaluate the precision and accuracy of individual samples. However, under professional judgment, the MS/MSD data in conjunction with other quality control criteria were used.

The MS/MSD results were inspected for recovery outside quality control limits. If MS/MSD results affected only the sample spiked, qualification was limited to that sample. The MS/MSD results were used to determine if a lab was having a systematic problem in the analysis of one or more analytes, which affects all associated samples.

Internal standards performance

Internal Standards performance criteria ensured that GC/MS sensitivity and response were stable during every run. Internal standard area counts must not vary by more than a factor of two (-50 percent to 100 percent) from the associated calibration standard. The retention time of the internal standard must not vary more than ±30 sec from the associated calibration standard.

The raw data were checked to verify the recoveries reported on the Internal Standard Area Summary. The retention times and Internal Standards areas were verifiable. If two analyses for a particular fraction were run, the best data were reported.

During the evaluation, positive results for compounds with internal standard outside the -50 percent or +100 percent limits were flagged as estimated (J) for that sample fraction. Non-detects for compounds with internal standards outside the above limits were flagged with the sample quantitation limit classified as estimated (UJ) for that sample fraction. If an internal standard retention time varied by more than 30 sec, the chromatographic profile for that sample was examined to determine if any false positives or negatives existed. If extremely low area counts were reported, or if performance exhibited a major abrupt drop-off, then a severe loss of sensitivity was indicated. Non-detects were flagged as unusable (R).

TCL compounds identification

TCL compound analysis for volatiles and semivolatiles was performed by GC/MS, which resulted in a low incidence of misidentification. A misdentification may either be a false positive (reporting a compound present when it is not) or a false negative (not reporting a compound when it is present). False positives are much easier to detect than false negatives because more information is available due to the requirement of supporting data submittals. Negatives or non-detected compounds represent an absence of data and are, therefore, much more difficult to assess.

The Relative Response Time (RRT) of reported compounds was within 0.06 RRT units of the reference standard. The laboratory standard spectra were compared to the sample compound spectra for a match. If incorrect identifications were made, all appropriate data were flagged as non-detected (U) or unusable (R).

For pesticide compounds, positive detects were confirmed using appropriate retention times and retention time windows. The non-detected compounds were verified as correct. Pesticide/PCB concentrations in the final sample extract which exceeded 10 ng/μL (nanograms per microliter) were confirmed by GC/MS. If incorrect identifications were made because of interference, all appropriate data were flagged as the estimated quantitation limit (UJ).

Tentatively identified compounds

Chromatographic peaks in volatile and semivolatile fraction analyses that were not TCL analytes, surrogates, or internal standards were potential tentatively identified compounds (TIC). TICs were qualitatively identified by GC/MS library search.

TIC identifications were conducted by the laboratory for each sample by using a mass spectral search of the NBS library and reporting the possible identity for the 10 largest VOA fraction peaks and the 20 largest BNA fraction peaks. These fraction peaks were not surrogate, internal standard, or TCL compounds, but had area/height greater than 10 percent of the size of the nearest internal standard.

All TIC results were flagged as tentatively identified with estimated concentrations (JN). The tentative identification of a non-TCL compound was not acceptable. Major ions in the reference spectrum should be presented in the sample spectrum. The relative intensities of the major ions should agree within 20 percent between the sample and the reference spectra. Molecular ions present in the reference spectrum should be present in the sample spectrum. Ions present in the sample spectra but not in the reference spectrum were reviewed for possible background contamination, interference, or additional TIC compounds. Any uncertain TIC identification was reported as unknown. Identifiable TICs are in Table 12.

Inorganic Analytes

Holding time

The holding time validation was based on the holding time of the sample from time of collection to time of analysis or sample preparation, as appropriate. All metals except mercury must be analyzed within 180 days and mercury must be analyzed within 28 days. Cyanide samples must be analyzed within 14 days. Table 8 shows the holding time for each analyte. If holding times were exceeded, all positive results were flagged as estimated (J) for results > instrument detection limit (IDL) and as estimated (UJ) for results < IDL . If holding times were grossly exceeded, professional judgment was used to determine the reliability of the data and the effects of additional storage on the sample results. The non-detect data could be determined unusable (R) for results < IDL.

Calibration

Instrument calibration ensures that the instrument is capable of producing acceptable quantitative data. Initial calibration demonstrates that the instrument is capable of acceptable performance in the beginning. Continuing calibration checks document satisfactory maintenance and adjustment of the instrument on a day-to-day basis.

The initial calibration for an ICP analysis requires a blank and at least one standard to establish an analytical curve. The atomic absorption analysis requires a blank and at least three standards, one of which must be at the contract required detection limit (CRDL), to establish an analytical curve. The correlation coefficient must be greater than or equal to 0.995. The mercury analysis requires a blank and at least four standards to establish an analytical curve. The correlation coefficient must be greater than or equal to 0.995. The initial calibration requirements for cyanide analysis are a blank and at least three standards to establish an analytical curve. The midrange standard must be distilled. The correlation coefficient must be greater than or equal to 0.995 for photometric determination.

If the minimum number of standards were not used for the above initial calibration, or if the instrument was not calibrated daily and each time the instrument was set up, the data were qualified as unusable (R). For a correlation coefficient less than 0.995, the results greater than IDL were as estimated (J) and estimated (UJ) for results less than IDL. The results were also as estimated (J) for midrange cyanide standards that were not distilled.

For the initial and continuing calibration verification (ICV and CCV, respectively), analysis results for mercury, metals other than mercury, and cyanide must fall within the control limits of 80-120, 90-110, and 85-115 %R, respectively. Positive results were qualified as unusable (R) if ICV or CCV %R was less than 70 percent, 75 percent, and 65 percent for mer-

cury, metals other than mercury, and cyanide, respectively. If the ICV or CCV %R was greater than 125 percent for metals except mercury, 130 percent for cyanide, and 135 percent for mercury, results greater than IDL were unusable (R) but acceptable for results less than IDL.

Blanks

Blank analysis for metals were to determine the existence and magnitude of possible contamination problems. The criteria for evaluation of blanks applied to any blank associated with the samples. If problems with any blank existed, all associated data were carefully evaluated to determine whether or not there was an inherent variability in the data, or if the problem was an isolated occurrence not affecting other data. No contamination should be present in the blank(s). The analytical results were not corrected by subtracting possible blank value.

Duplicate sample analysis

Duplicate samples were used as indicators of laboratory precision based on each sample matrix. The analyte data were evaluated by verifying that the results fell within the control limits of $\pm$ 20 percent for RPD, which should be used for sample values greater than five times CRDL. The control limit of $\pm$ CRDL for RPD was used for sample values less than five times CRDL, including the case where only one duplicate sample value was less than five times CRDL. If duplicate analysis results for a particular analyte fell outside the appropriate control limits, the results for that analyte in all associated samples of the same matrix were qualified as estimated (J). The analyte data also verified that the field blank was not used for duplicate analysis. If the field blank was used for a duplicate analysis, all appropriate QC data were checked and professional judgment was exercised when evaluating the data.

Matrix spike sample analysis

The matrix spike sample analysis provides information about the effect of each sample matrix on the digestion and measurement methodology. The results were verified by determining that they fell within the limits of 75-125 percent recovery. These limits do not apply when sample concentration exceeds the spike concentration by a factor of four or more. Samples used for spike recovery analysis were not identified as field blanks.

The data were acceptable for use when the spike recovery was greater than 125 percent and the reported sample results were less than IDL. The data were qualified as estimated (J) whenever the spike recovery was outside the limits of 75-125 percent and the sample results were greater than IDL. For spike recovery within the range of 30-74 percent or less than 30 percent and sample results were less than IDL, the data were qualified as estimated (UJ) and as unusable (R), respectively.

Furnace atomic absorption QC

The objectives of the furnace atomic absorption QC were to duplicate injections and furnace post digestion spikes establishing the precision and accuracy of the individual analytical determinations. The furnace atomic absorption raw data verified that the Furnace Atomic Absorption Scheme described in the July, 1988 Statement of Work of the Functional Guidelines was followed. The raw data were also checked to verify that duplicate injections agree within ±20 percent relative standard deviation (RSD) for sample concentration greater than CRDL. If duplicate injections were outside the ±20 percent RSD, the sample was rerun. If the sample was not rerun, the data were qualified as estimated (J). If the rerun sample results remained outside the ±20 percent RSD, the data were qualified as estimated (J). If the post digestion spike recovery was less than 40 percent and greater than IDL, the data were qualified as estimated (J). However, the data results less than IDL were qualified as estimated (UJ) for post digestion spike recovery greater than or equal to 10 percent but less than 40 percent. The post digestion spike recovery less than 10 percent and concentration results less than IDL were qualified as unusable (R).

ICP serial dilution

The objective of the serial dilution was to determine whether significant physical or chemical interferences existed due to sample matrix. The criterion of the serial dilution was the determination of whether the analyte concentration was sufficiently high (concentration in the original sample greater than a factor of 50 above the IDL). If the analyte concentration is high, an analysis of a 5-fold dilution must agree within 10 percent Difference (D) of the original results.

The raw data were checked and the %D was periodically recalculated to verify that the dilution analysis results agreed with the above criteria. When criteria were not met, the associated data were estimated (J). The raw data were checked for negative interference (results of the diluted sample significantly higher than the original sample). Professional judgment was used to qualify this data.

Data Validation Results

The groundwater analytical data were reviewed and were found to be acceptable, with the exception of those results qualified as unreliable (R).

First round data

Samples collected from wells 06C04, 06C04P2, 06C11, and 06C11P2 for VOAs had low Toluene D8 surrogate recoveries. These samples were rerun,

repeating the original results, which indicated a matrix effect affecting the Toluene D8 surrogate recoveries. The data were qualified as nondetected.

Acetone and methylene chloride were found in concentrations less than the detection limits in several wells and/or associated blanks from the Demolition and Old Rifle Range. The data were qualified as BJ for an estimate found in the blank and the sample.

Samples collected from wells 06C04 and 06C04P2 for BNAs had low chrysene d12 and/or perylene d12 internal standard areas. The samples were rerun yielding the same results. The data were accepted.

The BNA's surrogate recovery for wells 06-01A, 06-22, and 06-23 were outside the QC limits for 2-fluorophenol and phenol-d6, 2-fluorobiphenyl, and 2-fluorobiphenyl, respectively. The surrogate solution was remade checking for problems, yielding none. The data were accepted.

The first round analytical results at the Demolition Area and Old Rifle Range indicated that volatile organics, pesticides/PCBs, BNAs, and herbicides were not present in verifiable quantities. Explosives were detected at the Old Rifle Range but not at the Demolition Area.

Second round data

Samples collected from wells 06C01P3, 06C04P2, 06-06, 06-07, 06-12, 06-01A, 06C06, 06C08, 06C09, 06C12, 06C12P2, 06C13P2, 06-15, and 06-16 for BNAs had low chrysene d12 and/or perylene-d12 internal standard areas. An attempt to clean-up the extract was made, unsuccessfully. However, the extracts for other QC samples were verified. The surrogate recovery for wells 06-01A and 06-23 was also outside the QC limits for 2-fluorophenol and/or phenol-d6. The surrogate solution and the matrix spike solution were remade checking for any problem, yielding none. The data were qualified as an estimate (J) for detectables and UJ for nondetectables.

The matrix spike and matrix spike duplicate BNA samples for well 06C10 had high recovery of 2,4-dinitrotoluene and pentachlorophenol. The recoveries were remade and monitored to see if a problem existed. The associated data were qualified as an estimate, J for detectables and UJ for nondetectables.

Well 06-23 had a low 2-fluorobiphenyl recovery for BNA analysis. The recovery was monitored for any problem as the surrogate solution was remade. The surrogate was rerun yielding no detectable problem. The associated data were qualified as an estimate, J for detectables and UJ for nondetectables.

The herbicide holding time at the Old Rifle Range for all wells was exceeded by 4-7 days. The sulfide holding time at the Old Rifle Range for

wells 06-14A, 06C10, 06C10P2, 06C11, 06C11P2, 06C18, and 06C18P2 was exceeded by 2 days. The herbicide data were qualified as unreliable (R) for nondetects and were qualified as estimate (J) for detects. The sulfide and the other volatiles were qualified as estimate (J) for detects and (UJ) for nondetects.

The second round analytical results at the Demolition Area and Old Rifle Range indicated that volatile organics, pesticides/PCBs, BNAs, and herbicides were not present in verifiable amounts. Explosives were detected at the Old Rifle Range but not at the Demolition Area.

Third round data

Samples collected from well 06C09 for BNAs had a low perylene d12 internal standard areas. The sample was monitored for any problems, yielding none. The associated data were qualified as estimated (J) for detectables and UJ for nondetectables.

The surrogate recovery for well 06-23 was outside the QC limits for 2-fluorophenol. The surrogate solution and the matrix spike solution were remade checking for any problem, yielding none. The data were qualified as an estimate (J) for detectables and UJ for nondetectables.

The herbicide holding time at the Demolition Area for wells 06-06, 06-07, 06-12, 06C06P2, 06C07, 06C08, and 06C08P2 and well 06-16 at the Old Rifle Range was exceeded by two to three days. Therefore, the data were qualified as an estimate (J) for detectables and UJ for nondetectables. The volatile holding time for well 06-01A at the Demolition Area and well 06-16 at the Old Rifle Range was exceeded by 7 days and 4 days, respectively. The data were qualified as unreliable (R). The third round analytical results at the Demolition Area and Old Rifle Range indicated that volatile organics, pesticides/PCBs, BNAs, and herbicides were not present in verifiable amounts. Explosives were detected at the Old Rifle Range but not at the Demolition Area.

Fourth round data

The groundwater analytical data were reviewed and found to be acceptable. Because organics other than explosives were not detected in significant or verifiable amounts in the first three sampling rounds, they were not monitored in the fourth round. Explosives were detected at the Old Rifle Range in the fourth round but not at the Demolition Area.

Summary of Analytical Results

All compounds were successfully analyzed, with the exception of those results qualified as unreliable, (R). Some minor quality control deficiencies were observed during the validation process, but they did not affect the overall quality of the data (See Appendix F for validated (qualified) data).

The findings offered in this data validation section were based upon all available data including holding times, GC/MS tuning and calibration data, ICP interference check sample, furnace atomic absorption QC, laboratory and field blank results, ICP serial dilution, surrogate spike recoveries, matrix spike/matrix spike duplicate results, internal standards performance, field duplicate precision, compound identification and quantitation, and Tentatively Identified Compound (TIC) evaluation.

The quality of this data was assured first through sample collection verified by nondetects in the field blanks, trip blanks, and equipment blanks; secondly, through the comparison of four rounds of chemical data; and finally, through comparable results of quality assurance and quality control samples and blind sample results.

Analysis of groundwater from three rounds of sampling of monitoring wells indicated no significant or verifiable amounts of organic analytes other than explosives. Cyanide, sulfide and metals were detected at significant levels in several wells at both sites in four sampling rounds. Nitrates and nitrites were detected in several Demolition Area and Old Rifle Range wells in the fourth round. Explosives were detected in some Old Rifle Range wells in all four rounds.

6 Nature and Distribution of Groundwater Contamination

Detected Compounds

Appendix G is a printout of all compounds detected at any quantity in four rounds of sampling of monitoring wells at the Demolition Area and Old Rifle Range. Only inorganics (metals, cyanide, sulfides, nitrates and nitrites) and the organic compounds, explosives, were detected in significant and verifiable quantities. Other organics including volatiles, semivolatiles (BNAs), pesticides, herbicides and PCBs were not detected in significant and verifiable quantities. Appendix H is a series of tables of amounts detected of metals in Demolition Area/Old Rifle Range wells, sorted in order of amount detected, highest value first (descending order). Appendix H readily shows the persistence of certain metals in particular wells.

WES used two methods to evaluate the significance and distribution of metals in the groundwater: statistical and graphical. The statistical analysis follows the USEPA guidance for evaluation of groundwater monitoring data. The graphical approach, using bar charts, permits a visual comparison of results and supplements the statistical analysis. Only metals were analyzed statistically. Metals, explosives and nitrogen compounds were evaluated graphically.

Statistical Analysis of Metals

Selection of methods

Statistical analysis of metals concentrations reported for four rounds of sampling conducted between November 1990 and April 1992 in Demolition Area/Old Rifle Range wells was accomplished using the analysis of variance (ANOVA) statistical method suggested by USEPA. Guidance for selecting and applying the statistical analysis was provided in "Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, Interim Final Guidance," April, 1989 (EPA 1989). The actual analysis and reporting of results was performed on a personal computer using the Groundwater Information

Tracking System/Statistics (GRITS/STAT) software and manual developed for USEPA by Alliance Technologies Corporation (1992) and provided to the author by USEPA Region V (Chicago). The one-way parametric ANOVA statistical analysis method is recommended for detection and compliance monitoring data for which more than 50 percent of the values are above the detection limit (DL). The method compares data from detection or compliance (downgradient) wells to data from background (upgradient) wells. Compounds that commonly are present in background wells, for example naturally occurring metals, are most appropriately evaluated using ANOVA. If contamination of the groundwater occurs from facility activities and if the monitoring wells are hydraulically upgradient and downgradient from the activity, then contamination is unlikely to change the levels of a constituent in all wells by the same amount. Contamination from an activity can be seen as differences in average concentration among wells, and such differences can be detected by analysis of variance.

The ANOVA method checks the distribution of the observed data for certain statistical characteristics (normality and equal variance). If the checks fail, an analysis of the log-transformed[1] data is performed and checked. If the tests fail again, a non-parametric analysis of variance is performed to determine the likelihood of contamination of the wells.

Statistical procedures

ANOVA calculates the differences between the average (mean) concentrations in each well (X_i) and the mean concentrations in the background well (X_b), the means having been computed over the N number of sampling periods (in this case, N = 4). It then compares the differences to a statistical, tabulated value, D_i. If the difference (X_i - X_b) is greater than D_i, the method concludes that the "i"th well has significantly higher concentrations than the average background well, and that therefore it is contaminated. The software GRITS/STAT automatically performs all statistical analyses and data normality checks for each selected parameter and prints a report of the analysis. A non-detect reported for a parameter for a sampling round is assigned a value of one-half the detection limit (not zero) by the software for statistical calculations.

Appendix I is a reproduction of selected portions of the Guidance Manual explaining the method selection and analytical techniques for compliance monitoring data. Appendix I also provides a step-by-step example of statistical analysis of a hypothetical group of wells monitored for lead contamination.

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[1] For log-transformed data, the logarithms of the values, rather than the actual values of the data, are plotted.

A typical computer-generated statistical analysis for monitoring wells for metals contamination at the Demolition Area/Old Rifle Range proceeded as follows:

a. A list of all wells of a selected aquifer, the concentrations of all metals reported for the wells in four rounds of sampling, and the sampling dates were first entered into the software's database.

b. A background well was selected for the aquifer. Compliance wells (the remaining sampled wells in the aquifer) were selected.

c. A normality test of the original data was run for each metal to determine that parametric analysis was appropriate. A parametric analysis of variance determines whether differences in mean concentrations among wells are statistically significant. The software performed two tests on the data to determine whether the method was acceptable. The first test was the Shapiro-Francia or the Shapiro-Wilks[1] test on the pooled residuals (the residual was the difference between the actual observation and its predicted value, which was the mean for four rounds). The first test determined whether the values were normally distributed. The second test was Levene's test for variance. If either test failed, the one-way parametric ANOVA test for original data was concluded to be inappropriate for the data. If both tests passed, a parametric ANOVA was conducted and a list of wells with significant evidence of contamination with the selected metal was produced.

d. If either of the original data tests failed, a normality test of the log-transformed data was performed and the tests for normality and variance were run again. Log-transformed data sometimes conform to a normal distribution when the original data do not. If both tests passed, a parametric ANOVA was conducted and a list of probably contaminated wells was produced. If either test failed, the one-way parametric ANOVA for log-transformed data was concluded to be inappropriate, and a non-parametric ANOVA was performed to estimate probability of contamination in the wells.

e. If the parametric ANOVA test was found to be inappropriate, a non-parametric ANOVA test was performed on the data. The non-parametric ANOVA applies a procedure called the Kruskal-Wallis test. The procedure tests the hypothesis that all wells or groups of wells around a source area have the same median concentration of a given constituent. Non-parametric ANOVA is appropriate when the data or residuals from a parametric ANOVA are significantly different from normal and when a log transformation fails to normalize the data. If

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[1] The Shapiro-Francia test is performed for data with > 50 observations. The Shapiro-Wilks test is performed for data with < 50 observations.

the wells are found to differ, additional comparisons are made to determine if contamination is likely to exist. Observations in each well were ranked to compute the Kruskal-Wallis statistic, H, which then was compared to another tabulated value from the Chi-squared (χ^2) distribution. If $H > \chi^2$, the data were not normally distributed, the hypothesis that the wells have the same median concentration of the constituent was rejected, and another test was conducted. The difference between the rank average of each well and the rank average of the background well was computed. If the computed difference was greater than a critical difference calculated for the wells, there was considered to be evidence of contamination in the tested well. Statistical analyses were conducted for three aquifers: the Big Clifty/Beech Creek aquifer for the entire study area; the uppermost aquifer at the Old Rifle Range; and the upper Pennsylvanian aquifer at the Demolition Area.

f. Examples of statistical analyses of Demolition Area and Old Rifle Range wells for three metals is presented in Appendix J.

Results of statistical analyses for metals

Big Clifty/Beech Creek aquifer. Statistical ANOVA evaluation of 18 Demolition Area/Old Rifle Range wells screened in the lower portion of the Big Clifty/Beech Creek aquifer were performed for 13 heavy metals (metals listed for primary MCLs). The metals were aluminum, antimony, arsenic, barium, cadmium, chromium, cobalt, copper, lead, manganese, nickel, vanadium, and zinc. All of the selected metals were detected in more than one sampling round or in more than one well. Beryllium, mercury, selenium, silver, thallium and tin were not detected more than once each in the 18 wells. The sampling populations were comprised of all 18 wells, including those with no detected levels of a metal.

Well 06C07 was selected to be the background well for the statistical tests. Well 06C08 was originally intended to serve as background but was found to be higher in metals concentrations and in frequency of metals detected than many of the down-gradient compliance wells. Well 06C07, although topographically downslope from the Demolition Area, is laterally positioned from the Demolition Area active zone with respect to the direction of flow on the Big Clifty/Beech Creek piezometric surface, as shown by Figures 22 and 23. Well 06C07 also had relatively few detected metals and the metals were at low concentrations.

Only two metals, antimony and cobalt, were able to be analyzed using the one-way parametric ANOVA test (i.e, only the data for antimony and cobalt passed the statistical normality tests performed in the parametric ANOVA). The data for all other metals failed either the Shapiro-Francia/Wilks test or

the Levene test, or both. Log-transformed data also failed one or both tests. All metals except antimony and cobalt were subsequently analyzed using the non-parametric ANOVA test. The last page of the non-parametric ANOVA test results lists the rank differences for each well and the critical difference. A rank difference greater than the critical difference indicated significant evidence of contamination. Evidence was shown for contamination in one or more wells of the lower Big Clifty/Beech Creek aquifer by three metals: **aluminum, arsenic** and **manganese**. The results of all tests are summarized below.

Aluminum: Non-parametric test. Well 06C08 had significant evidence of contamination with respect to the background well 06C07. The well had a rank difference of 37.25 compared to a critical difference of 34.43.

Antimony: No wells showed evidence of contamination (see example of the statistical analysis for antimony in Appendix J).

Arsenic: Non-parametric test. Wells 06C03 and 06C08 had significant evidence of contamination. Well 06C03 had a rank difference of 40.25 and 06C08 a difference of 37.25 compared to the critical difference of 34.43. Well 06C18 had a rank difference of 30.13 and might be considered borderline for arsenic contamination (note that well 06C18P2, the upper well of this cluster, had significant evidence of arsenic contamination, as discussed below in the Old Rifle Range uppermost aquifer analysis (see example of the statistical analysis for arsenic in Appendix J).

Barium: No wells showed evidence of contamination.

Cadmium: No wells showed evidence of contamination.

Chromium: No wells showed evidence of contamination.

Cobalt: No wells showed evidence of contamination.

Copper: No wells showed evidence of contamination.

Lead: No wells showed evidence of contamination.

Manganese: Non-parametric test. Six wells, 06C02, 06C03, 06C04, 06C12, 06C14, and 06C18 had significant evidence of contamination. Rank differences were from 35.63 (06C04) to 59.13 (06C03) compared to the critical difference of 34.43. Two other wells, 06C01 and 06C06, were borderline with differences of 33.13 and 32.25, respectively

Nickel: No wells showed significant evidence of contamination, but well 06C17 had a rank difference of 28.25 compared to the critical difference of 34.42 and bears watching in future monitoring.

Vanadium: No wells showed evidence of contamination.

Zinc: No wells showed evidence of contamination.

Old Rifle Range, uppermost aquifer. The uppermost aquifer of the Old Rifle Range consists of wells screened in the alluvium and in the upper portion of the Big Clifty sandstone beneath the Old Rifle Range study area (the area of Figure 4). The deeper wells of these clusters (e.g. 06C18) screen the lower Big Clifty/Beech Creek aquifer and were included in the Demolition Area/Old Rifle Range Big Clifty/Beech Creek aquifer wells discussed earlier). Statistical ANOVA evaluation of 15 wells (8 RFI wells, C10P2, C11P2, C12P2, C13P2, C14P2, C15P2, C16P2, and C18P2, and

7 confirmation wells, 06-16, 06-17, 06-18, 06-19, 06-20, 06-22, and 06-23) screening the uppermost aquifer was performed for 14 heavy (primary MCL) metals. The metals were aluminum, arsenic, antimony, barium, cadmium, chromium, cobalt, copper, lead, manganese, nickel, tin, vanadium and zinc. The selected metals were detected in more than one sampling round or in more than one well. The sampling populations were comprised of all wells screening the aquifer.

Well 06C07, the background well for the Demolition Area/Old Rifle Range statistical tests, was used as the background well for the Old Rifle Range uppermost aquifer evaluation. Well 06C07 screens the same geologic formation as the wells at the Old Rifle Range and is desirable as background for the reasons noted earlier.

All metals data failed the two parametric ANOVA statistical normality tests and were evaluated using the non-parametric ANOVA. The last two pages of the printout for the non-parametric test data list the rank differences for each well and the critical difference for the well population. Contaminated wells are starred. Evidence was shown for contamination by three metals: **arsenic, manganese** and **nickel**. One well could be considered borderline for zinc contamination. The results are summarized below.

Aluminum: No wells showed evidence of contamination.
Antimony: No wells showed evidence of contamination.
Arsenic: Well 06C18P2 had significant evidence of contamination. The well ranked 31.5 compared to a critical difference of 30.59 (note that well 06C18, the deeper well of the cluster, was borderline for arsenic contamination). Well 06C13P2 ranked 26.25 and bears watching in future monitoring.
Barium: No wells showed evidence of contamination.
Cadmium: No wells showed evidence of contamination.
Chromium: No wells showed evidence of contamination.
Cobalt: No wells showed evidence of contamination.
Copper: No wells showed evidence of contamination.
Lead: No wells showed evidence of contamination.
Manganese: Four wells showed evidence of contamination with the non-parametric test. Well 06-19 ranked 32.63, well 06C11P2 ranked 32.25, well 06C13P2 ranked 38.25 and well 06C18P2 ranked 45.00 compared to a critical difference of 30.59 (note that well 06C18, the deeper well of the cluster, had significant evidence of manganese contamination). Wells 06-17, 06C12P2 and 06C16P2 ranked higher than 24 and bear watching in future monitoring (see example of the statistical analysis for manganese in Appendix J).
Nickel: Well 06-17 had significant evidence of contamination with a rank difference of 35.50 compared to the critical difference of 30.59.
Tin: No wells showed evidence of contamination.
Vanadium: No wells showed evidence of contamination.

Zinc: No wells showed evidence of contamination, but well 06-17 had a rank difference of 27.75 compared to the critical difference of 30.59 and bears watching.

Demolition Area, Upper Pennsylvanian aquifer. Statistical ANOVA evaluation of 5 wells screened in the upper Pennsylvanian section atop the Demolition Area ridge was performed for 14 heavy metals (metals listed as primary MCLs). The metals were aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, lead, manganese, nickel, vanadium and zinc. All of the selected metals were detected in more than one well or in more than one sampling period. Well 06-01A served as the background well.

The five wells, 06-01A, 06-06, 06-07, 06-12, and 06C01P3, have screens set in the Pennsylvanian sands at depths ranging from 7 ft in 06-01A to 50 ft in well 06-06. The locations of the wells are shown on Plate 1 and in Figure 37. Well 06-01A was selected as the background well for this group because it was the most removed from the main cluster of apparently contaminated wells of the group and was relatively low in detected levels of evaluated metals.

A total of 19 observations were tabulated for the ANOVA tests. Well 06C01P3 was dry in the first round of sampling and had only three observations per metal. The other wells had four observations each. Because the number of observations was less than 50, the Shapiro-Wilks test was used to check for normality of distribution in the parametric ANOVA. All of the metals data failed the normality and variance tests and were subsequently analyzed using the non-parametric ANOVA. The central cluster of three wells, 06-06, 06-07 and 06-12 were statistically contaminated with various metals, with 06-07 showing contamination by more metals in higher amounts than the other two wells.

Contaminating metals were **aluminum, arsenic, beryllium, cobalt, manganese, nickel**, and **zinc**. **Cadmium** and **chromium** were borderline. Detected amounts of the contaminating metals were much higher in the upper Pennsylvanian cluster of wells than in any other group of wells or aquifer in the Demolition Area/Old Rifle Range study area. Results of all non-parametric ANOVA tests, listed by metal, are summarized below.

Aluminum: Well 06-07 had significant evidence of contamination, with a rank difference of 10.50 versus a critical difference of 8.82.

Antimony: No wells showed evidence of contamination.

Arsenic: Well 06-07 had significant evidence of contamination, with a rank difference of 9.50 versus a critical difference of 8.82.

Barium: No wells showed evidence of contamination.

Beryllium: Well 06-07 had significant evidence of contamination, with a rank difference of 12.00 versus a critical difference of 8.82.

Cadmium: No wells showed significant evidence of contamination, but well 06-07 could be considered borderline with a rank difference of 8.25 versus a critical difference of 8.82.

Chromium: No wells showed significant evidence of contamination, but well 06-07 had a rank difference of 7.88 compared to a critical difference of 8.82 and bears watching in future monitoring.

Cobalt: Wells 06-06 and 06-07 had significant evidence of contamination with rank differences of 11.25 and 14.75, respectively compared to the critical difference of 8.82. Well 06-12 had a rank difference of 7.00 of 8.82 and bears watching in future monitoring.

Copper: No wells showed evidence of contamination.

Lead: No wells showed evidence of contamination.

Manganese: Wells 06-06 and 06-12 had significant evidence of contamination with rank differences of 15.00 and 9.75, respectively versus the 8.82 critical difference. Well 06-07 was borderline with a rank difference of 8.25 versus 8.82.

Nickel: Wells 06-06 and 06-07 had significant evidence of contamination with rank differences of 11.25 and 14.75, respectively compared to the critical difference of 8.82. Well 06-12 had a rank difference of 7.00 versus 8.82 and bears watching.

Vanadium: No wells showed evidence of contamination.

Zinc: Wells 06-06 and 06-07 had significant evidence of contamination with rank differences of 9.75 and 14.50 compared to the critical difference of 8.82.

Distribution of Contaminants

Parameters detected in the four rounds of sampling at the Demolition Area and Old Rifle Range are tabulated in Appendix G. The amounts detected and MCLs are also shown in the tabulation. Only those detected amounts above detection limit (no "J" values) are shown. The "VALUE_A" field is a data qualifier. A "B" for an organic compound indicates the analyte was found in the associated blank; a "B" for an inorganic compound indicates the reported value is less than the contract required detection limit but greater than the instrument detection limit.

Data evaluation methods

Several metals were detected at least occasionally in wells at the Demolition Area and Old Rifle Range. Explosives compounds were detected only in five wells at the Old Rifle Range, but persistently. Bar charts were prepared for nine selected metals for all wells and for detected explosives and nitrates in the five Old Rifle Range wells. Bar charts permit a visual comparison of the levels of monitored parameters in different wells and groups of wells.

This graphical presentation of metals values supplements the statistical analyses presented in the earlier section. Pertinent results obtained in the statistical analyses are italicized in this section for comparison. The bar charts and accompanying well location maps are presented in Figures 29 through 79. Metals selected for comparison in all wells were copper, chromium, barium, manganese, nickel, antimony, lead, zinc, aluminum and arsenic. Supplementary charts were prepared for iron and magnesium. Detected amounts of beryllium, cadmium and vanadium and unusually high amounts of cobalt were reported for the group of shallow wells in the Demolition Area and were plotted for those wells only. The bar charts for metals compare detected quantities for four rounds of sampling for groups of four or five wells per chart. Three compounds (metals) are presented on each figure. Each chart displays the detection limit for the metal and the MCL, if exceeded. Wells in which a compound was not detected in any of the four rounds are labeled with ND (Not Detected) for that compound. If a compound was detected in at least one of the four rounds, a value of one-half the detection limit, rather than zero, was plotted for the remaining (not-detected) rounds for that compound. The use of one-half the detection limit is a conservative (safe-side) approach to contaminant evaluation, implying that, statistically, the undetected compound is likely to be present at levels below detection if it was detected during any other sampling event.

The reader can better appreciate the meaning of the statistical results, especially the significance of rank differences versus critical differences, by visually comparing the bar charts for a particular metal in a particular well with the list of metals and wells determined to be "statistically significant" in the previous section. For example, the statistical analysis of arsenic in Big Clifty/Beech Creek wells indicated that 06C03 and 06C08 had significant evidence of contamination with arsenic. The bar charts for arsenic in these wells (Figure 37) showed graphically that 06C08 and 06C03 were indeed consistently positive for arsenic. The statistical analysis also indicated that 06C18 ranked close to the critical difference for arsenic and bears watching. The bar chart for 06C18 for arsenic (Figure 52), showed that the well had consistent levels of arsenic above DL, although the actual levels were less than the one-time and two-time occurrences in neighboring wells 06C10 and 06C11, neither of which had statistical evidence of arsenic contamination. The comparisons of the arsenic graphs of Figure 52 with the statistical results emphasizes the importance of consistently elevated levels in a well in establishing contamination status.

The distribution of metals in the study area is also shown by contour maps of *mean* concentrations of each contaminant over the four sampling rounds, for each aquifer. Nitrogen as nitrates and nitrites was also monitored in the fourth (final) round. Contour maps of concentration of nitrates and nitrites for the fourth round were also prepared. The contour maps were prepared using the inverse distance squared gridding algorithm, wherein the influence of a well value decreases as the inverse of the square of the distance to neighboring wells. Contaminant distribution maps prepared for detected

parameters for four aquifers are provided as Appendix K. Selected maps are further presented in discussions of contaminant distribution in this section. Tables 13a and 13b present the calculated *mean* values of mapped parameters (metals, nitrogen and explosives) over the four sampling rounds.

Metals

Demolition Area. Well 06C08 was originally selected to be the background well for the Demolition Area because it was situated north (outside) of the active operations area. Statistical analysis of metals in the Demolition Area/Old Rifle Range, presented earlier, subsequently indicated that 06C08 was actually contaminated with some metals and thus a poor background well. Well 06C07 was used as background for the statistical analyses. Comparisons of metals occurrences were made for two groups of wells, with well 06C08 common to both. The groups were: (1) 06C08, 06C07, 06C06, 06C05, and 06C04 and (2) 06C08, 06C12, 06C01, 06C02, and 06C03. All of the wells were Big Clifty-Beech Creek aquifer wells and were screened in the lower Big Clifty sandstone-Beech Creek limestone.

A third group of Demolition Area wells, 06-01A, 06-06, 06-07, 06-12 and 06C01P3, located in the northeast portion of the operations area, near the Navy E.O.D. area, and screening the upper Pennsylvanian sandstone, was evaluated for presence of metals (locations on Plate 1 and Figure 37).

Bar charts and a map for the first group of wells are presented in Figures 29 through 33. The first group of wells lies generally to the west and south of the operations area at the toe of the Demolition Area ridge, except for 06C08. Barium, copper and antimony were the most persistent metals detected in the group. Arsenic, aluminum and zinc were detected often in well 06C08 but only rarely in any of the other wells of the group. There was no apparent preference of all nine metals for any particular sampling round, nor was there an apparent trend (rise or fall over time). *Statistical analysis identified 06C08 as contaminated with aluminum and arsenic*. Bar charts and map for the second group of wells are presented in Figures 34 through 38. The second group lies generally to the northeast of the operations area at the foot of the slope, except wells 06C08 and 06C01. Barium, copper and antimony were again the most persistent metals detected. Arsenic was detected in concentrations near 0.01 mg/l (detection limit = 0.002 mg/l) in well 06C03, the only Demolition Area well other than 06C08 in which arsenic persisted. There was no apparent preference of all nine metals for any particular sampling round, nor was there an apparent trend. *Statistical analysis identified well 06C03 as contaminated with arsenic*.

The series of contour maps for the Lower Big Clifty/Beech Creek aquifer (Appendix K) indicate that nickel, zinc ,aluminum and nitrates and nitrites

were prevalent in the northern half of the Demolition Area. Other metals were widely distributed.

Bar charts and map for the third group of wells are presented in Figures 39 through 45. The wells in this group, 06-01A, 06-06, 06-07, 06-12 and 06C01P3, are shallow wells screened in the upper Pennsylvanian sandstone of the Demolition Area. Wells 06-06, 06-07 and 06-12 of this group were the only wells in the Demolition Area/Old Rifle Range in which beryllium, cadmium and vanadium were found in more than one sampling round (except that vanadium was found in 06C08 in two rounds). Additional bar charts were prepared for the three metals because there appeared to be a relationship between the metals' occurrence and the well locations.

Statistical ANOVA evaluation of the sampling data showed that wells 06-06, 06-07, and, to a lesser extent, well 06-12, had significant evidence of contamination, or were borderline, with several metals. The bar charts prepared for the well group provide graphic representation of the contaminant distribution. Well 06-07 had above-detection levels of all three metals in at least two sampling events. Cobalt was anomalously high in wells 06-06, 06-07 and 06-12. Figure 41 is a bar chart of cobalt values for the five wells of the group. Levels of cobalt ranged from 0.077 to 0.665 mg/l in the three central wells, but were never higher than 0.04 mg/l in any other well sampled for the Demolition Area/Old Rifle Range study. Wells 06-06, 06-07 and 06-12, especially 06-07, were unusually high in other metals as well.

Zinc was as high as 3 mg/l in 06-07 (Figure 44) and generally less than 0.08 mg/l in other Demolition Area/Old Rifle Range wells. Aluminum was exceedingly high in 06-07, up to 145 mg/l compared to not-detected to 0.2 mg/l in other wells (Figure 44). Arsenic, nickel, and antimony were comparatively high in the three wells, *but antimony was not shown by statistical analysis to be significantly high.* Nickel was as high as 2.0 mg/l in 06-07 (MCL for nickel is 0.1 mg/l). Manganese was statistically insignificant in 06C01P3 relative to the other four wells in this group, but was higher than levels in other Demolition Area wells that were significant. Manganese should probably be considered a contaminant in the group three wells. Iron and magnesium, which were not considered in the statistical analyses because they are not listed for primary MCLs, were anomalously high for wells 06-06 and 06-07 (iron) and 06-06, 06-07, 06-12, and 06-01A (magnesium), Figures 46 and 47. The high levels of metals in this group of shallow wells is strong indication of a local contaminant source at the surface or in the shallow subsurface in the vicinity of 06-06, 06-07 and 06-12. Additional probing should be done in the area to locate the source of the metals.

Investigations at other NSWCC SWMUs containing Pennsylvanian aged aquifers showed a correlation between low pH and relatively high levels of metals in the groundwater. Contour maps of mean pH and conductivity measured during four rounds of sampling were prepared for the upper Penn

(third group) wells (Figure 48). Relatively low pH and high conductivity in the centrally located wells, especially 06-06, 06-07, and 06-12, correlated with relatively high levels of several metals including aluminum, beryllium, cadmium, chromium, cobalt, manganese, nickel, vanadium, and zinc. Mean groundwater conductivity in the three wells was much higher than in other Demolition Area/Old Rifle Range wells. Other Demolition Area/Old Rifle Range aquifers did not show a correlation between metals and pH/ conductivity. Measured and mean values of pH and conductivity for all Demolition Area/Old Rifle Range wells were presented in Appendix E.

The series of contour maps for the Demolition Area, Upper Penn Wells, Appendix K, emphasizes the concentration of certain metals near wells 06-06, 06-07 and 06-12, particularly zinc, aluminum, nickel, beryllium, and cadmium. Barium, common in most wells, was conspicuously absent in well 06-07, the well highest in the other metals including nickel, zinc and aluminum. See Tables 13a and 13b for a tabulation of means.

Occurrence of the secondary MCL metals iron and magnesium in all wells was evaluated briefly because the metals comprise a portion of casings, warheads and drums treated at the Demolition Area/Old Rifle Range. Figures 46 and 47 present the mean levels over four sampling rounds of iron and magnesium, respectively, reported for all wells. Six wells were markedly higher in iron than the remaining wells, with mean values from 5.98 mg/l to 65.5 mg/l (06-07). Four of the wells were within the Demolition Area, including wells 06-06 and 06-07 of the third group of wells discussed two paragraphs above. The other two wells were 06C03, a Beech Creek well, and 06C08P2, a Pennsylvanian well (see Plate 1 for well cluster locations). Twelve wells were markedly higher in magnesium, with mean values from 31.0 mg/l to 392 mg/l (06-06). Seven of the wells were within the Demolition Area, including four wells of the third group of wells discussed above. Other Demolition Area wells high in magnesium were 06C01P3 (Pennsylvanian), 06C02P2 (upper Big Clifty/Beech Creek), and 06C04P2 (Golconda Haney).

Summary of Metals Occurrence in the Demolition Area. *Statistical analysis of metals in the lower (Big Clifty/Beech Creek) aquifer of the Demolition Area identified only aluminum, arsenic and manganese as significant contaminants*. Barium, copper and antimony persisted in four rounds of sampling in Big Clifty-Beech Creek wells monitoring the Demolition Area. The initially selected background well, 06C08, was actually as high or higher in several metals (nickel, antimony, copper, arsenic, aluminum and zinc) than the other wells. Conversely, 06C08 was one of few wells with relatively low levels of the otherwise ubiquitous compound, barium. Metals are persistent in monitoring wells at other SWMUs at NSWC. Certain metals are likely contaminants from the ordnance operations within NSWC, including Demolition Area activities, but may be present in the natural rocks and soils as well. Additional background evaluation for metals base-wide is needed.

The persistent metals barium, copper and antimony are concluded to be naturally occurring (background) components of the Big Clifty/Beech Creek aquifer or artifacts of rinsates and field blanks (copper and antimony occurred in the rinsate blanks at comparable levels). The metal antimony was detected at a level above MCL (0.01 mg/l) in all wells in the second sampling round (but is probably attributable to sampling artifacts). No other metals were detected at levels above MCL in Big Clifty-Beech Creek wells.

Occurrence of the metals vanadium, cadmium, and beryllium was limited to the shallow wells in the northeast portion of the Demolition Area operations area. Cadmium and beryllium were above MCL (0.005 mg/l for cadmium; 0.001 mg/l for beryllium) in well 06-07. The levels and the statistically significant occurrence of these metals and of zinc, nickel, aluminum, arsenic, manganese and cobalt in wells 06-06, 06-07 and 06-12, which are within 300 ft of each other, imply that the uppermost groundwater in that isolated area is being contaminated by a local source. Wells 06-01A and 06C01P3, which are 650 west and 350 ft east, respectively, of the group of wells, had essentially no significant levels of the metals (with the possible exception of manganese in 06C01P3). Additional sampling of surface and shallow soils and continued monitoring of the wells will be necessary to confirm contamination and to delineate its source.

Iron and magnesium were markedly high in at least six Demolition Area wells.

Old Rifle Range. Well cluster 06C16 was selected as the common well for qualitative comparison of the Old Rifle Range wells. The cluster is located to the north and west of the Old Rifle Range open burning activities area. The deep well of the cluster, 06C16, screens the Beech Creek limestone and the lower part of the Big Clifty sandstone. The middle well, 06C16P2, screens the upper part of the Big Clifty sandstone (well 06C16P3 screens the Golconda/Haney limestone). Comparisons of monitored metals were made for two aquifer levels: the "lower zone" represented by the deep wells of each cluster, and the "upper zone" represented by the shallow wells of clusters and by the single wells emplaced for the 1981-83 confirmation study. The surface of the upper zone is the water table. Two groups of 5 or 6 wells each were compared for metals in the lower zone, using bar charts. Refer to Figure 4 for Old Rifle Range well locations. The wells were 06C16, 06C10, 06C11, 06C12 and 06C18 (charts in Figures 49 through 53), and 06C16, 06C15, 10C14, 06C17, 06C09 and 06C13 (charts 54 through 58). Three groups of 5 or 6 wells each were compared for metals in the upper zone. They were 06C16P2, 06C10P2, 06C11P2, 06C12P2 and 06C18P2 (charts 59 through 63), 06C16P2, 06C15P2, 06C14P2, 06-16 (shallow well for 06C17), 06-18 (shallow well for 06C09), and 06C13P2 (charts 64 through 68), and confirmation wells 06-17, 06-20, 06-22, 06-23, 06-19 and 06-14A (charts 69 through 73).

The first group of lower zone wells is in the southern portion of the Old Rifle Range (Figure 49). As in Demolition Area wells, barium, copper and antimony were the most persistent metals detected in the group. Chromium, nickel, arsenic and zinc were detected several times in some of the wells. Chromium and arsenic were detected several times in wells 06C10, 06C11 and 06C18, all located to the southeast and generally downgradient of the Old Rifle Range operations area. Chromium and arsenic were not detected in lower zone wells north or west of 06C13 (see Figure 54) and were not detected in the comparison well, 06C16.

The second group of lower zone wells is in the central and northern portion of the Old Rifle Range (Figure 54). Barium, copper and antimony were again persistent but nickel and zinc were also present in most of the wells in several sampling rounds. Nickel and zinc were higher in wells 06C17 and 06C09, respectively, than in any other Big Clifty/Beech Creek well. Chromium was not detected; arsenic was detected only once.

Contour maps of mean values of detected metals in the lower Big Clifty/Beech Creek aquifer of the Demolition area and Old Rifle Range (Appendix K) include the "lower zone" wells of the Old Rifle Range. The maps for chromium, arsenic, nickel and zinc emphasize the preference of the metals for certain regions within the Old Rifle Range. *The statistical analysis of metals in the Big Clifty/Beech aquifer identified only arsenic (borderline) and manganese as contaminants in Old Rifle Range "lower zone" wells, although well 06C17 was high for nickel.*

The first group of upper zone wells is the upper equivalent of the lower zone wells in the southern portion of the Old Rifle Range (Figure 59). The distribution of metals in the upper zone wells is similar to that of the lower zone. Barium, copper and antimony persist. Chromium occurs in the southeast wells 06C10P2, 06C11P2 and 06C18P2, and arsenic in 06C10P2 and 06C18P2. Zinc is slightly more common in the upper wells than in the lower in the southern part of the Old Rifle Range.

The second group of upper zone wells is the upper equivalent of the lower zone wells in the central and northern portion of the Old Rifle Range (Figure 64). The distribution of metals in the upper zone wells is similar to that of the lower zone. Barium, copper and antimony persist but nickel and zinc were also detected often, as in the upper wells. Arsenic was noticeably present in 06C13P2 and 06C18P2, which are downgradient of the operations area. *Statistical analysis indicated that 06C18P2 and 06C13P2 (borderline) had evidence of arsenic contamination.*

The third group of upper zone wells consists of six confirmation wells that screen the Big Clifty sandstone or the alluvial soils of the Old Rifle Range. Included are the three monitoring wells closest to the flashing pits of the operations area: 06-20, 06-22 and 06-23 (see Figures 4 and 69). No unusual

occurrences of the nine metals evaluated were evident in the six wells, with the possible exception of one-time high values of nickel detected in 06-20 and 06-23 and detectable levels in all four rounds in well 06-17 (Figure 71). Nickel was above its MCL of 0.1 mg/l in 06-20 and 06-23 in one sample event each. *However, the statistical ANOVA indicated that only 06-17, with consistently elevated levels, had significant evidence of nickel contamination.* The only comparable value of nickel detected in Old Rifle Range wells was a single occurrence of 0.112 mg/l in 06C17, a deep zone well southwest of the flashing pits. Again, barium, copper and antimony were common.

Maps of the calculated means of contaminant concentration for the uppermost aquifer at the Old Rifle Range were prepared and are exhibited in Appendix K. Tabulated means were presented in Tables 13a and 13b. The wells of the uppermost aquifer include the wells of the "upper zone" and the confirmation wells for which bar charts were prepared (the 06CXXP2 and 06-XX series of wells). The only apparent preferred distribution for metals was for nickel, aluminum, and lead, which were most common in the northern half of the Old Rifle Range, and arsenic, which was highest in the southeast quadrant near wells 06C13P2 and 06C18P2.

Occurrence of the secondary MCL metals iron and magnesium was evaluated because the metals comprise part of the materials treated at the Old Rifle Range. Figures 46 and 47 present the mean levels of iron and magnesium over four sampling rounds. Two Old Rifle Range wells, 06C13P2 and 06C18P2, located east of the operations area near Highway 8 (Figure 4, locations 06C13 and 06C18), were markedly higher than other wells in iron, with mean values of 8.73 mg/l and 51.9 mg/l, respectively Wells 06C16P2 and 06C16P3 were markedly higher than other wells in magnesium, with mean values of 49.2 mg/l and 31.0 mg/l, respectively These four Old Rifle Range wells are the shallower wells of the respective clusters.

Summary of metals occurrence in the Old Rifle Range. *Statistical analysis identified only arsenic, nickel and manganese as significant contaminants in the uppermost aquifer at the Old Rifle Range.* Barium, copper and antimony persisted in four rounds of sampling in upper and lower alluvial, Big Clifty and Beech Creek wells monitoring the Old Rifle Range, but are considered background (naturally occurring) or artifacts of sampling rinsates or field blanks. Chromium and arsenic were detected several times in upper and lower zone wells in the southeast (downgradient) quadrant of the Old Rifle Range, and nickel in the upper zone wells of the northern half. Nickel was detected at relatively high values (> 0.1 mg/l, where MCL = 0.1 mg/l) one time in two shallow wells close to the flashing pits and consistently *and statistically* in 06-17, located about 200 ft north of the pits.

The metal antimony was detected at a level above MCL (0.01 mg/l) in most of the Old Rifle Range wells in many sampling rounds (*antimony was not statistically significant, however, when compared to background levels*).

Nickel was detected at levels above its MCL of 0.1 mg/l in three wells on one occasion each (including the two shallow wells near the flashing pits). All other metals detected were below MCL.

The secondary MCL metals iron and magnesium were markedly higher in a few wells.

Metals in the Golconda/Haney aquifer. Positions of the four wells screened in the Golconda/Haney limestone aquifer are shown in Figure 74. The wells are 06C04P2, 06C03P2, 06-21 and 06C16P3. Bar charts of detected levels of the nine evaluated metals are presented in Figures 75 through 77. The levels of metals detected in the groundwater of the Golconda/Haney were noticeably less than in other aquifers of the study area. Barium, copper and antimony were most persistent but occurred at lower levels than in other aquifers. Nickel was detected twice in well 06-21, zinc once in 06C04P2, and arsenic once in 06C16P3. Chromium, lead and aluminum were not detected. Antimony was above MCL in six samples, but both copper and antimony were determined to be probable sampling artifacts.

Statistical analysis was not conducted for the Golconda/Haney because of the limited number of wells. Contour maps of calculated mean values of metals in the four Golconda/Haney wells are presented in Appendix K.

Wells 06-21 and 06C04P2 (Figure 74 and Plate 1) were markedly high in the secondary MCL metal magnesium (means of 84.8 mg/l and 48.7 mg/l, respectively).

Explosives and related compounds

Explosives. Eight explosives compounds were monitored for four rounds; nitrates and nitrites were monitored for the fourth round only. TNT, RDX and HMX were the only explosives detected in the Demolition Area/Old Rifle Range study area, and they were detected in only five wells, all within the northern half of the Old Rifle Range. Table 14 lists the detected values of explosives for each sampling round in the five wells. Seven of the 13 detection events for explosives were of "J" values (estimated values below detection limit). The only HMX detection was a "J" value in well 06C09. Values of any explosives above detection limit were recorded only in wells 06-20 and 06-22, both shallow wells near the flashing pits.

A map and bar charts for detected explosives are presented in Figures 78 and 79. TNT occurred in well 06-22 in all four sampling rounds at levels above detection limit. The highest TNT value was 0.148 mg/l in the first round. Measured TNT levels decreased with each succeeding round (Figure 79). RDX occurred twice above detection in well 06-20. All other explosives recorded were below detection limit.

Contour maps of calculated mean values of TNT, HMX and RDX for the four rounds were prepared. The maps are presented in Appendix K with the metals maps and in Figures 80, 81 and 82. Wells plotted on the maps are all uppermost aquifer wells for the Old Rifle Range. The positions of the flashing pits are also shown on the maps. The maps illustrate the limited and preferred distribution of the three explosives in wells near the flashing pits. The highest levels of explosives were in the shallow wells 06-20 and 06-22 near the flashing pits. No explosives compound was detected more than once in deep wells (06C09 and 06C15) and then only at "J" levels. Explosives apparently are migrating from the source area through the aquifer very slowly if at all.

Nitrogen compounds. Nitrates commonly occur with explosives compounds as breakdown byproducts, and can serve as indicators for explosives contamination. For example, the explosive TNT reacts in the presence of oxygen (from ozone) and ultraviolet light to produce the following: $C_7H_5N_3O_6 + 18[O] \rightarrow 7CO_2 + H_2O + 3NO_3^- + 3H^+$ (ICF Kaiser). Nitrates are sometimes attributable to agricultural activities (runoff or infiltration of fertilizers), but the study area has no history of such use. Also, there is an apparent correspondence of high nitrate wells to explosives-contaminated wells at the Old Rifle Range. Nitrates were detected in 33 Demolition Area/ Old Rifle Range wells in the fourth round, the only round in which nitrates were monitored. Nitrates were anomalously high, however, in four of the five Old Rifle Range wells in which explosives compounds were detected. Figure 83 is a bar chart of nitrate levels for the five wells evaluated for explosives. The nitrate levels in wells 06C09, 06-20, 06-22 and 06-18 were all greater than 3 mg/l. The level in 06-20 was 18.2 mg/l. MCL for nitrates is 10 mg/l. Nitrate levels detected in all other Demolition Area/Old Rifle Range wells were less than 1 mg/l. There was no relationship shown for nitrites.

A contour map of detected values of nitrates in the uppermost aquifer wells at the Old Rifle Range is presented in Appendix K and in Figure 84. Nitrates were detected in all but two of the wells shown, but only levels greater than 3 mg/l were contoured. Detected levels of nitrates are tabulated in Table 13b. The concentration of high levels of nitrates near the flashing pits is similar to that of TNT, HMX and RDX and supports the assertion that nitrates and explosives are related in occurrence.

Contour maps of nitrates and nitrites concentrations in the Golconda/ Haney wells are presented in Appendix K.

Summary of contaminant distribution

Statistical analysis of metals detected in four rounds of sampling in Demolition Area and Old Rifle Range monitoring wells provided evidence of contamination in some wells by the following metals: aluminum, arsenic, beryl-

lium, cobalt, manganese, nickel and zinc at the Demolition Area and arsenic, manganese and nickel at the Old Rifle Range. The following metals were considered borderline contaminants, i.e., their statistical values were just below tabulated critical values: cadmium and chromium at the Demolition Area and zinc at the Old Rifle Range.

Non-statistical evaluation of explosives and nitrates indicated contamination of a centrally located group of Old Rifle Range wells by TNT, RDX and nitrates.

Contamination is limited to specific wells or groups of wells. Two maps are provided to show the location and distribution of the named contaminants. Figure 85 shows the distribution of contaminants in Demolition Area wells. Figure 86 shows the distribution of contaminants in Old Rifle Range wells.

7 Conclusions and Recommendations

Conclusions

Hydrogeology

Groundwater flow is generally to the south and southwest in aquifers monitored in the Demolition Area/Old Rifle Range study area, but locally is to the east toward Turkey Creek in the vicinity of the Old Rifle Range. The Big Clifty sandstone-Beech Creek limestone aquifer is the deepest aquifer monitored in the study area. It is continuous beyond the Demolition Area and Old Rifle Range and has the greatest potential of the aquifers for transporting groundwater contaminants outside the area.

Other aquifers monitored in the study area are discontinuous because of topographic isolation or stratigraphic discontinuity, or are hydraulically connected to the deeper aquifer.

The Big Clifty-Beech Creek transmits groundwater through structural discontinuities (joints and bedding planes) and through pores between mineral grains. The aquifer exhibits both confined and unconfined conditions. The Elwren formation, a 10-ft thick shale, underlies the Beech Creek limestone and provides a barrier to vertical infiltration of groundwater.

Most surface runoff and groundwater seepage from the Demolition Area is intercepted and collected by sedimentation ponds around the toe of the ridge. Runoff escaping the ponds ultimately drains to Boggs and Turkey Creeks, which flow to the south, eventually off-base.

Surface runoff from the Old Rifle Range drains to Turkey Creek, and thence south.

Groundwater quality

Certain chemical compounds believed to be derived from operations at the Demolition Area and Old Rifle Range were detected, primarily at low levels,

in the groundwater from four rounds of monitoring of wells. Compounds present in the groundwater of the Big Clifty-Beech Creek aquifer included metals and nitrates at the Demolition Area and metals, nitrates and selected explosives at the Old Rifle Range.

Statistically significant metals detected at the Demolition Area were aluminum, arsenic and manganese. Statistically significant metals detected at the Old Rifle Range were arsenic, nickel and manganese.

Explosives were detected only at the Old Rifle Range. Detected explosives were TNT, RDX and HMX and were limited to five wells, all in the northern half of the Old Rifle Range.

Nitrates were detected in 33 wells of the study area but were anomalously high only in four Old Rifle Range wells, all of which were also positive for explosives.

Several metals were detected in the four wells monitoring the Golconda-Haney limestone aquifer, but at levels notably less than those in the Big Clifty/Beech Creek aquifer.

Unusually high levels of the metals vanadium, cadmium, beryllium, zinc, nickel, aluminum, arsenic, manganese and cobalt occurred in three shallow wells monitoring the Pennsylvanian sediments in an area of limited areal extent in the northeast portion of the Demolition Area. The levels of metals in the wells strongly indicates a local source of contamination in that part of the Demolition Area. The anomalously high levels of metals are accompanied by low pH and high conductivity.

Organics other than explosives compounds were not detected in verifiable quantities in three rounds of sampling. Organic compounds monitored included volatiles, semi-volatiles, pesticides, herbicides and PCBs.

Recommendations

Additional monitoring wells should be installed downgradient (southwest) of the Demolition Area in the Big Clifty-Beech Creek aquifer to determine the extent of metals contamination. Only metals should be monitored. Well installation and monitoring could be incorporated into the Risk Assessment currently planned for the Demolition Area.

Additional source identification and location should be conducted in the local area of the Demolition Area that produced anomalously high metals levels in the shallow Pennsylvanian wells in the northeast portion of the Demolition Area. The specific area requiring additional source investigation is the vicinity of wells 06-06, 06-07 and 06-12.

One additional well cluster should be installed at the Old Rifle Range in the groundwater flow trough defined by equipotential groundwater contour maps in the alluvial-Big Clifty/Beech Creek aquifer.[1] Well clusters 06C13 and 06C18, located west of Highway 8 near the north and south limits of the trough, were two of only a few wells at the Old Rifle Range showing statistically significant metals contamination. The additional well cluster should be screened at the water table and in the lower portion of the aquifer in the Beech Creek limestone and should be placed to the east of Highway 8 in the center of the contour-defined trough to monitor potential contaminant movement to the east toward Turkey Creek. The additional well-cluster might be incorporated into the Risk Assessment currently planned for the Demolition Area.

Subsequent compliance monitoring of Demolition Area/Old Rifle Range wells should monitor explosives, metals, cyanides/sulfides, and nitrates and nitrites.

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[1] An additional well cluster has since been installed east of the Old Rifle Range between Highway 8 and Turkey Creek.

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Table 1
Examples of Concentrations Meeting Criteria for Action Levels (Federal Register 1990)

Constituent Name	Class	Air (ug/m^3)	Water (mg/L)	Soils (mg/kg)
Acetone	D		4E-00	8E+03
Acetonitrile	D		2E-01	5E+02
Acetophenone	D	2E-01	4E-00	8E+03
Acrylamide	B2	8E-04	8E-06	2E-01
Acrylonitrile	B1	1E-02	6E-05	1E-00
Aldicarb	D		5E-02	1E+02
Aldrin	B2	2E-04	2E-06	4E-02
Allyl alcohol	D		2E-01	4E+02
Aluminum phosphide	D		1E-02	3E+01
Aniline	B2		6E-03	1E+02
Antimony	D		1E-02	3E+01
Arsenic	A	7E-05	(1)	8E+01
Asbestos(2)	A	2E-02		
Barium cyanide	D		2E-00	6E+03
Barium, ionic	D	4E-01	(1)	4E+03
Benzidine	A	2E-05	2E-07	3E-03
Beryllium	B2	4E-04	8E-06	2E-01
Bis(2-ethylhexyl)phthalate	B2		3E-03	5E+01
Bis(chloroethyl)ether	B2	3E-03	3E-05	6E-01
Bromodichloromethane(3)	B2		3E-05	5E-01
Bromoform(3)	D		7E-01	2E+03
Bromomethane	D	3E+01	5E-02	1E+02
Butyl benzyl phthalate	C		7E-00	2E+04
Cadmium	B1	6E-04	(1)	4E+01
Calcium cyanide	D		1E-00	3E+03
Carbon disulfide	D		4E-00	8E+03
Carbon tetrachloride	B2	3E-02	3E-04	5E-00
Chloral	D		7E-02	2E+02
Chlordane	B2	3E-03	3E-05	5E-01
Chlorine cyanide	D		2E-00	4E+03
Chlorobenzene	D	2E+01	7E-01	2E+03
Chloroform(3)	B2	4E-02	6E-03	1E+02
2-Chlorophenol	D		2E-01	4E+02

(Sheet 1 of 5)

1 MCL available; see Appendix B.
2 The air action level for asbestos is measured in units of fibers/mililiters.
3 There is an MCL for total trihalomethanes, which includes four constituents: bromoform, bromodichloromethane, chloroform, and dibromochloromethane. Concentration derived using exposure assumptions in Appendix D and reference doses for systemic toxicants and verified risk-specific doses at 10-6 for Class A and B carcinogens and 10-5 for Class C carcinogens (see section VI.F.2.6 for further discussion). A, B and C represents Class A, B and C carcinogens, respectively, D represents a systemic toxicant.

Table 1 (Continued)

Constituent Name	Class	Air (ug/m^3)	Water (mg/L)	Soils (mg/kg)
Chromium (VI)	A	9E-05	(1)	4E+02
Copper cyanide	D		2E-01	4E+02
m-Cresol	D		2E-00	4E+03
o-Cresol	D		2E-00	4E+03
p-Cresol	D		2E-00	40+03
Cyanide	D		7E-01	2E+03
Cyanogen	D		1E-00	3E+03
Cyanogen bromide	D		3E-00	7E+03
DDD	B2		1E-04	3E-00
DDE	B2		1E-04	2E-00
DDT	B2	1E-02	1E-04	2E-00
Dibutyl phthalate	D		4E-00	8E+03
Dibutylnitrosamine	B2	6E-04	6E-06	1E-01
3,3'-Dichlorobenzidine	B2		8E-05	2E-00
Dichlorodiffluoromethane	D	2E+02	7E-00	2E+04
1,2-Dichloroethane	B2	4E-02	(1)	8E-00
1,1-Dichtoroethylene	C	3E-02	(1)	1E+01
2,4-Dichlorophenol	D		1E-01	2E+02
2,4-Dichorophenoxyacetic acid	D		4E-01	8E+02
1,3-Dichloropropene	B2		1E-02	2E+01
Dieldrin	B2	2E-04	2E-06	4E-02
Diethyl phthalate	D		3E+01	6E+04
Diethylnitrosamine	B2	2E-05	2E-07	5E-03
Dimethoate	D		7E-01	2E+03
Dimethylnitrosamine	B2	7E-05	7E-07	1E-02
m-Dinitrobenzene	D		4E-03	8E-00
2,4 Dinitrophenol	D		7E-02	2E+02
2,3-Dinitrotoluene (and 2,6-,mixture)	B2		5E-05	1E-00
1,4-Dioxane	B2		3E-03	6E+01
Diphenylamine	D		9E-01	2E+03
1,2-Diphenylhydrazine	B2	4E-03	4E-05	9E-01
Disulfoton	D		1E-03	3E-00
Endosulfan	D		2E-03	4E-00
Endothall	D		7E-01	2E+03
Endrin	D		(1)	2E+01
Epichlorohydrin	B2	8E-01	4E-03	7E+01
Ethylbenzene	D		4E-00	8E+03
Ethylene dibromide	B2	5E-03	4E-07	8E-03
Formaldehyde	B1	8E-02		
Formic acid	D		7E+01	2E+05

Table 1 (Continued)

Constituent Name	Class	Air (ug/m^3)	Water (mg/L)	Soils (mg/kg)
Glycidyaldehyde	D		1E-02	3E+01
Heptachlor	B2	8E-04	8E-06	2E-01
Heptachlor epoxide	B2	4E-04	4E-06	8E-02
Hexachlordibenzo-p-dioxin	B2	6E-07	1E-08	1E-04
Hexachlorobutadiene	C	4E-01	4E-03	9E+01
alpha-Hexachlorocyclohexane	B2	6E-04	6E-06	1E-01
beta-Hexachlorocyclohexane	C	2E-02	2E-04	4E-00
Hexachlorocyclopentadiene	D	7E-02	2E-01	6E+02
Hexachloroethane	C	3E-00	3E-02	8E+01
Hexachlorophene	D		1E-02	2E+01
Hydrazine	B2	2E-04	1E-05	2E-01
Hydrogen cyanide	D		7E-01	2E+03
Hydrogen sulfite	D		1E-01	2E+02
Isobutyl alcohol	D		1E+01	2E+04
Isophorone	C		9E-02	2E+03
Lead	B2		(1)	
Lindane (gamma-hexachlorocyclohexane)	B2/C		(1)	5E-01
m-Phenylenediamine	D		2E-01	5E+02
Maleic anhydride	D		4E-00	8E+03
Maleic hydrazide	D		2E+01	4E+04
Mercury (inorganic)	D		(1)	2E+01
Methacrylonitrile	D	7E-01	4E-03	8E-00
Methomyl	D		9E-01	2E+03
Methyl chlorocarbonate	D			
Methyl ethyl ketone	D	3E+02	2E-00	4E+03
Methyl isobutyl ketone	D	7E+01	2E-00	4E+03
Methyl parathion	D		9E-03	2E+01
Methylene chloride	B	3E-01	5E-03	9E+01
n-Nitroso-di-n-butylamine	B2	6E-04	6E-06	1E-01
n-Nitroso-n-ethylurea	B			
n-Nitroso-n-methylethylamine	B2		2E-06	3E-02
n-Nitrosodi-n-propylamine	B2		5E-06	1E-01
n-Nitrosodiethanolamine	B2		1E-05	3E-01
n-Nitrosodiphenylamine	B2		7E-03	1E+02
n-Nitrosopyrrolidine	B2	2E-03	2E-05	3E-01
Nickel	D		7E-01	2E+03
Nickel refinery dust	A	4E-03		
Nitric oxide	D		4E-00	8E+03
Nitrobenzene	D	2E-00	2E-02	4E+01
Nitrogen dioxide	D		4E+01	8E+04

(Sheet 3 of 5)

Table 1 (Continued)

Constituent Name	Class	Air (ug/m^3)	Water (mg/L)	Soils (mg/kg)
Osmium tetroxide	D		4E-04	8E-01
Parathion	C		2E-01	5E+02
Pentachlorobenzene	D		3E-02	6E+01
Pentachloronitrobenzene	C	1E-01	1E-01	2E+02
Pentachlorophenol	D		1E-00	2E+03
Phenol	D		2E+01	5E+04
Phenyl mercuric acetate	D		3E-03	6E-00
Phosphine	D		1E-02	2E+01
Phthalic anhydride	D		7E+01	2E+05
Polychlorinated biphenyls	B2		5E-06	9E-02
Potassium cyanide	D		2E-00	4E+03
Potassium silver cyanide	D		7E-00	2E+04
Pronamide	D		3E-00	6E+03
Pyridine	D		4E-02	8E+01
Selenious acid	D		1E-01	2E+02
Selenourea	D		2E-01	4E+02
Silver	D		(1)	2E+02
Silver cyanide	D		4E-00	8E+03
Sodium cyanide	D		1E-00	3E+03
Strychnine	D		1E-02	2E+01
Styrene	C		7E-00	2E+04
1,1,1,2-Tetrachlorethane	C	1E-00	1E-02	3E+02
1,2,4,5-Tetrachlorobenzene	D		1E-02	2E+01
1,1,1,2-Tetrachloroethane	C	1E-00	1E-02	3E+02
1,1,2,2-Tetrachloroethane	C	2E-01	2E-03	4E+01
Tetrachloroethylene	B2	1E-00	7E-04	1E+01
2,3,4,6-Tetrachlorophenol	D		1E-00	2E+03
Tetraethyl lead	D		4E-06	8E-03
Tetraethyldithiopyrophosphate	D		2E-02	4E+01
Thallic oxide	D		2E-03	6E-00
Thallium acetate	D		3E-03	7E-00
Thallium carbonate	D		3E-03	6E-00
Thallium chloride	D		3E-03	6E-00
Thallium nitrate	D		3E-03	7E-00
Thallium sulfate	D		3E-03	6E-00
Thiosemicarbazide	D		2E-01	5E+02
Tairam	D		2E-01	4E+02
Toluene	D	7E+03	1E+01	2E+04
Toxaphene	B2	3E-03	(1)	6E-01
1,2,4-Trichlorobenzene	D	1E+01	7E-01	2E+03

(Sheet 4 of 5)

Table 1 (Concluded)

Constituent Name	Class	Air (ug/m^3)	Water (mg/L)	Soils (mg/kg)
1,1,1-Trichloroethane	D	1E+03	3E-00	7E+03
1,1,2-Trichloroethane	C	6E-01	6E-03	1E+02
Trichloroethylene	B2		(1)	6E+01
Trichloromonofluoromethane	D	7E+02	1E+01	2E+04
2,4,5-Trichlorophenol	D		4E-00	8E+03
2,4,6-Trichlorophenol	B2	2E-01	2E-03	4E+01
2,4,5-Trichlorophenoxyacetic acid	D		(1)	8E+02
1,2,3-Trichloropropane	D		2E-01	5E+02
Vanadium pentoxide	D		3E-01	7E+02
Xylenes	D	1E+03	7E+01	2E+05
Zinc cyanide	D		2E-00	4E+03
Zinc phosphide	D		1E-02	2E+01

(Sheet 5 of 5)

Table 2
Maximum Contaminant Levels (MCL) for Drinking Water (April 1992)

Chemicals	Status[1] Reg.	MCLG (mg/l)	MCL (mg/l)	Sampled, SWMU 06
Organics				
Acrylamide	F	zero	TT[2]	
Acrylonitrile	L			
Adipates (diethylhexyl)	P	.5	.5	
Alachlor	F	zero	0.002	
Aldicarb	F	0.001	0.003	
Aldicarb sulfone	F	0.001	0.002	
Aldicarb sulfoxide	F	0.001	0.004	
Atrazine	F	0.003	0.003	
Bentazon	L			
Benzo(a)anthracene (PAH)	P	zero	0.0001	X
Benzene	F	zero	0.005	X
Benzo(a)pyrene (PAH)	P	zero	0.0002	X
Benzo(b)fluoranthene (PAH)	P	zero	0.0002	X
Benzo(k)fluoranthene (PAH)	P	zero	0.0002	X
Bromacil	L			
Bromobenzene	L			
Bromochloroacetonitrile	L			
Bromodichloromethane (THM)	L		0.1	X
Bromoform (THM)	L		0.1	X
Bromomethane	L			X
Butyl benzyl phthalate (PAE)	P	zero	0.1	X
Carbofuran	F	0.04	0.04	
Carbon Tetrachloride	F	zero	0.005	X
Chloral hydrate	L			
Chlordane	F	zero	0.002	X
Cholorodibromomethane (THM)	L		0.1	
Chloroethane	L			X
Chloroform (THM)	L		0.1	X
Chloromethane	L			X
Chloropicrin	L			
Chlorotoluene o-	L			
Chlorotoluene p-	L			
Chrysene (PAH)	P	zero	0.0002	X
Cyanazine	L			
Cyanogen chloride	L			
2,4-D	F	0.07	0.07	X
DCPA (Dacthal)	L			

(Sheet 1 of 4)

[1] F = Final, L = Listed for regulation, and P = Proposed.
[2] TT = Treatment technique.

Table 2 (Continued)

Chemicals	Status[1] Reg.	MCLG (mg/l)	MCL (mg/l)	Sampled, SWMU 06
Dalapon	P	0.2	0.2	
Di[2-ethylhexyl]adipate	P	0.4	0.4	
Dibenzo(a,h)anthracene (PAH)	P	zero	0.0003	X
Dibromoacetonitrile	L			
Dibromochloropropane (DBCP)	F	zero	0.0002	
Dibromomethane	L			
Dicamba	L			
Dichloroacetaldehyde	L			
Dichloroacetic acid	L			
Dichloroacetonitrile	L			
Dichlorobenzene p-	F	0.075	0.075	X
Dichlorobenzene o-,m-	L	0.6	0.6	X
Dichlorodifluoromethane	L			
Dichloroethane (1,1-)	L			X
Dichloroethane (1,2-)	F	zero	0.005	X
Dichloroethylene (1,1-)	F	0.007	0.007	X
Dichloroethylene (cis-1,2-)	F	0.07	0.07	X
Dichloroethylene (trans-1,2-)	F	0.1	0.1	X
Dichloromethane (methylene chloride	P	zero	0.005	X
Dichloropropane (1,2-)	F	zero	0.005	X
Dichloropropane (1,3-)	L			
Dichloropropane (2,2-)	L			
Dichloropropene (1,1-)	L			
Dichloropropene (1,3-)	L			
Diethylhexyl phthalate (PAE)	P	zero	0.004	
Dinitrotoluene (2,4-)	L			X
Dinitrotoluene (2,6-)	L			X
Dinoseb	P	0.007	0.007	X
Diquat	P	0.02	0.02	
Endothall	P	0.1	0.1	
Endrin	P	0.002	0.002	X
Epichlorohydrin	F	zero	TT	
Ethylbenzene	F	0.7	0.7	X
Ethylene dibromide (EDB)	F	zero	0.00005	
ETU	L			
Fluorotrichloromethane	L			
Glyphosate	P	0.7	0.7	
Heptachlor	F	zero	0.0004	X
Heptachlor epoxide	F	zero	0.0002	X
Hexachlorobenzene	P	zero	0.001	X

(Sheet 2 of 4)

Table 2 (Continued)

Chemicals	Status[1] Reg.	MCLG (mg/l)	MCL (mg/l)	Sampled, SWMU 06
Hexachlorobutadiene	L			X
Hexachlorocyclopentadiene	P	0.05	0.05	X
Hexachloroethane	L			X
Hypochlorite	L			
Indeno(1,2,3,-c,d)pyrene (PAH)	P	zero	0.0004	X
Isophorone	L			X
Lindane	F	0.0002	0.0002	
Methomyl	L			
Methoxychlor	F	0.04	0.04	X
Methyl ethyl ketone	L			
Methyl tert butyl ether	L			
Metolachlor	L			
Metribuzin	L			
Monochloroacetic acid	L			
Monochlorobenzene	F	0.1	0.1	
Oxamyl (Vydate)	P	0.2	0.2	
Ozone by-products	L			
Pentachlorophenol	F	zero	0.001	X
Picloram	P	0.5	0.5	
Polychlorinated biphenyls (PCBs)	F	zero	0.0005	X
Prometon	L			
Simazine	P	0.004	0.004	
Styrene	F	0.1	0.1	X
2,4,5-T	L			X
2,3,7,8-TCDD (Dioxin)	P	zero	$5X10^{-8}$	
Tetrachloroethane (1,1,1,2-)	L			
Tetrachloroethane (1,1,2,2-)	L			X
Tetrachloroethylene	F	zero	0.005	X
Toluene	F	1	1	X
Toxaphene	F	zero	0.003	X
2,4,5-TP	F	0.05	0.05	X
Trichloroacetic acid	L			
Trichlroacetonitrile	L			
Trichlorobenzene (1,2,4-)	P	0.007	0.007	X
Trichloroethane (1,1,1-)	F	0.2	0.2	X
Trichloroethane (1,1,2-)	P	0.003	0.005	X
Trichloroethanol (2,2,2-)	L			
Trichlorethylene	F	zero	0.005	X
Trichlorophenol (2,4,6-)	L			X
Trichloropropane (1,2,3-)	L			
Trifluralin	L			

(Sheet 3 of 4)

Table 2 (Concluded)

Chemicals	Status[1] Reg.	MCLG (mg/l)	MCL (mg/l)	Sampled, SWMU 06
Organics (Continued)				
Vinyl chloride	F	zero	0.002	X
Xylenes	F	10	10	X
Inorganics				
Aluminum	L			X
Antimony	P	0.003	0.01/0.005	X
Arsenic	under rev.		0.05	X
Asbestos (fibers > 10um)	F	7 MFL	7 MFL	
Barium	F	2	2	X
Beryllium	P	zero	0.001	X
Boron	L			
Cadmium	F	0.005	0.005	X
Chloramine	L			
Chlorate	L			
Chlorine	L			
Chlorine dioxide	L			
Chlorite	L			
Chromium (total)	F	0.1	0.1	X
Copper	P	1.3	TT action level 1.3	X
Cyanide	P	0.2	0.2	X
Fluoride (under review)	F	4	4	
Lead (at tap)	F	zero	TT action level 0.015	X
Manganese	F		0.05	X
Mercury	F	0.002	0.002	X
Molybdenum	L			
Nickel	P	0.1	0.1	X
Nitrate (as N)	F	10	10	X
Nitrite (as N)	F	1	1	X
Nitrate + Nitrite (both as N)	F	10	10	
Selenium	F	0.05	0.05	X
Strontium	L			
Sulfate	P	400/500	400/500	
Thallium	P	0.0005	0.002/0.001	X
Vanadium	L			X
Zinc	L			X

(Sheet 4 of 4)

Table 3
Monitoring Well Data for SWMU 06 Demolition Area/Old Rifle Range

Well Number	Date Installed	Total Depth, ft	Elevation TOC ft NGVD	Elevation Screen Top, ft	Elevation Screen Bottom, ft	Screen Position
06-01A	17-Sep-81	19	685.96	678.36	668.26	Upper Penn SS
06-01B	06-Nov-81	44.7	685.93	652.96	643.79	Upper Penn SS
06-02	21-Sep-81	39	NA	NA	NA	
06-03	21-Sep-81	20.3	NA	NA	NA	
06-04	01-Oct-81	30	NA	NA	NA	
06-05	02-Oct-81	27	NA	NA	NA	
06-06	13-Oct-81	62.3	674.71	624.06	614.78	Upper Penn SS
06-07	15-Oct-81	29	663.06	645.66	636.36	Upper Penn SS
06-08	14-Oct-81	27.5	NA	NA	NA	
06-09	16-Oct-81	39.17	NA	NA	NA	
06-10	17-Oct-81	32.1	NA	NA	NA	
06-11	17-Oct-81	30.5	NA	NA	NA	
06-12	03-Nov-81	51.7	669.87	629.70	620.55	Upper Penn SS
06-13	05-Nov-81	52	NA	NA	NA	
06-14A	04-Aug-83	20	508.36	499.07	489.97	Alluv/Big Clift (?)
06-15	31-Oct-81	17	513.07	507.51	498.40	Big Clifty SS
06-16	02-Nov-81	45.15	530.45	496.95	487.85	Big Clifty SS
06-17	10-Nov-81	22.55	513.65	502.80	493.46	Big Clifty SS
06-18	13-Nov-81	26.2	510.7	496.1	486.8	Alluvial/Big Clifty
06-19	23-Nov-81	20	505.93	493.67	488.38	Alluvial/Big Clifty
06-20	24-Nov-81	30.5	518.39	499.45	490.31	Alluvial/Big Clifty
06-21	16-Jul-83	48	578.27	541.77	532.67	Golconda/Haney LS
06-22	25-Aug-83	26	510.25	495.93	486.80	Alluvial/Big Clifty
06-23	30-Sep-83	26	508.99	494.44	485.34	Alluvial/Big Clifty
06C01	23-Nov-89	242.2	678.63	484.13	444.13	Big Clifty/Beech Crk
06C01P2	29-Nov-89	117	678.59	569.09	559.09	Pennsylvanian
06C01P3	30-Nov-89	55	678.69	631.19	621.19	Upper Penn SS
06C02	07-Dec-89	73.8	513.57	463.97	443.97	Big Clifty/Beech Crk
06C02P2	11-Dec-89	40	513.35	480.85	470.85	Big Clifty upper
06C03	13-Dec-89	91.8	507.43	438.13	418.13	Big Clifty/Beech Crk
06C03P2	15-Dec-89	20	507.56	495.06	485.06	Golconda/Haney LS
06C04	22-Jan-90	103.3	520.2	439.7	419.7	Big Clifty/Beech Crk
06C04P2	23-Jan-90	27	520.39	500.89	490.89	Golconda/Haney LS
06C05	25-Jan-90	86.4	506.93	444.03	424.03	Big Clifty/Beech Crk
06C06	29-Jan-90	75.4	512.19	460.29	440.29	Lower Penn/Beech Crk
06C06P2	30-Jan-90	132.5	512.05	487.05	477.05	Pennsylvanian
06C07	06-Feb-90	87.5	513.26	449.16	429.16	Beech Creek LS
06C08	20-Feb-90	283.2	709.15	466.85	426.85	Big Clifty/Beech Crk

(Continued)

Table 3 (Concluded)

Well Number	Date Installed	Total Depth, ft	Elevation TOC ft NGVD	Elevation Screen Top, ft	Elevation Screen Bottom, ft	Screen Position
06C08P2	22-Feb-90	91.5	709.1	625.1	615.1	Pennsylvanian
06C09	28-Feb-90	63	511.66	459.46	449.46	Beech Creek LS
06C10	05-Mar-90	72.5	513.38	465.38	445.38	Big Clifty/Beech Crk
06C10P2	06-Mar-90	33	513.27	487.77	477.77	Big Clifty upper
06C11	08-Mar-90	61.1	502.31	463.61	443.61	Big Clifty/Beech Crk
06C11P2	08-Mar-90	30	502.31	479.81	469.81	Big Clifty upper
06C12	12-Mar-90	82.8	522.7	463.7	443.7	Big Clifty/Beech Crk
06C12P2	13-Mar-90	38	522.56	492.06	482.06	Big Clifty upper
06C13	19-May-90	62.9	507.66	470.16	450.16	Big Clifty/Beech Crk
06C13P2	19-May-90	30	507.44	484.94	474.94	Big Clifty upper
06C14	24-May-90	52.7	510.53	480.03	460.03	Big Clifty/Beech Crk
06C14P2	25-May-90	25	510.46	492.96	482.96	Big Clifty upper
06C15	26-May-90	62.2	513.95	475.45	455.45	Big Clifty/Beech Crk
06C15P2	27-May-90	30	513.92	491.42	481.42	Big Clifty upper
06C16	04-Jun-90	88.5	532.96	466.66	446.66	Big Clifty/Beech Crk
06C16P2	06-Jun-90	40	532.58	500.08	490.08	Big Clifty upper
06C16P3	07-Jun-90	20	532.67	520.17	510.17	Golconda/Haney LS
06C17	12-Jun-90	81.2	529.54	467.84	447.84	Beech Creek LS
06C18	14-Jun-90	62.4	507.74	466.04	446.04	Big Clifty/Beech Crk
06C18P2	15-Jun-90	33	507.81	482.31	472.31	Big Clifty upper
06C19	25-Nov-94	54.4	504.68	466.74	446.74	Beech Creek
06C19P2	19-Nov-94	25.00	504.46	489.37	479.37	Big Clifty upper

Table 4
Survey Data for SWMU 06, Demolition Area/Old Rifle Range

Well Number	Date Installed	East Coord, ft	North Coord, ft	Elev TOC ft, NGVD
06-01A	17-Sep-81	571462	484072	685.96
06-01B	06-Nov-81	571464	484079	685.93
06-02	21-Sep-81	NA	NA	NA
06-03	21-Sep-81	NA	NA	NA
06-04	01-Oct-81	NA	NA	NA
06-05	02-Oct-81	NA	NA	NA
06-06	13-Oct-81	572087	483462	674.71
06-07	15-Oct-81	572036	483679	663.06
06-08	14-Oct-81	NA	NA	NA
06-09	16-Oct-81	NA	NA	NA
06-10	17-Oct-81	NA	NA	NA
06-11	17-Oct-81	NA	NA	NA
06-12	03-Nov-81	572210	483428	669.87
06-13	05-Nov-81	NA	NA	NA
06-14A	04-Aug-83	573199	484427	508.36
06-15	31-Oct-81	573359	485522	513.07
06-16	02-Nov-81	572951	485113	530.45
06-17	10-Nov-81	573358	485529	513.65
06-18	13-Nov-81	573269	484992	510.70
06-19	23-Nov-81	573219	484719	505.93
06-20	24-Nov-81	573304	485239	518.39
06-21	16-Jul-83	572607	485309	578.27
06-22	25-Aug-83	573419	485285	510.25
06-23	30-Sep-83	573423	485150	508.99
06C01	23-Nov-89	572568	483459	678.63
06C01P2	29-Nov-89	572572	483461	678.59
06C01P3	30-Nov-89	572577	483462	678.69
06C02	07-Dec-89	573527	483501	513.57
06C02P2	11-Dec-89	573527	483506	513.35
06C03	13-Dec-89	571965	481567	507.43
06C03P2	15-Dec-89	571964	481572	507.56
06C04	22-Jan-90	571501	479270	520.20
06C04P2	23-Jan-90	571497	479267	520.39
06C05	25-Jan-90	569436	479365	506.93
06C06	29-Jan-90	569354	481160	512.19
06C06P2	30-Jan-90	569357	481156	512.05
06C07	06-Feb-90	568515	483127	513.26
06C08	20-Feb-90	570384	485027	709.15
06C08P2	22-Feb-90	570389	485023	709.10

(Continued)

Table 4 (Concluded)				
Well Number	Date Installed	East Coord, ft	North Coord, ft	Elev TOC ft, NGVD
06C09	28-Feb-90	573263	485007	511.66
06C10	05-Mar-90	573171	484104	513.38
06C10P2	06-Mar-90	573167	484106	513.27
06C11	08-Mar-90	573448	484003	502.31
06C11P2	08-Mar-90	573447	484007	502.31
06C12	12-Mar-90	572771	484275	522.70
06C12P2	13-Mar-90	572776	484275	522.56
06C13	19-May-90	573573	484932	507.66
06C13P2	19-May-90	573572	484927	507.44
06C14	24-May-90	573908	485445	510.53
06C14P2	25-May-90	573904	485442	510.46
06C15	26-May-90	573405	485667	513.95
06C15P2	27-May-90	573401	485670	513.92
06C16	04-Jun-90	573139	485884	532.96
06C16P2	06-Jun-90	573141	485879	532.58
06C16P3	07-Jun-90	573142	485874	532.67
06C17	12-Jun-90	572953	485101	529.54
06C18	14-Jun-90	573508	484472	507.74
06C18P2	15-Jun-90	573508	484478	507.81
06C19	25-Nov-94	573822	484566	504.68
06C19P2	19-Nov-94	573812	484566	504.46

Table 5
Water Level Measurements in Demolition Area/Old Rifle Range Wells

Well Number	Geologic Formation	TOC Elev ft, NGVD	Ground Water Elev, ft May-Jun 1991	Ground Water Elev, ft Nov 1991	Ground Water Elev, ft Mar-Apr 1992
06-01A	Upper Pennsylvanian	685.96	675.21	671.61	673.26
06-01B	Upper Pennsylvanian	685.93	Dry	Dry	Dry
06-06	Upper Pennsylvanian	674.71	629.41	629.41	629.46
06-07	Upper Pennsylvanian	663.06	644.21	644.66	646.46
06-12	Upper Pennsylvanian	669.87	630.12	630.47	630.17
06-14A	Alluvial/Big Clifty	508.36	502.16	500.61	504.56
06-15	Big Clifty SS	513.07	501.17	Dry	500.52
06-16	Big Clifty SS	530.45	499.95	494.50	499.75
06-17	Big Clifty SS	513.65	501.30	495.55	500.60
06-18	Alluvial/Big Clifty	510.00	498.10	493.65	498.05
06-19	Alluvial/Big Clifty	505.93	498.53	493.53	501.93
06-20	Alluvial/Big Clifty	518.39	499.39	494.29	498.59
06-21	Golconda	578.27	535.32	Dry	535.82
06-22	Alluvial/Big Clifty	510.25	499.30	494.20	498.75
06-23	Alluvial/Big Clifty	508.99	499.14	493.84	499.99
06C01	Big Clifty/Beech Creek	678.63	499.43	493.53	496.23
06C01P2	Lower Pennsylvanian	678.59	Dry	Dry	Dry
06C01P3	Upper Pennsylvanian	678.69	636.14	635.44	634.79
06C02	Big Clifty/Beech Creek	513.57	496.17	493.07	496.02
06C02P2	Big Clifty	513.35	497.00	493.05	496.75
06C03	Big Clifty/Beech Creek	507.43	491.98	487.58	492.58
06C03P2	Golconda	507.56	503.41	502.86	505.06
06C04	Big Clifty/Beech Creek	520.20	490.55	485.20	490.60
06C04P2	Golconda	520.39	499.04	498.49	499.99
06C05	Big Clifty/Beech Creek	506.93	489.18	482.78	488.68
06C06	Beech Creek	512.19	491.39	485.59	491.24
06C06P2	Pennsylvanian	512.05	501.85	498.15	505.70
06C07	Beech Creek	513.26	492.51	488.06	492.91
06C08	Big Clifty/Beech Creek	709.15	497.65	494.95	497.65
06C08P2	Pennsylvanian	709.10	640.65	636.20	640.65
06C09	Beech Creek	511.66	497.26	493.46	497.21
06C10	Big Clifty/Beech Creek	513.38	498.23	493.78	497.98
06C10P2	Big Clifty Upper	513.27	498.82	494.12	498.77
06C11	Big Clifty/Beech Creek	502.31	496.86	492.81	496.71
06C11P2	Big Clifty Upper	502.31	496.86	492.71	496.76
06C12	Big Clifty/Beech Creek	522.70	498.70	494.10	498.35
06C12P2	Big Clifty Upper	522.56	499.11	494.26	498.91
06C13	Big Clifty/Beech Creek	507.66	497.31	493.46	497.06
06C13P2	Big Clifty Upper	507.44	497.49	493.39	497.39

(Continued)

Table 5 (Concluded)					
Well Number	Geologic Formation	TOC Elev ft, NGVD	Ground Water Elev, ft May-Jun 1991	Ground Water Elev, ft Nov 1991	Ground Water Elev, ft Mar-Apr 1992
06C14	Big Clifty/Beech Creek	510.53	497.38	493.08	497.18
06C14P2	Big Clifty Upper	510.46	498.11	494.41	498.01
06C15	Big Clifty/Beech Creek	513.95	497.15	493.30	497.05
06C15P2	Big Clifty Upper	513.92	499.87	494.97	498.37
06C16	Big Clifty/Beech Creek	532.96	497.36	493.26	497.06
06C16P2	Big Clifty Upper	532.58	501.43	496.58	499.78
06C16P3	Golconda	532.67	515.67	514.47	516.52
06C17	Beech Creek	529.54	497.29	493.44	497.09
06C18	Big Clifty/Beech Creek	507.74	497.09	493.39	496.99
06C18P2	Big Clifty Upper	507.81	497.01	493.21	497.06

Table 6
Detection Limits (in mg/l) of Monitored Compounds

Parameter	IDL	MDL	CRDL
Metals			
Aluminum	0.01	0.1	0.2
Antimony	0.003	0.005	0.06
Arsenic	0.002	0.005	0.01
Barium	0.01	0.1	0.2
Beryllium	0.001	0.005	0.005
Cadmium	0.004	0.02	0.005
Calcium	0.2	0.2	5
Chromium	0.005	0.02	0.01
Cobalt	0.006	0.05	0.05
Copper	0.005	0.02	0.025
Iron	0.01	0.03	0.1
Lead	0.001	0.001	0.005
Magnesium	0.1	0.03	5
Manganese	0.005	0.01	0.015
Mercury	0.0002	0.0002	0.0002
Nickel	0.005	0.02	0.04
Potassium	1	varies	5
Selenium	0.002	0.005	0.005
Silver	0.001	0.02	0.01
Sodium	0.1	0.1	5
Thallium	0.002	0.01	0.03
Tin	0.035	0.05	not on CLP
Vanadium	0.005	0.02	0.05
Zinc	0.006	0.01	0.02
CN, Sulfide			
Cyanide	0.005	---	---
Sulfide	0.02	---	---
Nitrates, Nitrites			
Nitrates	0.02	---	---
Nitrites	0.005	---	---
Explosives			
DNB	0.02	0.0024	not on CLP
HMX	0.02	0.013	not on CLP
RDX	0.02	0.012	not on CLP
Tetryl	0.02	0.026	not on CLP
TNB	0.02	0.005	not on CLP
TNT	0.02	0.0026	not on CLP
2,4-DNT	0.02	0.0157	not on CLP

(Sheet 1 of 5)

IDL = Instrument Detection Limit
MDL = Method Detection Limit
CRQL = Contract Required Quantitation Limit
HMX = octahydro-1,3,5,7-tetranito-1,3,5,7-tetrazocine
RDX = hexahydro-1,3,5-trinitro-1,3,5-triazine
DNB = 1,3-dinitrobenzene
TNB = 1,3,5-trinitrobenzene
TNT = 2,4,6-trinitrotoluene
2,4-DNT = 2,4-dinitrotoluene

Table 6 (Continued)

Parameter	IDL	MDL	CRDL
Volatiles			
Acetone	0.10	0.1	0.1
Benzene	0.005	0.005	0.005
Bromodichloromethane	0.005	0.005	0.005
Bromoform	0.005	0.005	0.005
Bromomethane	0.01	0.01	0.01
Carbondisulfide	0.005	0.005	0.005
Carbon Tetrachloride	0.005	0.005	0.005
Chlorobenzene	0.005	0.005	0.005
Chloroethane	0.01	0.01	0.01
Chloroform	0.005	0.005	0.005
Chloromethane	0.01	0.01	0.01
Cis-1,2-Dichloroethene	0.005	0.005	0.005
Cis-1,3-Dichloropropene	0.005	0.005	0.005
Dibromochloromethane	0.005	0.005	0.005
Ethylbenzene	0.005	0.005	0.005
Methylene Chloride	0.005	0.005	0.005
Styrene	0.005	0.005	0.005
Tetrachloroethene	0.005	0.005	0.005
Toluene	0.005	0.005	0.005
Trans-1,2-Dichloroethene	0.005	0.005	0.005
Trans-1,3-Dichloropropene	0.005	0.005	0.005
Trichloroethene	0.005	0.005	0.005
T-Xylene	0.005	0.005	0.005
Vinyl Acetate	0.05	0.05	0.05
Vinyl Chloride	0.01	0.01	0.01
1,1-Dichloroethene	0.005	0.005	0.005
1,1,1-Trichloroethane	0.005	0.005	0.005
1,1,2-Trichloroethane	0.005	0.005	0.005
1,1,2,2-Tetrachloroethane	0.005	0.005	0.005
1,2-Dichloroethane	0.005	0.005	0.005
1,2-Dichloropropane	0.005	0.005	0.005
2-Butanone	0.10	0.10	0.1
2-Hexanone	0.05	0.05	0.01
4-Methyl-2-Pentanone	0.05	0.05	0.05
BNA			
Acenaphthene	0.01	0.01	0.01
Acenaphthylene	0.01	0.01	0.01
Aniline	0.02	---	---
Anthracene	0.01	0.01	0.01
Benzidine	0.05	---	---
Benzo(a)Anthracene	0.01	0.01	0.01
Benzo(a)Pyrene	0.01	0.01	0.01
Benzo(b)Fluoranthene	0.01	0.01	0.01

(Sheet 2 of 5)

Table 6 (Continued)

Parameter	IDL	MDL	CRDL
BNA (Continued)			
Benzo(G,H,I)Perylene	0.01	0.01	0.01
Benzo(k)Fluoranthene	0.01	0.01	0.01
Benzoic Acid	0.05	0.05	0.05
Benzyl Alcohol	0.02	0.02	0.01
Bis(2-Chloroethoxy)Methane	0.01	0.01	0.01
Bis(2-Chloroethyl)Ether	0.01	0.01	0.01
Bis(2-chloroisopropyl)Ether	0.01	0.01	0.01
Bis(2-Ethylthexyl)Phthalate	0.01	0.01	0.01
Butylbenzylphthalate	0.01	0.01	0.01
Chrysene	0.01	0.01	0.01
Dibenzo(A,H)Anthracene	0.01	0.01	0.01
Dibenzofuran	0.01	0.01	0.01
Dibutylphthalate	0.01	0.01	0.01
Diethyl Phthalate	0.01	0.01	0.01
Dimethyl Phthalate	0.01	0.01	0.01
Di-N-Octylphthalate	0.01	0.01	0.01
Fluoranthene	0.01	0.01	0.01
Fluorene	0.01	0.01	0.01
Hexachlorobenzene	0.01	0.01	0.01
Hexachlorobutadiene	0.01	0.01	0.01
Hexachlorocyclopentadiene	0.01	0.01	0.01
Hexachloroethane	0.01	0.01	0.01
Indeno(1,2,3-C,D)Pyrene	0.01	0.01	0.01
Isophorone	0.01	0.01	0.01
Naphthalene	0.01	0.01	0.01
Nitrobenzene	0.01	0.01	0.01
N-Nitrosodiphenyl Amine	0.01	0.01	0.01
N-Nitroso-Di-N-Propylamine	0.01	0.01	0.01
N-Nitrosodimethylamine	0.01	---	---
Pentachlorophenol	0.05	0.05	0.05
Phenanthrene	0.01	0.01	0.01
Phenol	0.01	0.01	0.01
Pyrene	0.01	0.01	0.01
1,2-Dichlorobenzene	0.01	0.01	0.01
1,2-Diphenylhydrazine	0.01	---	---
1,2,4-Trichlorobenzene	0.01	0.01	0.01
1,3-Dichlorobenzene	0.01	0.01	0.01
1,4-Dichlorobenzene	0.01	---	---
2-Chlorophenol	0.01	0.01	0.01
2-Methylnaphthalene	0.01	0.01	0.01
2-Methylphenol	0.01	0.01	0.01
2-Methyl-4,6-Dinitrophenol	0.05	0.05	0.05
2-Nitroaniline	0.05	0.05	0.05

(Sheet 3 of 5)

Table 6 (Continued)			
Parameter	IDL	MDL	CRDL
BNA (Continued)			
2-Nitrophenol	0.01	0.01	0.01
2,4-Dichlorophenol	0.01	0.01	0.01
2,4-Dimethylphenol	0.01	0.01	0.01
2,4-Dinitrophenol	0.05	0.05	0.05
2,4-Dinitrotoluene	0.01	0.01	0.01
2,4,5-Trichlorophenol	0.01	0.01	0.05
2,4,6-Trichlorophenol	0.01	0.01	0.01
2,6-Dinitrotoluene	0.01	0.01	0.01
3,3-Dichlorobenzidine	0.02	0.02	0.02
3-Nitroaniline	0.05	0.05	0.05
4-Bromophenyl Ether	0.01	0.01	0.01
4-Chloroaniline	0.02	0.02	0.02
4-Chlorophenyl Phenyl Ether	0.01	0.01	0.01
4-Chloro-3-Methylphenol	0.02	0.02	0.02
4-Methylphenol	0.01	0.01	0.01
4-Nitroaniline	0.05	0.05	0.05
4-Nitrophenol	0.05	0.05	0.05
Pesticides, Herbicides, and PCBs			
A-BHC	0.000030	0.000003	0.00005
a-Chlordane	0.000050	---	---
A-Endosulfan	0.00014	0.000014	0.000014
Aldrin	0.000040	0.000004	0.00005
B-BHC	0.000090	0.000009	0.00009
B-Endosulfan	0.000040	0.000004	0.00004
D-BHC	0.000090	0.000009	0.00009
Dieldrin	0.000020	0.000002	0.0001
Disulfoton	0.000700	0.0002	0.002
Endosulfan Sulfate	0.00066	0.000066	0.00066
Endrin	0.000060	0.000006	0.0001
Endrin Aldehyde	0.00023	0.000023	0.00023
Ethyl Parathion	0.00060	---	---
Famphur	0.0012	---	---
G-BHC	0.00040	0.000004	0.00005
g-Chlordane	0.000050	---	---
Heptachlor	0.000030	0.000003	0.00005
Heptachlor Epoxide	0.00080	0.000083	0.00005
Kepone	0.0060	---	---
Methoxychlor	0.0017	0.000176	0.0005
Methyl Parathion	0.0012	0.00003	0.0003
PCB-1016	0.006	---	---
PCB-1221	0.006	---	---
PCB-1232	0.006	---	---
PCB-1242	0.0006	0.000065	0.00065

(Sheet 4 of 5)

Table 6 (Concluded)

Parameter	IDL	MDL	CRDL
Pesticides, Herbicides, and PCBs (Continued)			
PCB-1248	0.0006	---	---
PCB-1254	0.0013	---	---
PCB-1260	0.0013	---	---
Phorate	0.00040	0.00015	0.0015
PPDDD	0.00011	0.000011	0.00011
PPDDE	0.000040	0.000004	0.0004
PPDDT	0.00012	0.000012	0.00012
Toxaphene	0.0024	0.00024	0.0024
2,4-D	0.012	0.0012	0.012
2,4,5-T	0.0020	0.0002	0.002
2,4,5-TP	0.0020	0.00017	0.0017
Dinoseb	0.0007	0.00007	0.0007

(Sheet 5 of 5)

NOTE: Herbicide, Pesticide IDL varies from batch to batch.

Table 7
Parameter Groups Sampled[1], Rounds I Through 4

Well Number	Date Sampled	Vol Org	BNA	Pest/ PCB	Herb	Metal	Expl	Cyan Sulf	NO3/N O2
06-01A	Nov 1990	X	X	X	X	X	X	X	
06-01A	Jun 1991	X	X	X	X	X	X	X	
06-01A	Nov 1991	X				X		X	
06-01A	Apr 1992					X	X	X	X
06-06	Nov 1990	X	X	X	X	X	X	X	
06-06	Jun 1991	X	X	X	X	X	X	X	
06-06	Nov 1991	X	X	X	X	X	X	X	
06-06	Apr 1992					X	X	X	X
06-07	Nov 1990	X	X	X	X	X	X	X	
06-07	Jun 1991	X	X	X	X	X	X	X	
06-07	Nov 1991	X	X	X	X	X	X	X	
06-07	Apr 1992					X	X	X	X
06-12	Nov 1990	X	X	X	X	X	X	X	
06-12	Jun 1991	X	X	X	X	X	X	X	
06-12	Nov 1991	X	X	X	X	X	X	X	
06-12	Apr 1992					X	X	X	X
06-14A	Mar 1991	X	X	X	X	X	X	X	
06-14A	Jun 1991	X	X	X	X	X	X	X	
06-14A	Nov 1991	X	X	X	X	X	X	X	
06-14A	Apr 1992					X	X	X	X
06-15	Nov 1990	X	X	X	X	X	X	X	
06-15	Jun 1991	X	X	X	X	X	X	X	
06-15	Apr 1992					X	X	X	X
06-16	Nov 1990	X	X	X	X	X	X	X	
06-16	Jun 1991	X	X	X	X	X	X	X	
06-16	Nov 1991	X	X	X	X	X	X	X	
06-16	Apr 1992					X	X	X	X
06-17	Nov 1990	X	X	X	X	X	X	X	
06-17	Jun 1991	X	X	X	X	X	X	X	
06-17	Nov 1991	X				X		X	
06-17	Apr 1992					X	X	X	X
06-18	Nov 1990	X	X	X	X	X	X	X	
06-18	Jun 1991	X	X	X	X	X	X	X	
06-18	Nov 1991	X	X	X	X	X	X	X	
06-18	Apr 1992					X	X	X	X

(Sheet 1 of 5)

[1] Key to Groups: VOLORG = volatile organics, BNA = BNA semivolatiles, PEST/PCB = pesticides and PCBs, HERB = herbicides, METAL = metals, EXPL = explosives, CYAN SULF = cyanide and sulfides.

Table 7 (Continued)

Well Number	Date Sampled	Vol Org	BNA	Pest/ PCB	Herb	Metal	Expl	Cyan Sulf	NO3/N O2
06-19	Mar 1991	X	X	X	X	X	X	X	
06-19	Jun 1991	X	X	X	X	X	X	X	
06-19	Nov 1991	X	X			X	X	X	
06-19	Apr 1992					X	X	X	X
06-20	Nov 1990	X	X	X	X	X	X	X	
06-20	Jun 1991	X	X	X	X	X	X	X	
06-20	Nov 1991	X	X	X	X	X	X	X	
06-20	Apr 1992					X	X	X	X
06-21	Nov 1990	X	X	X	X	X	X	X	
06-21	Jun 1991	X	X	X	X	X	X	X	
06-21	Apr 1922					X	X	X	X
06-22	Nov 1990	X	X	X	X	X	X	X	
06-22	Jun 1991	X	X	X	X	X	X	X	
06-22	Nov 1991	X	X	X	X	X	X	X	
06-22	Apr 1922					X	X	X	X
06-23	Nov 1990	X	X	X	X	X	X	X	
06-23	Jun 1991	X	X	X	X	X	X	X	
06-23	Nov 1991	X	X	X	X	X	X	X	
06-23	Apr 1922					X	X	X	X
06C01	Nov 1990	X	X	X	X	X	X	X	
06C01	Jun 1991	X	X	X	X	X	X	X	
06C01	Nov 1991	X	X	X	X	X	X	X	
06C01	Apr 1992					X	X	X	X
06C01P3	Nov 1990	X	X	X	X		X	X	
06C01P3	Jun 1991	X	X	X	X	X	X	X	
06C01P3	Nov 1991	X	X	X	X	X	X	X	
06C01P3	Apr 1992					X	X	X	X
06C02	Mar 1991	X	X	X	X	X	X	X	
06C02	Jun 1991	X	X	X	X	X	X	X	
06C02	Nov 1991	X	X	X	X	X	X	X	
06C02	Apr 1992					X	X	X	X
06C02P2	Mar 1991	X	X	X	X	X	X	X	
06C02P2	Jun 1991	X	X	X	X	X	X	X	
06C02P2	Nov 1991	X	X	X	X	X	X	X	
06C02P2	Apr 1992					X	X	X	X
06C03	Mar 1991	X	X	X	X	X	X	X	
06C03	Jun 1991	X	X	X	X	X	X	X	
06C03	Nov 1991	X	X	X	X	X	X	X	
06C03	Apr 1992					X	X	X	X

(Sheet 2 of 5)

Table 7 (Continued)

Well Number	Date Sampled	Vol Org	BNA	Pest/ PCB	Herb	Metal	Expl	Cyan Sulf	NO3/N O2
06C03P2	Mar 1991	X	X	X	X	X	X	X	
06C03P2	Jun 1991	X	X	X	X	X	X	X	
06C03P2	Nov 1991	X	X	X	X	X	X	X	
06C03P2	Apr 1992					X	X	X	X
06C04	Mar 1991	X	X	X	X	X	X	X	
06C04	Jun 1991	X	X	X	X	X	X	X	
06C04	Nov 1991	X	X	X	X	X	X	X	
06C04	Apr 1992					X	X	X	X
06C04P2	Mar 1991	X	X	X	X	X	X	X	
06C04P2	Jun 1991	X	X	X	X	X	X	X	
06C04P2	Apr 1992					X	X	X	X
06C05	Mar 1991	X	X	X	X	X	X	X	
06C05	Jun 1991	X	X	X	X	X	X	X	
06C05	Nov 1991	X	X	X	X	X	X	X	
06C05	Apr 1992					X	X	X	X
06C06	Mar 1991	X	X	X	X	X	X	X	
06C06	Jun 1991	X	X	X	X	X	X	X	
06C06	Nov 1991	X	X	X	X	X	X	X	
06C06	Apr 1992					X	X	X	X
06C06P2	Mar 1991	X	X	X	X	X	X	X	
06C06P2	Jun 1991	X	X	X	X	X	X	X	
06C06P2	Nov 1991	X	X	X	X	X	X	X	
06C06P2	Apr 1992	X	X	X	X	X	X	X	X
06C07	Mar 1991	X	X	X	X	X	X	X	
06C07	Jun 1991	X	X	X	X	X	X	X	
06C07	Nov 1991	X	X	X	X	X	X	X	
06C07	Apr 1992					X	X	X	X
06C08	Nov 1990	X	X	X	X	X	X	X	
06C08	Jun 1991	X	X	X	X	X	X	X	
06C08	Nov 1991	X	X	X	X	X	X	X	
06C08	Apr 1992					X	X	X	X
06C08P2	Nov 1990	X	X	X	X	X	X	X	
06C08P2	Jun 1991	X	X	X	X	X	X	X	
06C08P2	Nov 1991	X	X	X	X	X	X	X	
06C08P2	Apr 1992					X	X	X	X
06C09	Nov 1990	X	X	X	X	X	X	X	
06C09	Jun 1991	X	X	X	X	X	X	X	
06C09	Nov 1991	X	X	X	X	X	X	X	
06C09	Apr 1992					X	X	X	X

(Sheet 3 of 5)

Table 7 (Continued)

Well Number	Date Sampled	Vol Org	BNA	Pest/ PCB	Herb	Metal	Expl	Cyan Sulf	NO3/N O2
06C10	Mar 1991	X	X	X	X	X	X	X	
06C10	Jun 1991	X	X	X	X	X	X	X	
06C10	Nov 1991	X	X	X	X	X	X	X	
06C10	Apr 1992					X	X	X	X
06C10P2	Mar 1991	X	X	X	X	X	X	X	
06C10P2	Jun 1991	X	X	X	X	X	X	X	
06C10P2	Nov 1991	X	X	X	X	X	X	X	
06C10P2	Apr 1992					X	X	X	X
06C11	Mar 1991	X	X	X	X	X	X	X	
06C11	Jun 1991	X	X	X	X	X	X	X	
06C11	Nov 1991	X	X	X	X	X	X	X	
06C11	Apr 1992					X	X	X	X
06C11P2	Mar 1991	X	X	X	X	X	X	X	
06C11P2	Jun 1991	X	X	X	X	X	X	X	
06C11P2	Nov 1991	X	X	X	X	X	X	X	
06C11P2	Apr 1992					X	X	X	X
06C12	Mar 1991	X	X	X	X	X	X	X	
06C12	Jun 1991	X	X	X	X	X	X	X	
06C12	Nov 1991	X	X	X	X	X	X	X	
06C12	Apr 1992					X	X	X	X
06C12P2	Mar 1991	X	X	X	X	X	X	X	
06C12P2	Jun 1991	X	X	X	X	X	X	X	
06C12P2	Nov 1991	X	X	X	X	X	X	X	
06C12P2	Apr 1992					X	X	X	X
06C13	Nov 1990	X	X	X	X	X	X	X	
06C13	Jun 1991	X	X	X	X	X	X	X	
06C13	Nov 1991	X	X	X	X	X	X	X	
06C13	Apr 1992					X	X	X	X
06C13P2	Nov 1990	X	X	X	X	X	X	X	
06C13P2	Jun 1991	X	X	X	X	X	X	X	
06C13P2	Nov 1991	X	X	X	X	X	X	X	
06C13P2	Apr 1992					X	X	X	X
06C14	Nov 1990	X	X	X	X	X	X	X	
06C14	Jun 1991	X	X	X	X	X	X	X	
06C14	Nov 1991	X	X	X	X	X		X	
06C14	Apr 1992					X	X	X	X
06C14P2	Nov 1990	X	X	X	X	X	X	X	
06C14P2	Jun 1991	X	X	X	X	X	X	X	
06C14P2	Nov 1991	X	X	X	X	X		X	
06C14P2	Apr 1992					X	X	X	X

(Sheet 4 of 5)

Table 7 (Concluded)

Well Number	Date Sampled	Vol Org	BNA	Pest/ PCB	Herb	Metal	Expl	Cyan Sulf	NO3/N O2
06C15	Nov 1990	X	X	X	X	X	X	X	
06C15	Jun 1991	X	X	X	X	X	X	X	
06C15	Nov 1991	X	X	X	X	X		X	
06C15	Apr 1992					X	X	X	X
06C15P2	Nov 1990	X	X	X	X	X	X	X	
06C15P2	Jun 1991	X	X	X	X	X	X	X	
06C15P2	Nov 1991	X	X	X	X	X		X	
06C15P22	Apr 1992					X	X	X	X
06C16	Nov 1990	X	X	X	X	X	X	X	
06C16	Jun 1991	X	X	X	X	X	X	X	
06C16	Nov 1991	X	X	X	X	X		X	
06C16	Apr 1992					X	X	X	X
06C16P2	Nov 1990	X	X	X	X	X	X	X	
06C16P2	Jun 1991	X	X	X	X	X	X	X	
06C16P2	Nov 1991	X	X	X	X	X		X	
06C16P2	Apr 1992					X	X	X	X
06C16P3	Nov 1990	X	X	X	X	X	X	X	
06C16P3	Jun 1991	X	X	X	X	X	X	X	
06C16P3	Nov 1991	X	X	X	X	X		X	
06C16P3	Apr 1992					X	X	X	X
06C17	Nov 1990	X	X	X	X	X	X	X	
06C17	Jun 1991	X	X	X	X	X	X	X	
06C17	Nov 1991	X	X	X	X	X	X	X	
06C17	Apr 1992					X	X	X	X
06C18	Nov 1990	X	X	X	X	X	X	X	
06C18	Jun 1991	X	X	X	X	X	X	X	
06C18	Nov 1991	X	X	X	X	X	X	X	
06C18	Apr 1992					X	X	X	X
06C18P2	Nov 1990	X	X	X	X	X	X	X	
06C18P2	Jun 1991	X		X	X	X	X	X	
06C18P2	Nov 1991	X	X	X	X	X	X	X	
06C18P2	Apr 1992					X	X	X	X

(Sheet 5 of 5)

Table 8
Preservatives and Holding Times for Ground-Water Samples

Parameters	Preservation	Holding time[1]
Metals	Nitric acid to pH <2	180 days
Mercury	Nitric acid to pH <2	28 days
Cyanide	Sodium hydroxide to pH >12	14 days
Sulfide	Sodium hydroxide to pH>12	7 days
Nitrate/Nitrite	Sulfuric acid to pH <2	28 days
Herbicides	Cooled to 4°C	7/40 days
Pesticides/PCBs	Cooled to 4°C	7/40 days
Volatiles	Cooled to 4°C	14 days
BNA	Cooled to 4°C	7/40 days
Explosives	Cooled to 4°C	7/40 days

[1] Same for all sample matrices.

Table 9
Blind Samples and Associated Well Numbers

Round Number	Well Number	Blind Sample Number
1	06C15	06C19P4
	06C18P2	06C20P4
2	None	
3	06C04	06C04P3
	06C08	06C08P3
	06C10	06C10P3
	06C13P2	06C13P3
4	06C14	06C14P3

Table 10
Aquifer Assignments for Demolition Area/Old Rifle Range Wells

Aquifer	Well Numbers	
Upper Pennsylvanian Sandstones	06-01A 06-06 06-07 06-12 06C01P3	
Pennsylvanian Undifferentiated	06C01P2} 06C06P2} statigraphic position uncertain 06C08P2}	
Old Rifle Range Uppermost (includes the soil zone and the upper Big Clifty-Beech Creek)	06-15 06-16 06-17 06-18 06-19 (screened in alluvium) 06-20 06-22 06-23	06C10P2 06C11P2 06C12P2 06C13P2 06C14P2 06C15P2 06C16P2 06C18P2 06C19P2
Golconda/Haney Limestone	06-21 06C03P2 06C04P2 06C16P3	
Big Clifty-Beech Creek	06C01 06C02 06C03 06C04 06C05 06C06 06C07 06C08 06C09	06C10 06C11 06C12 06C13 06C14 06C15 06C16 06C17 06C18 06C19
Unassigned (in perched upper zone, ORR)	06-14A	
Upper Big Clifty, Demolition Area	06C02P2	

Table 11
Laboratory Analytical Procedures

Parameter	Method	Reference
Volatile Organics (VOA)	GC/MS	USEPA Method 8240
Semivolatile or Base Neutral Acid Extractibles (BNAs)	GC/MS	USEPA Method 8270
Organochlorine Pesticides and PCBs	GC	USEPA Method 8080
Organophosphorus Pesticides	GC	USEPA Method 8140
Chlorinated Herbicides	GC	USEPA Method 8150
Explosives	HPLC	USEPA Method 8330
Metals	ICP and Furnace Methods	USEPA Method 6010 USEPA Series 7000 Methods
Cyanide	Colorimetric	USEPA Method 9012
Sulfides	Acid Soluble/Insoluble	USEPA Method 9030

Notes:
GC/MS = Gas Chromatograph/Mass Spectrometer
HPLC = High Performance Liquid Chromatography
ICP = Inductive Coupled Plasma Atomic Emission Spectroscopy

Table 12
Tentatively Identified Compounds, Demolition Area/Old Rifle Range Wells

Well Number:	06-18	06-19	06-22	06C08	06C18
Lab Number:	16830	16831	16833	16959	16962
Compound					
caprolactum	X				
cyclohex-adecane		X			
hexanedioic acid, diotylester				X	X
2-methyl-1,3,5-trinitro-benzene			X		

Table 13a
Mean Values of Mapped Parameters Over Four Sampling Rounds, mg/l

Well No.	Cu	Cr	Ba	Ni	Sb	Pb	Zn	Al	As
Lower Big Clifty/Beech Creek Wells									
06C01	0.0066	0	0.1130	0.0034	0.0040	0	0.0170	0.0088	0
06C02	0.0049	0	0.1095	0	0.0361	0	0	0.0065	0
06C03	0.0065	0.0031	0.0813	0	0.0053	0.0008	0.0036	0	0.0112
06C04	0	0	0.1325	0	0.0061	0.0008	0.0046	0	0
06C05	0.0080	0	0.0588	0	0.0068	0	0.0044	0	0
06C06	0.0049	0.0031	0.0370	0	0.0067	0.0007	0.0034	0	0
06C07	0.0131	0	0.2103	0	0.0322	0	0.0054	0	0
06C08	0.0088	0	0.0133	0.0048	0.0082	0	0.0339	0.1338	0.0078
06C09	0.0049	0	0.0335	0	0.0062	0	0.1941	0	0
06C10	0.0128	0.0043	0.0353	0.0046	0.0038	0	0	0	0.0026
06C11	0.0275	0.0031	0.0878	0	0.0131	0	0.0036	0.0460	0.0025
06C12	0.0093	0	0.0665	0.0031	0.0072	0.0006	0	0	0
06C13	0.0086	0	0.0300	0	0.0078	0	0.0056	0.0088	0.0068
06C14	0.0129	0	0.0370	0.0040	0.0092	0	0.0095	0	0
06C15	0.0074	0	0.0248	0.0039	0.0067	0	0.0048	0	0
06C16	0.0133	0	0.0998	0.0031	0.0098	0	0.0390	0	0
06C17	0.0130	0	0.0150	0.0321	0.0064	0	0.0073	0	0
06C18	0.0048	0.0031	0.1305	0	0.0110	0	0.0039	0	0.0032
Demolition Area, Upper Penn Wells									
06-01A	0.0150	0	0.0130	0.0050	0.0120	0	0	0	0
06-06	0.0210	0.005	0.0100	1.0600	0.0070	0.0020	0.9770	0.4600	0
06-07	0.0140	0.0180	0	1.6730	0.0080	0.0010	2.5430	109.7	0.0050
06-12	0	0	0.0110	0.3590	0.0350	0	0.4690	0	0
06C01P3	0.0280	0	0.0120	0.1070	0.0060	0	0.0450	0	0
Golconda/Haney Wells									
06-21	0.0360	0	0.0150	0	0.0100	0	0.0066	0	0
06C03P2	0.0120	0	0.0580	0	0.0070	0	0	0	0
06C04P2	0.0360	0	0.0150	0	0.0100	0	0.0066	0	0
06C16P3	0.0114	0	0.0488	0	0.0107	0	0	0	0.0013

(Continued)

Table 13a (Concluded)

Well No.	Cu	Cr	Ba	Ni	Sb	Pb	Zn	Al	As
Uppermost Aquifer, Old Rifle Range									
06-14A	0.0153	0.0034	0.0900	0.0034	0.0075	0.0007	0.0078	0.0078	0
06-16	0.0090	0	0.0140	0	0.0095	0	0.0154	0	0
06-17	0.0433	0.0059	0.0608	0.0190	0.0103	0.0103	0.0213	0.0775	0
06-18	0.0363	0	0.0228	0.0031	0.0121	0	0.0109	0	0
06-19	0.0248	0	0.1373	0.0094	0.0075	0	0.0135	0	0
06-20	0.0101	0	0.0255	0.0483	0.0109	0	0	0	0
06-22	0.0163	0	0.0260	0	0.0100	0	0.0049	0	0
06-23	0.0288	0	0.0240	0.0325	0.0114	0	0.0050	0.0210	0
06C10P2	0.0243	0.0034	0.0478	0	0.0117	0	0.0036	0	0.0013
06C11P2	0.0060	0.0031	0.0290	0	0.0075	0	0.0036	0	0
06C12P2	0.0276	0	0.0220	0.0044	0.0073	0	0.0116	0	0
06C13P2	0.0056	0.0031	0.0613	0	0.0074	0	0.0039	0	0.0207
06C14P2	0.0255	0	0.0260	0.0058	0.0082	0	0.0098	0	0
06C15P2	0.0110	0	0.0228	0.0034	0.0103	0.0007	0.0136	0	0
06C16P2	0.0099	0	0.0588	0.0031	0.0100	0	0.0056	0	0.0014
06C18P2	0.0135	0.0036	0.1353	0	0.0067	0	0.0305	0	0.0143

Table 13b
Mean Values of Mapped Parameters Over Four Sampling Rounds, mg/l (con'd)

Well No.	Be	Cd	V	Nitrate[1]	Nitrite[1]
Lower Big Clifty/Beech Creek Wells					
06C01	0	0	0	0	0.0060
06C02	0	0	0	0.0250	0.0050
06C03	0	0	0	0.0150	0
06C04	0	0	0	0.0300	0
06C05	0	0	0	0.0260	0
06C06	0	0	0	0.0400	0
06C07	0	0	0	0	0.0070
06C08	0	0	0.0048	0.1460	0.0300
06C09	0	0	0	3.3400	0
06C10	0.0004	0	0	0	0
06C11	0	0	0	0.0390	0
06C12	0	0	0	0	0
06C13	0	0	0	0.8710	0
06C14	0	0.0021	0	0.0330	0.0070
06C15	0	0	0	0.1860	0
06C16	0	0	0	0	0
06C17	0	0.0002	0	0.2670	0.0050
06C18	0	0	0.0041	0.0410	0
Demolition Area, Upper Penn Wells					
06-01A	0	0	0	0.3990	0
06-06	0.0020	0.0020	0	0	0
06-07	0.0120	0.0070	0.0070	0	0.0160
06-12	0.0030	0.0002	0.0050	0	0
06C01P3	0.0007	0	0	0	0
Golconda/Haney Wells					
06-21	0	0.0001	0	0	0.0100
06C03P2	0	0	0	0.0190	0
06C04P2	0	0.0001	0	0.2070	0
06C16P3	0	0	0	0	0

(Continued)

Table 13b (Concluded)

Well No.	Be	Cd	V	Nitrate[1]	Nitrite[1]
Uppermost Aquifer, Old Rifle Range					
06-14A	0	0	0.0069	0.0890	0
06-16	0	0.0003	0.0036	0.0830	0
06-17	0	0.0003	0	0.6020	0
06-18	0	0	0	6.94	0.0140
06-19	0	0	0.0031	0.0890	0
06-20	0	0	0.0046	18.2	0
06-22	0	0	0.0031	3.75	0.0050
06-23	0	0	0.0041	0.2460	0.0090
06C10P2	0	0	0.0046	0.9680	0
06C11P2	0	0	0	0.0570	0.0060
06C12P2	0	0	0.0031	0.0620	0
06C13P2	0	0	0	0	0.0100
06C14P2	0	0	0	0.0610	0
06C15P2	0	0.0002	0	0.3850	0
06C16P2	0	0	0	0	0
06C18P2	0.0009	0	0.0029	0.0720	0.0250

[1] Nitrates and nitrites for 4th Round only.

Table 14
Detected Values of Explosives, Old Rifle Range Wells

Round No., Explosive	Well Number				
	06-18	06-20	06-22	06C09	06C15
Round 1, TNT	0.0140 J	ND	0.1480	ND	ND
Round 2, TNT	0.0150 J	ND	0.1310	ND	0.0120 J
Round 3, TNT	0.0160 J	ND	0.0980	ND	ND
Round 4, TNT	0.0100 J	ND	0.0880	ND	ND
Round 1, HMX	ND	ND	ND	ND	ND
Round 2, HMX	ND	ND	ND	0.0190 J	ND
Round 3, HMX	ND	ND	ND	ND	ND
Round 4, HMX	ND	ND	ND	ND	ND
Round 1, RDX	ND	ND	ND	0.0170 J	ND
Round 2, RDX	ND	0.0340	ND	ND	ND
Round 3, RDX	ND	0.0350	ND	ND	ND
Round 4, RDX	ND	ND	ND	ND	ND

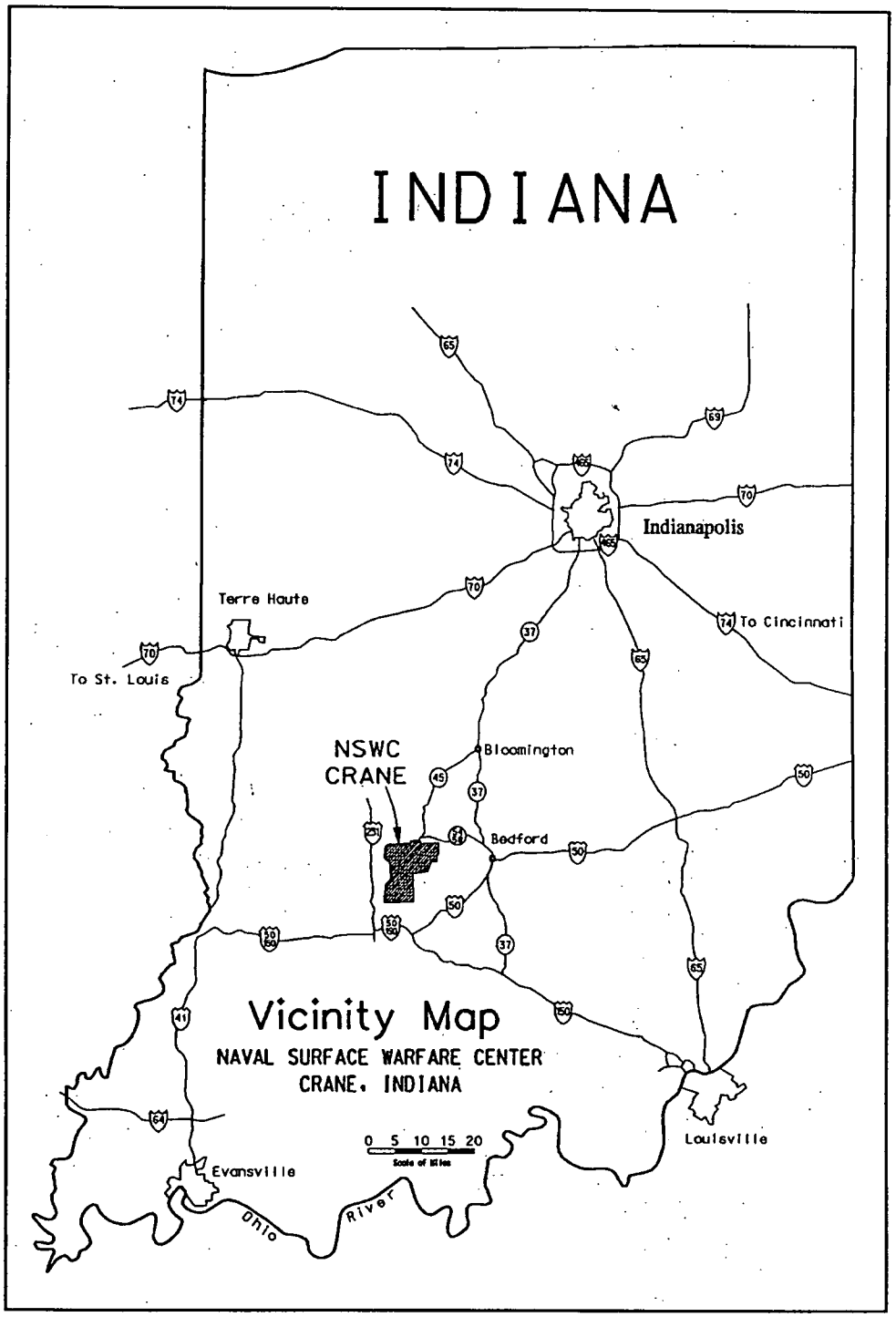


Figure 1. Location of Naval Surface Warfare Center Crane (NSWCC), Indiana

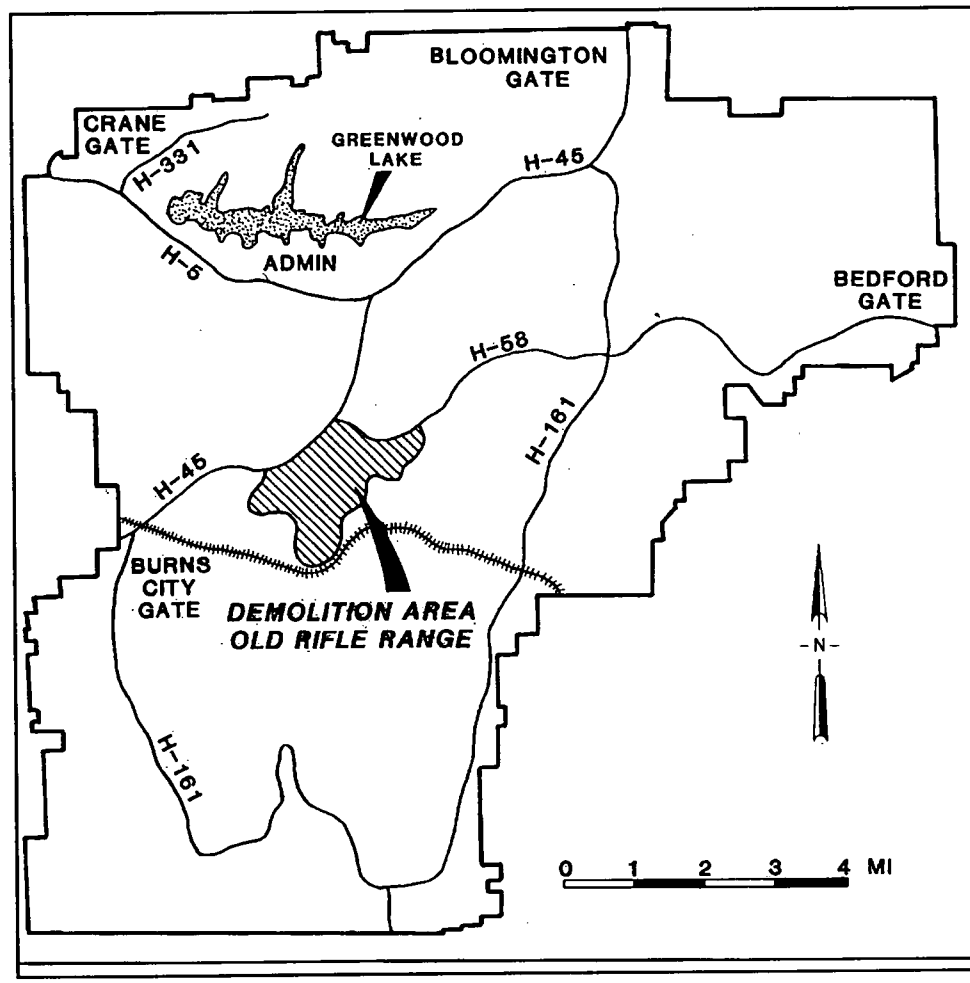


Figure 2. Location of Demolition Area and Old Rifle Range

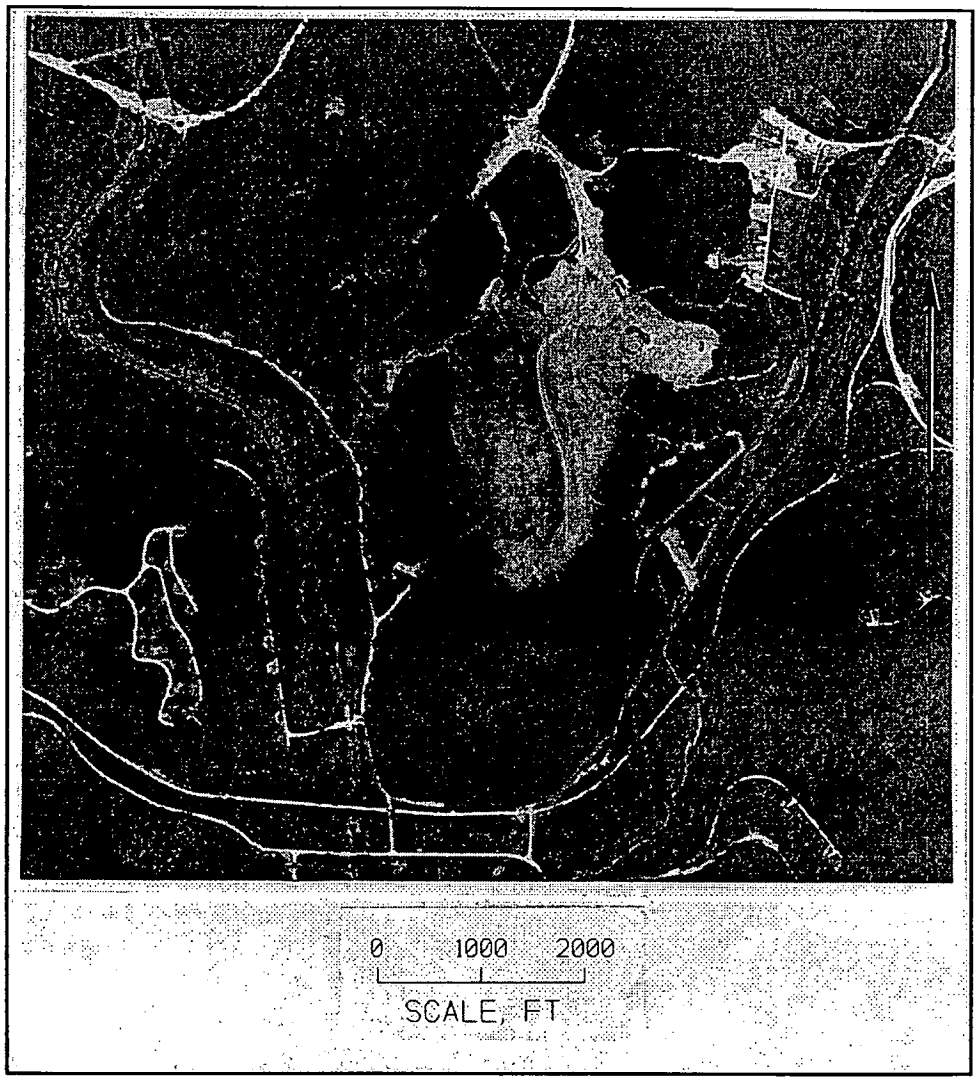


Figure 3. High altitude color infrared aerial photo (reproduced in monochrome) of Demolition Area/Old Rifle Range study area (date of photo 5\25\88; arrow points north)

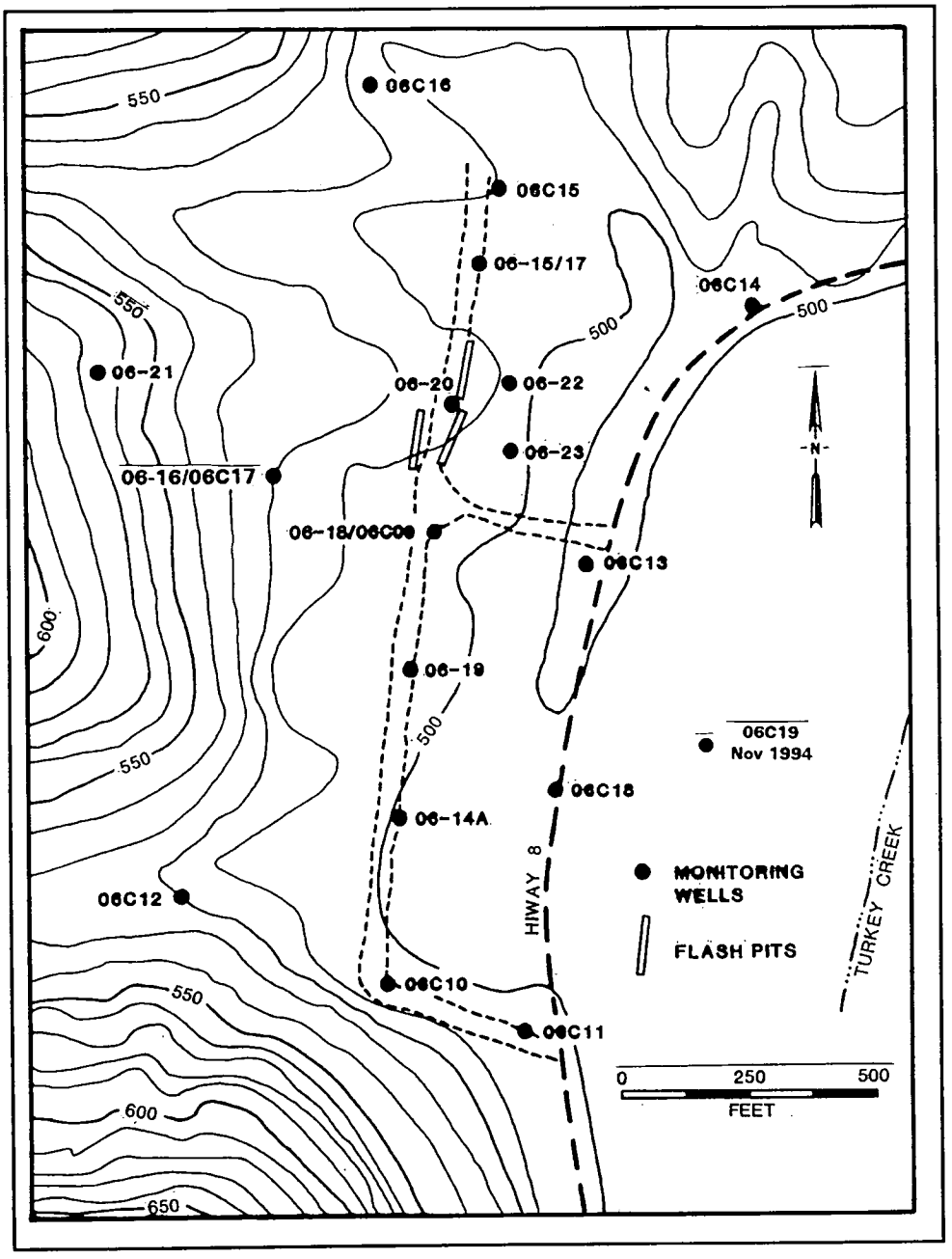


Figure 4. Locations of wells and cluster wells at Old Rifle Range

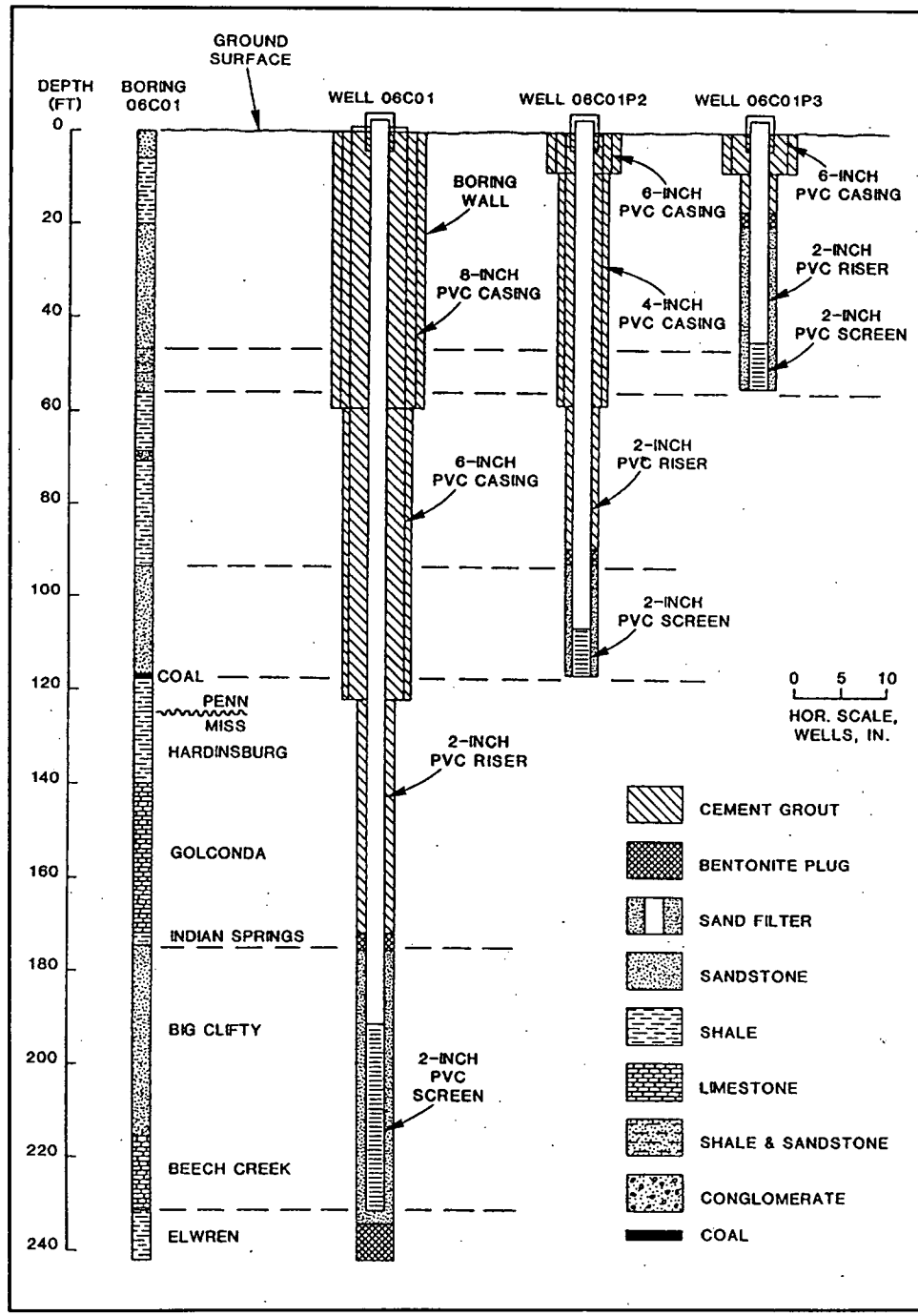


Figure 5. Well installation diagrams for Demolition Area/Old Rifle Range

U.S. Army Corps of Engineers

Chain of Custody Record
(ER 1110-1-263)

Proj. No.	Project Name														
Sampler : (Signature)															
Date	Time	Pres.	Grab	Comp	Site Code/Sample Number	Number of Containers									Remarks:

Sampler Relinquished by:	Date/Time	Received by: (Sig.)	Date/Time	Hazards Associated with Samples
Relinquished by: (Sig.)	Date/Time	Received by: (Sig.)	Date/Time	
Relinquished by: (Sig)	Date/Time	Received for Laboratory by: (Sig.)	Date/Time	Remarks at time of receipt:
Custody Seal No.		Lab case No.:		

ENG Form 5021-R, Oct. 90

Figure 6. Chain-of-custody form for groundwater sampling

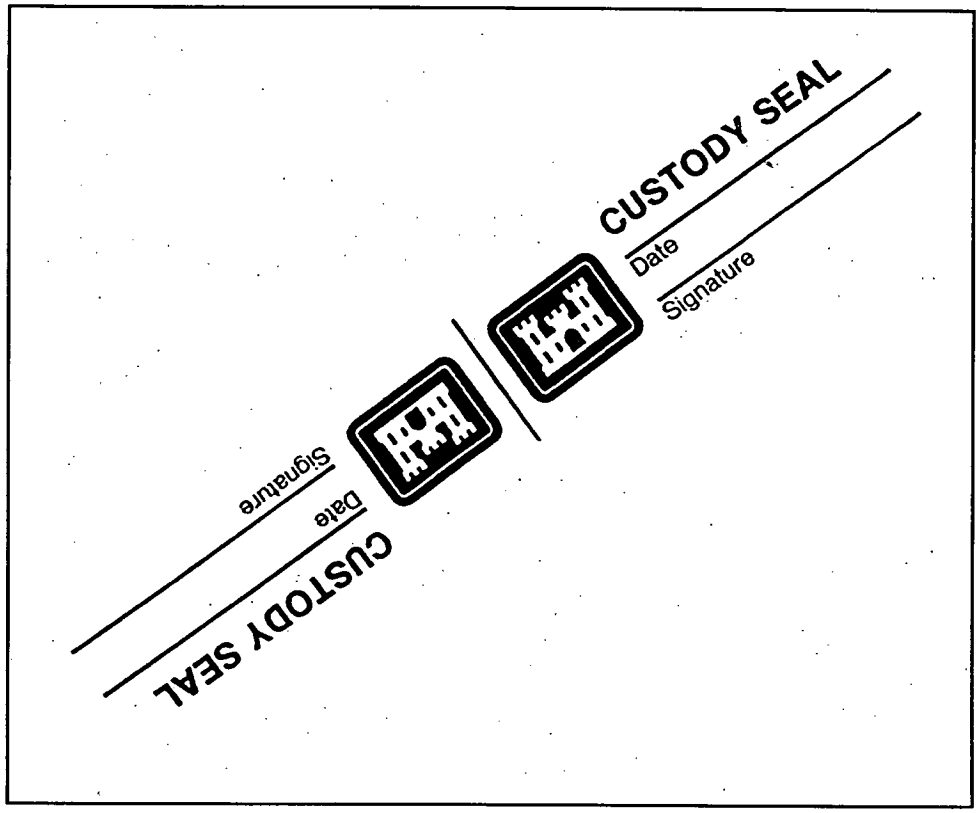


Figure 7. Example of chain-of-custody sample tag

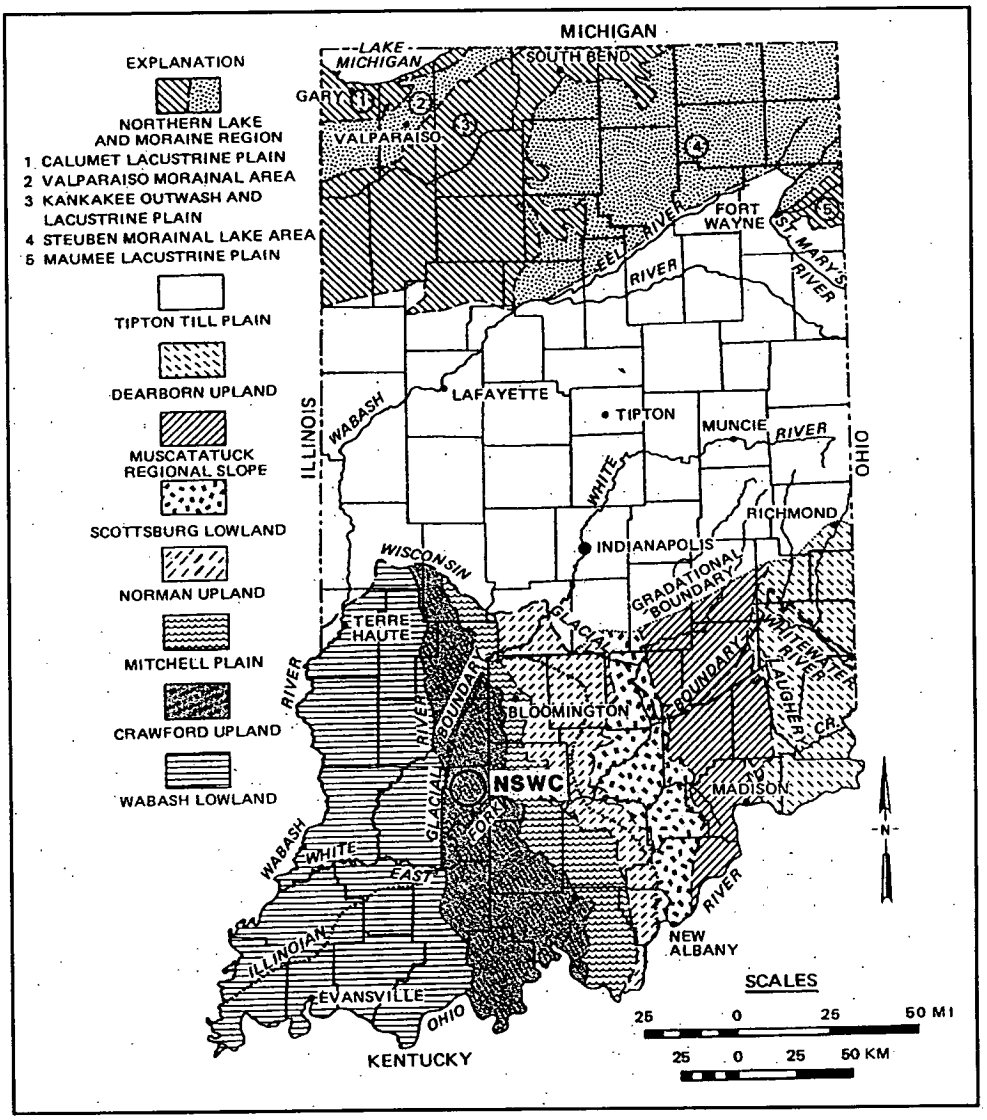


Figure 8. Physiographic divisions of Indiana (Perry and Smith, 1958)

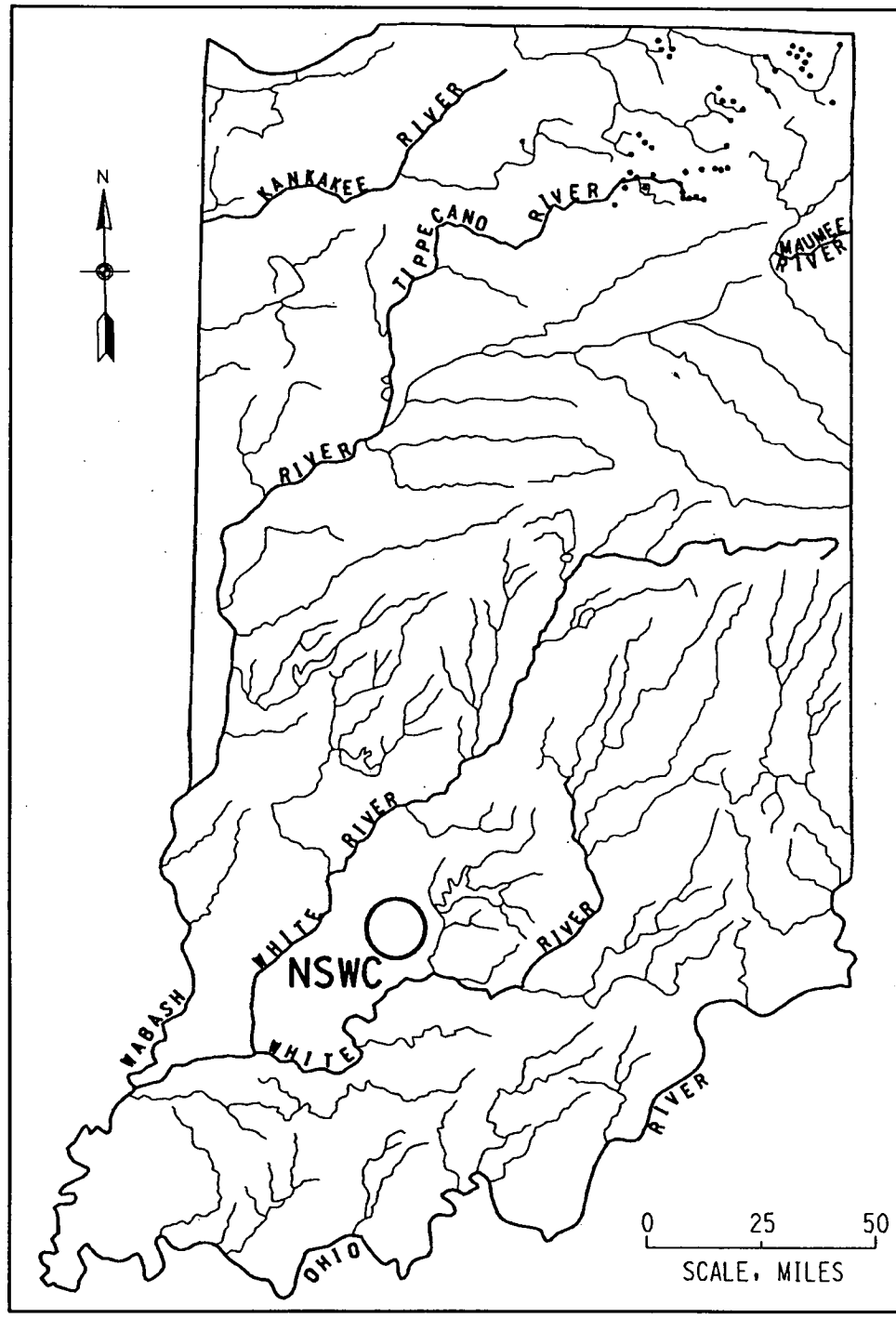


Figure 9. Surface drainage in Indiana (Academy of Science, 1966)

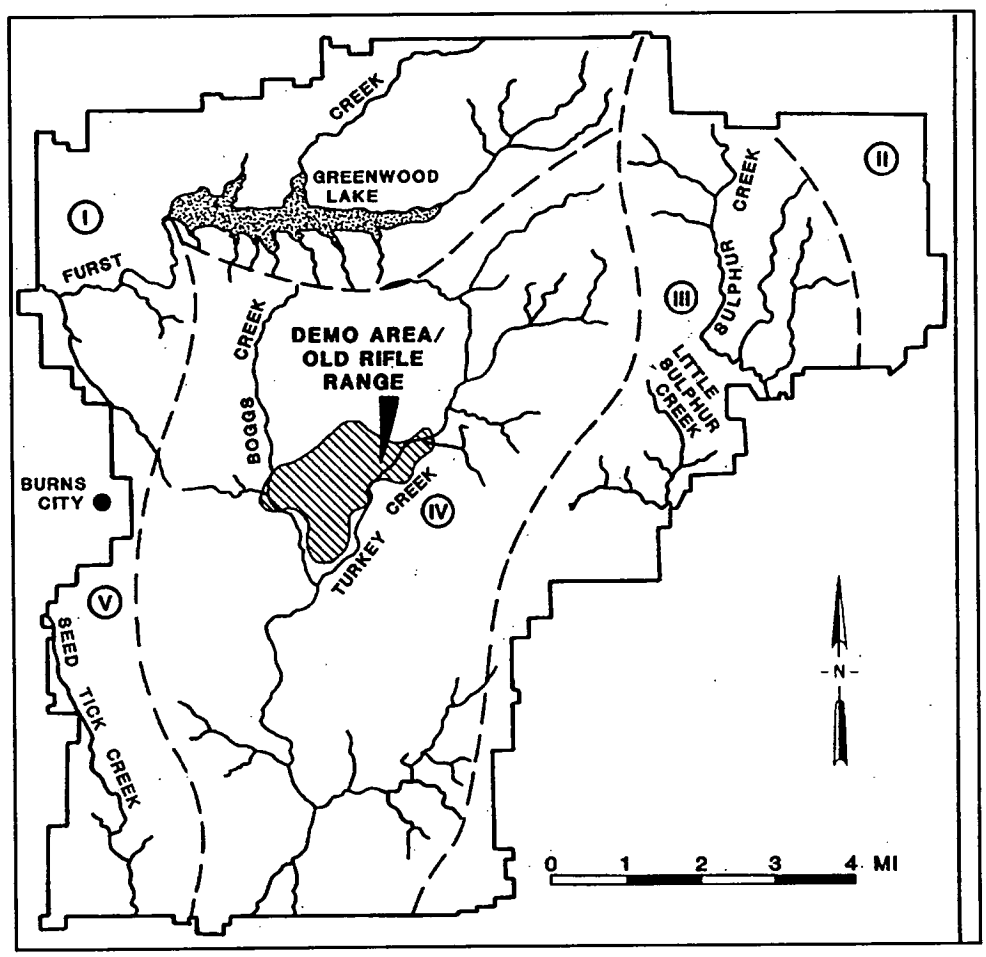


Figure 10. Surface drainage at NSWCC

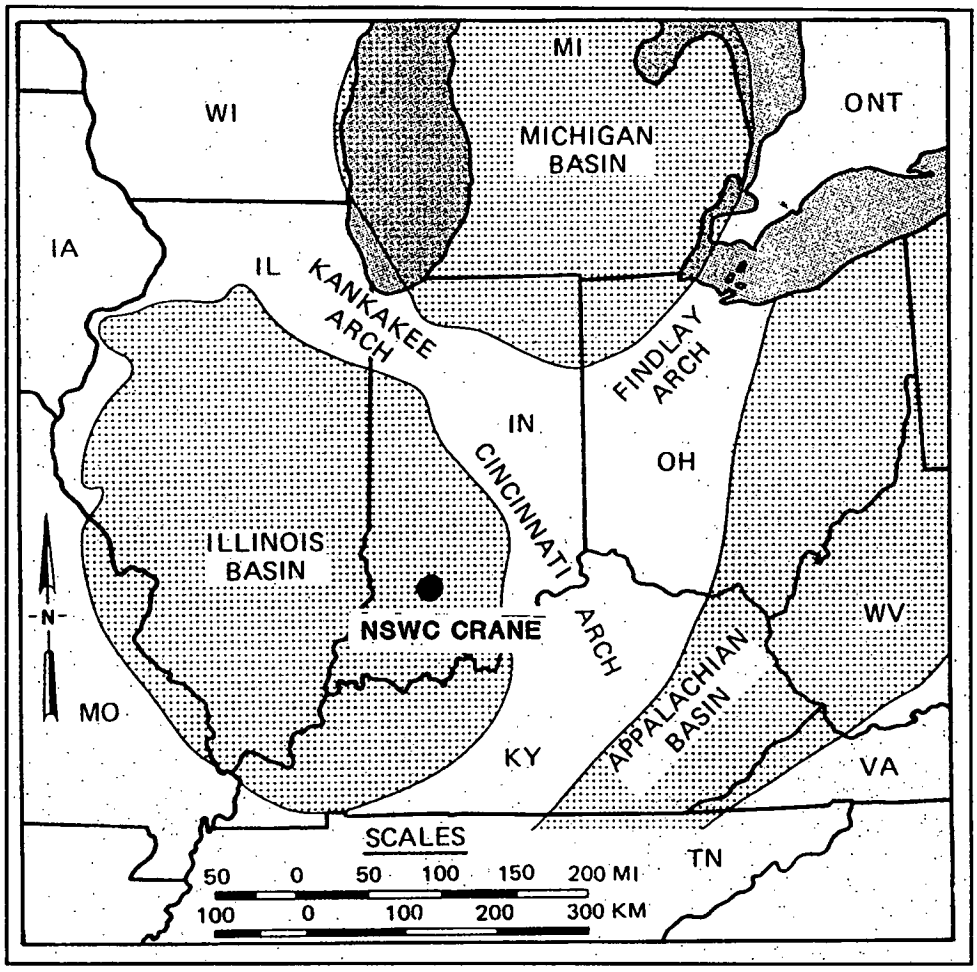


Figure 11. Structural provinces of the Midwest (Carpenter et al, 1975)

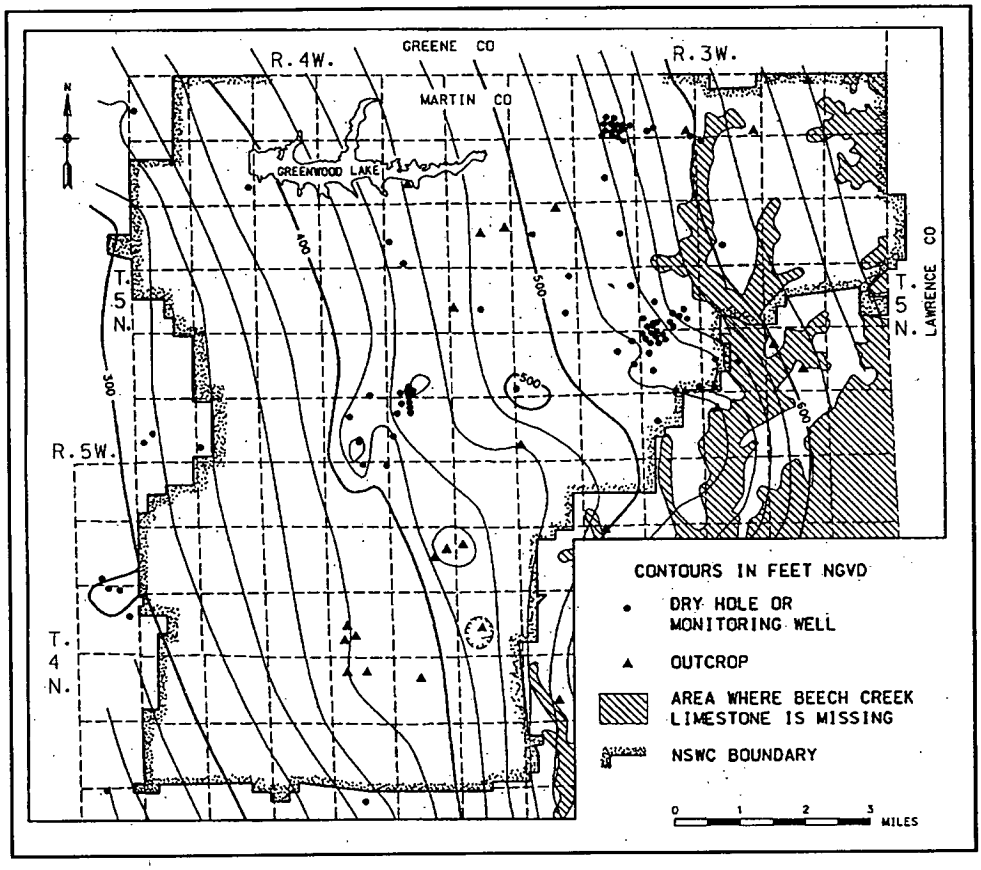


Figure 12. Geologic structure map, base of Beech Creek limestone, Martin County, Indiana (Indiana Geological Survey, 1980, revised 1991)

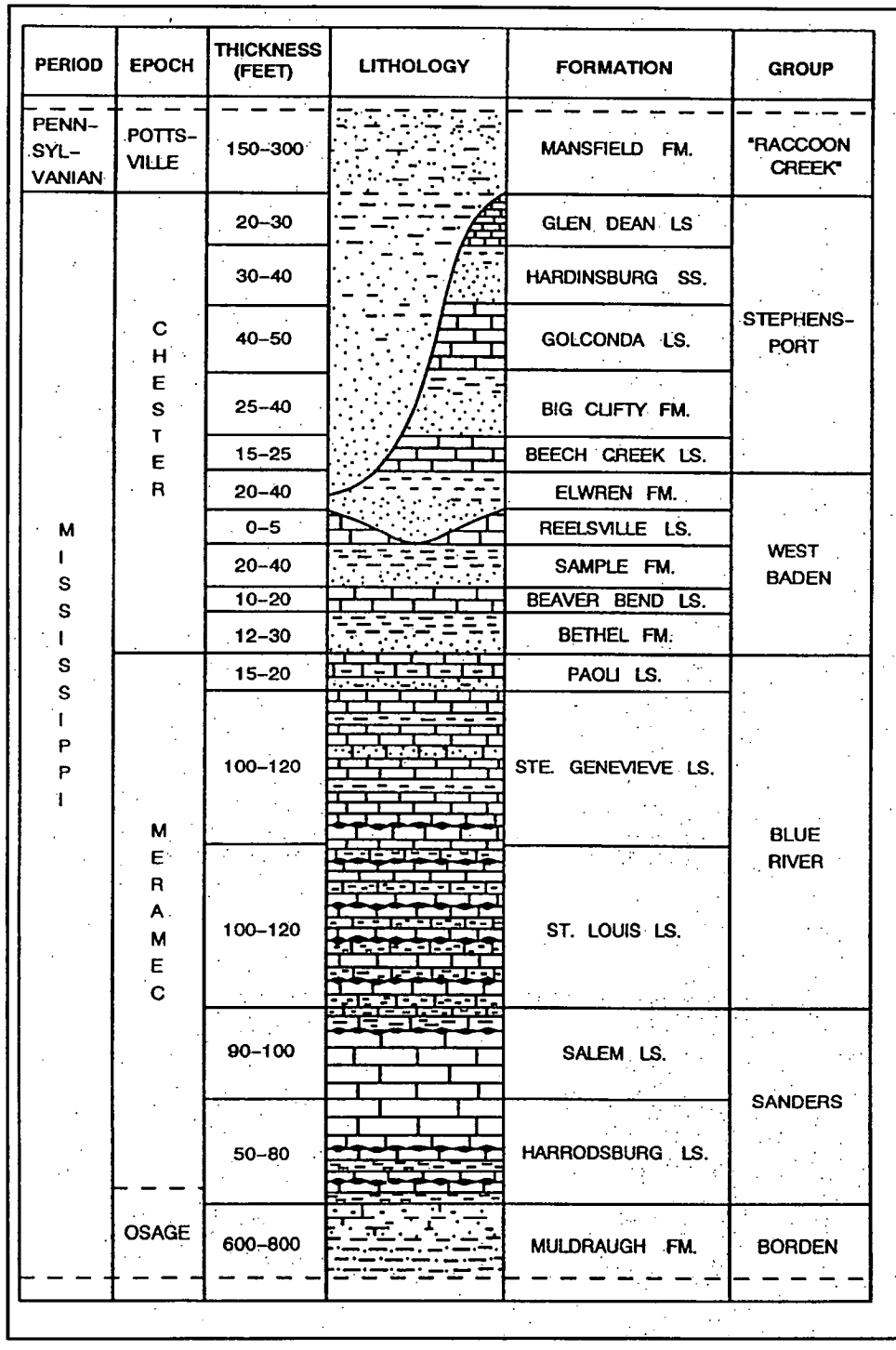


Figure 13. Stratigraphic column for rock units encountered at NSWCC (Palmer, 1969)

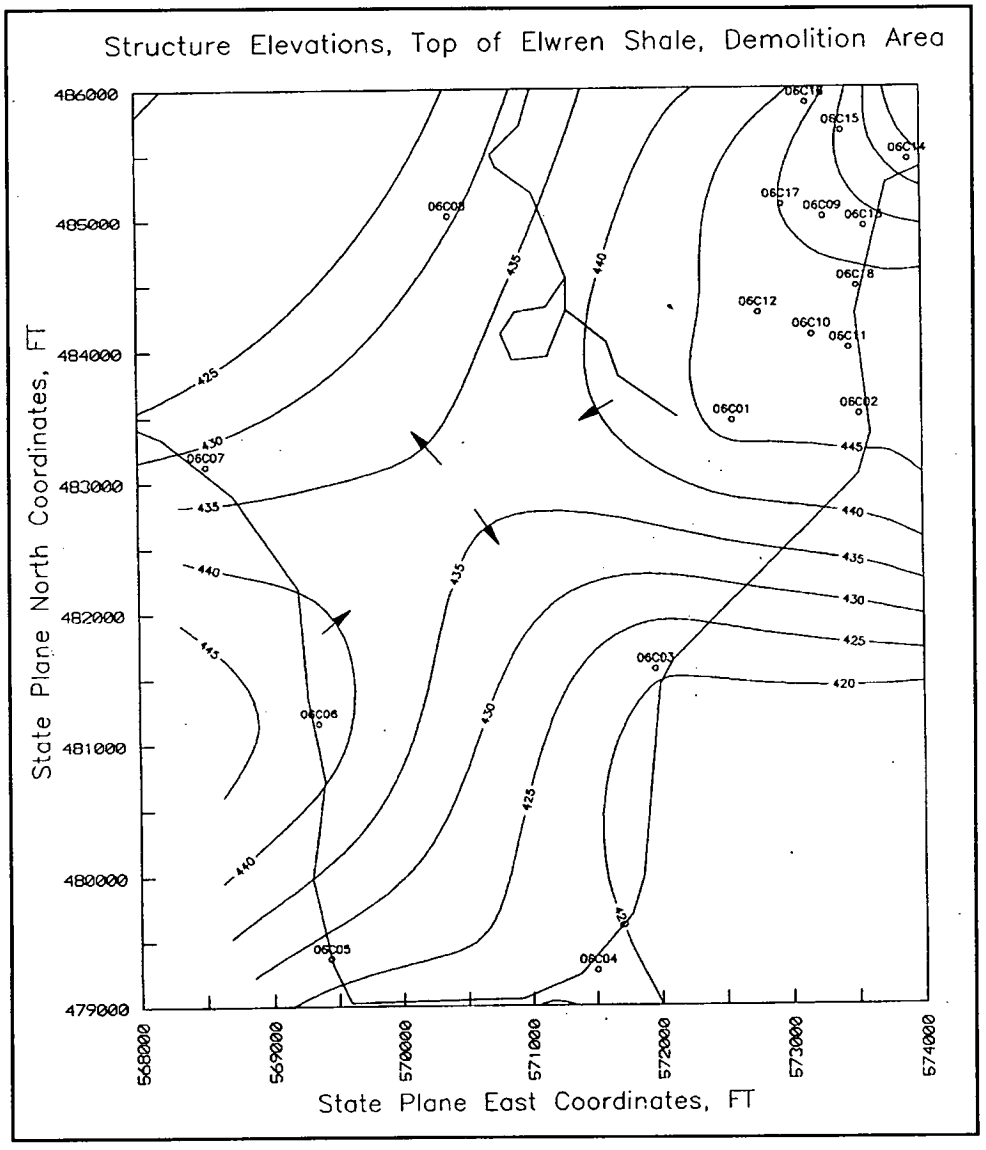


Figure 14. Structure contour map of Demolition Area (top of Elwren shale)

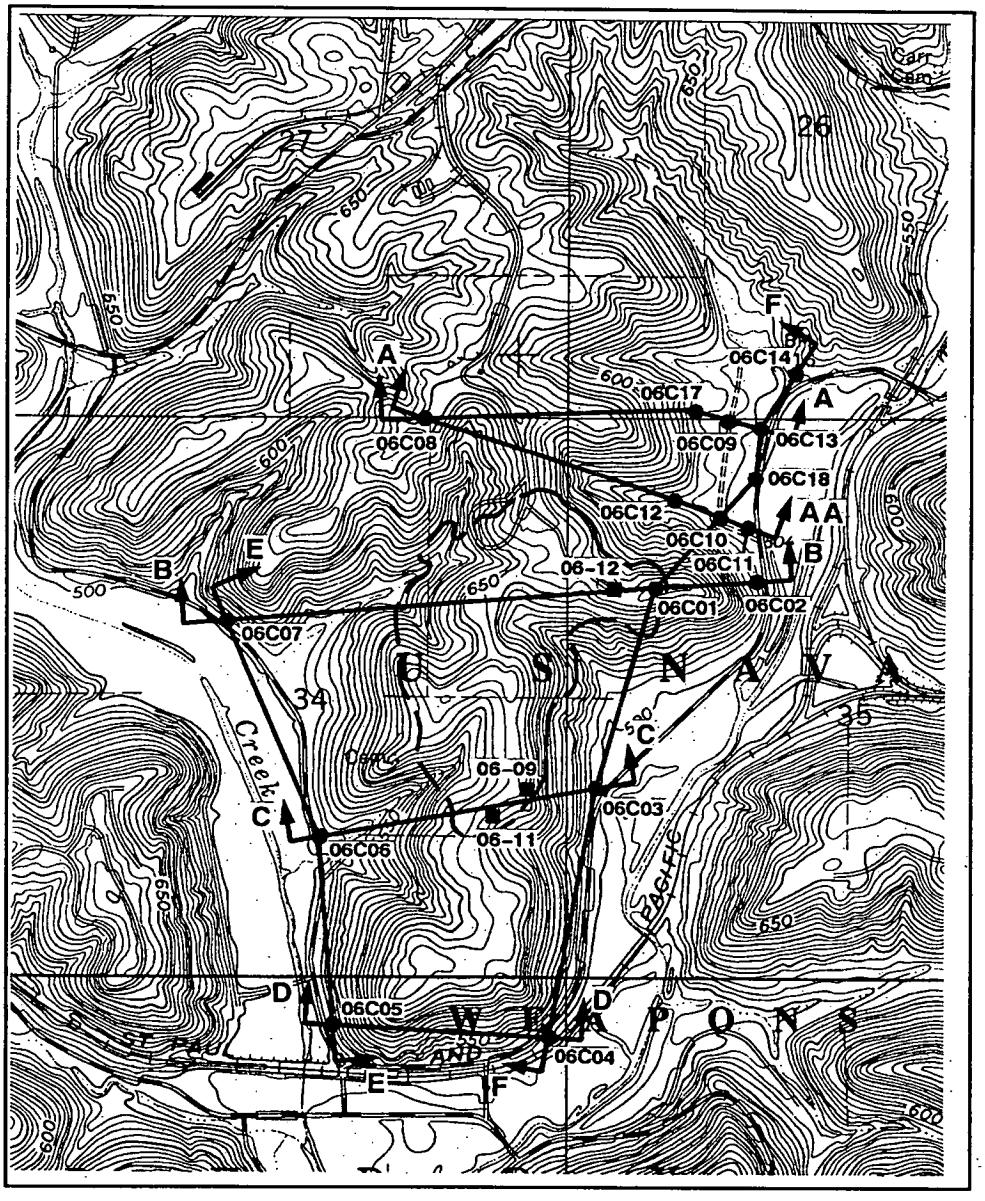


Figure 15. Location of geologic cross sections AA through FF, Demolition Area

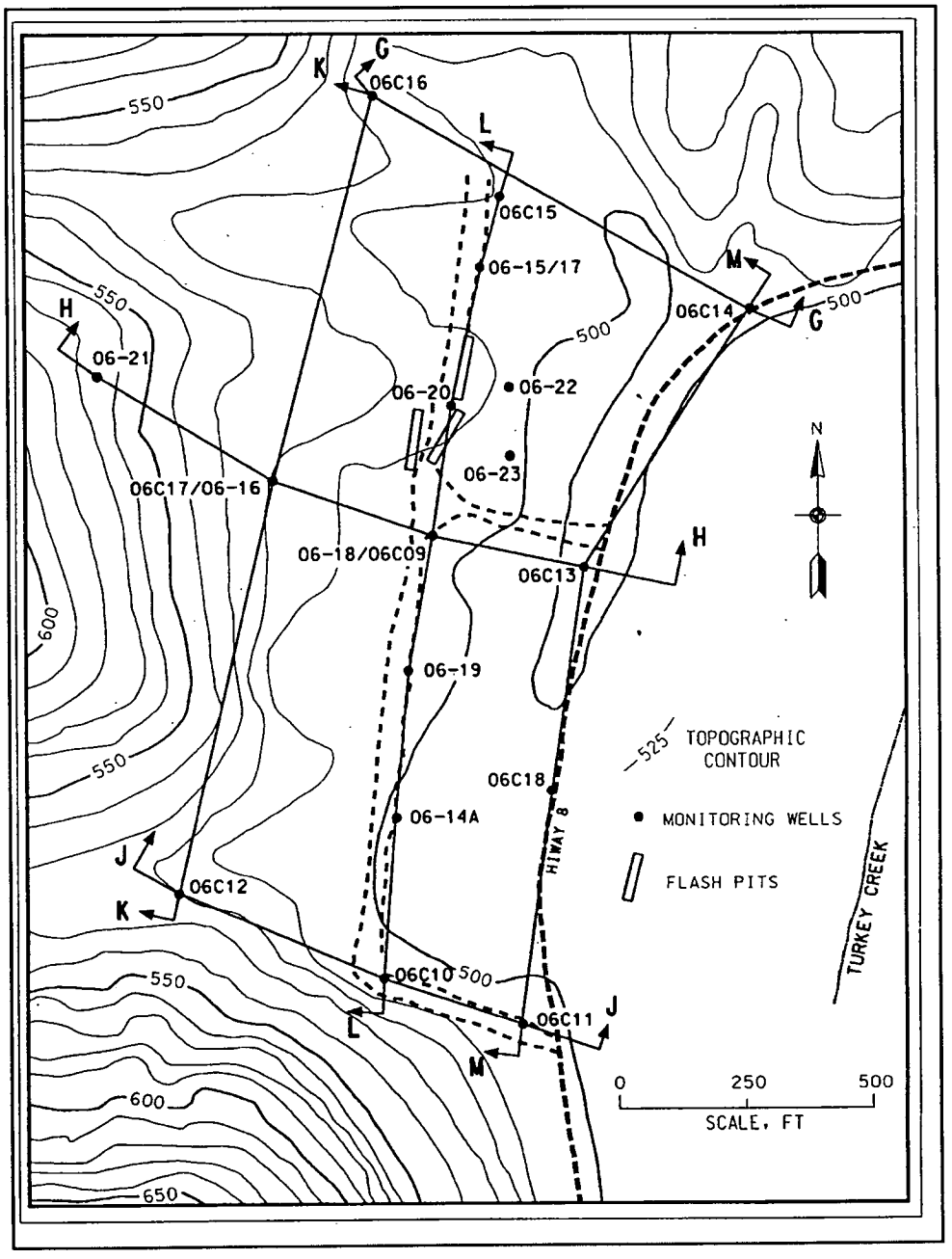


Figure 16. Locations of geologic cross sections GG through MM, Old Rifle Range

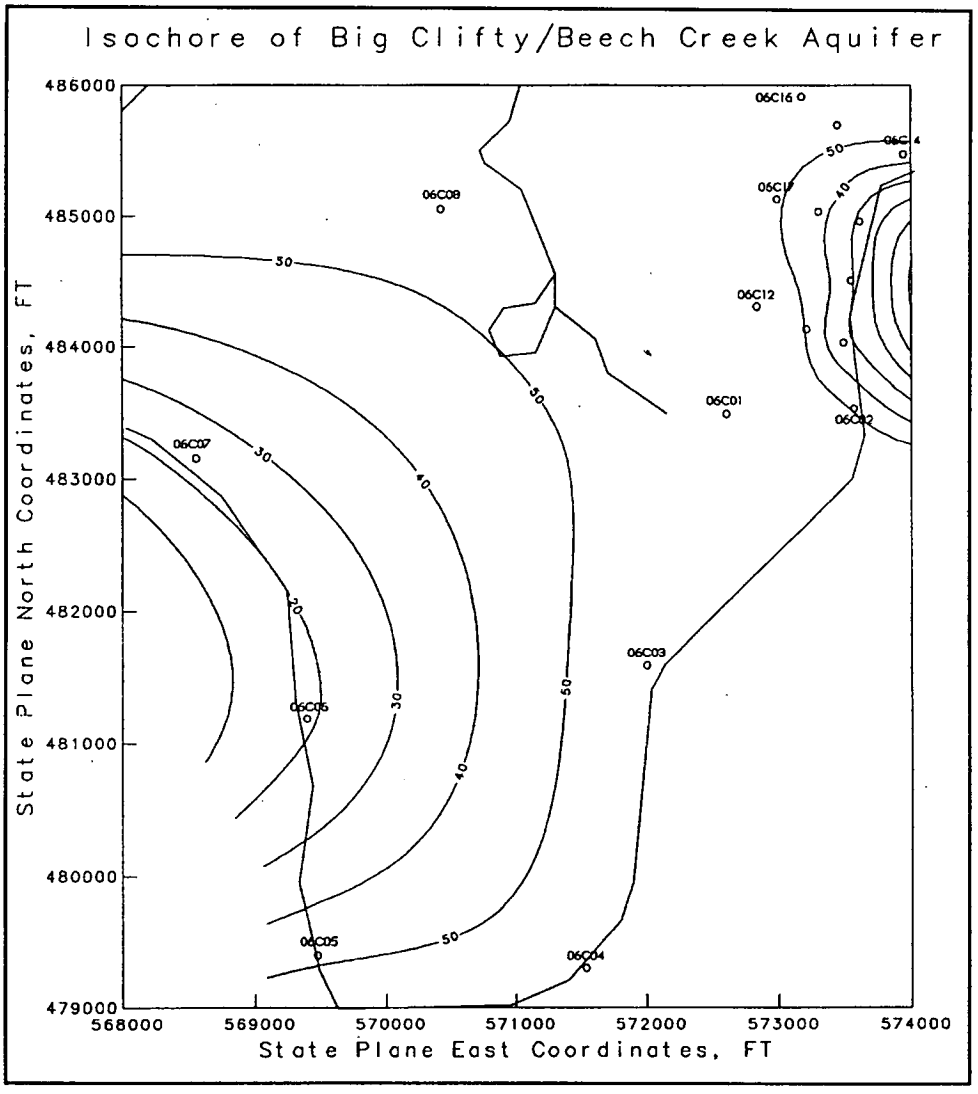


Figure 17. Isochore (drilled thickness) map of Big Clifty/Beech Creek aquifer, Demolition Area/Old Rifle Range (contours show thickness in feet)

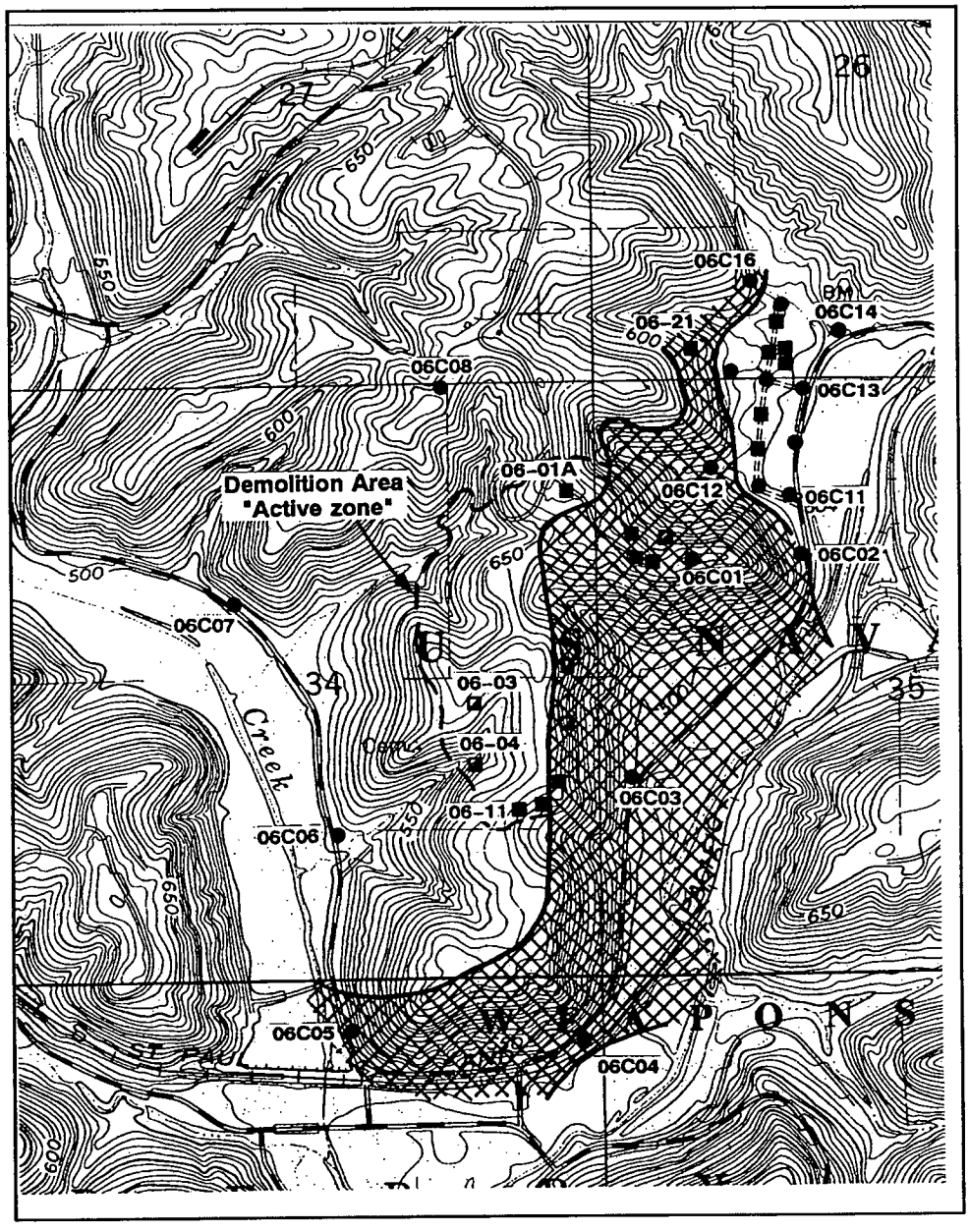


Figure 18. Extent of Golconda/Haney formation (cross-hatched) beneath Demolition Area (see text for explanation)

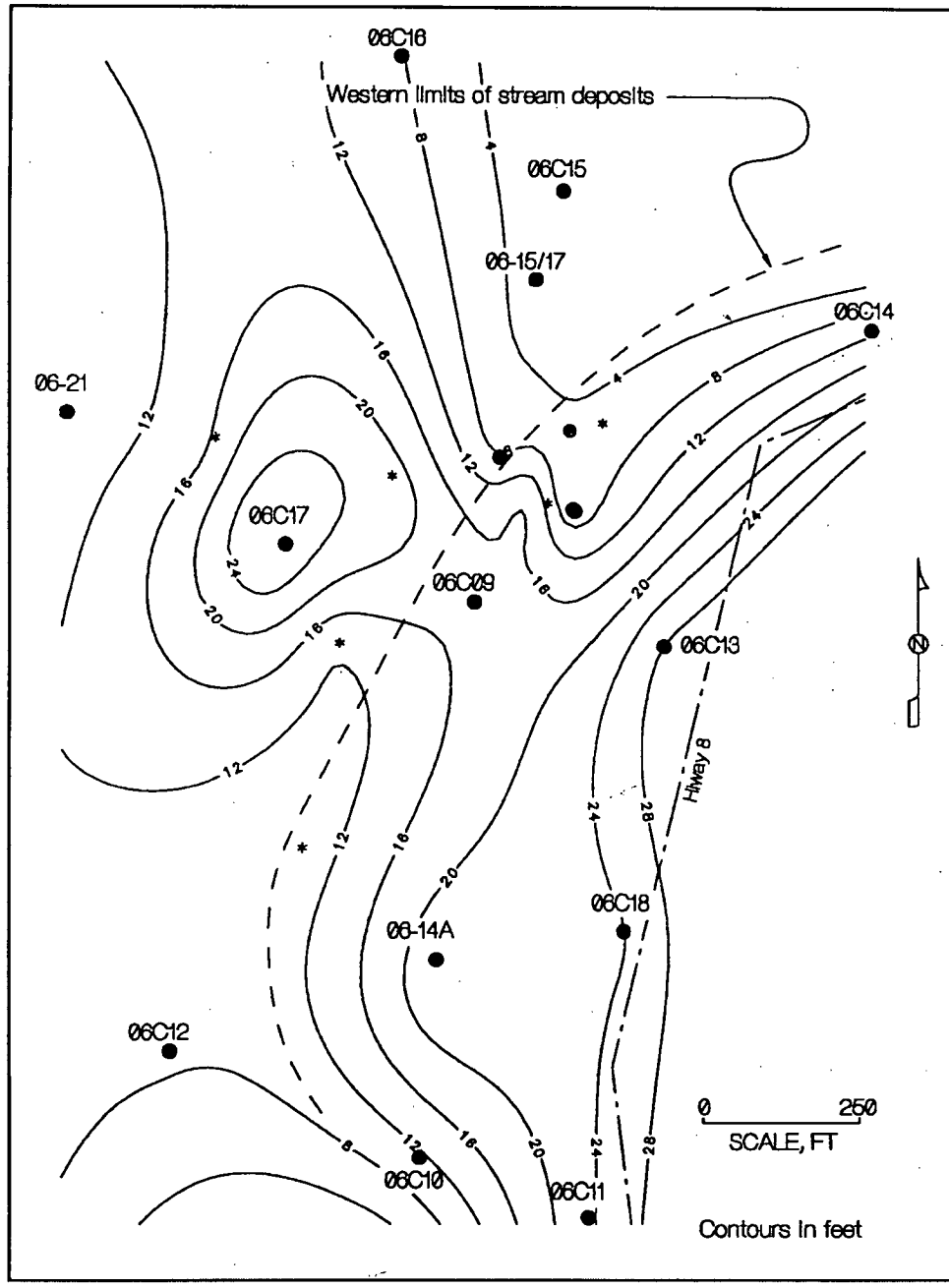


Figure 19. Contour map of soil (overburden) thickness, Old Rifle Range

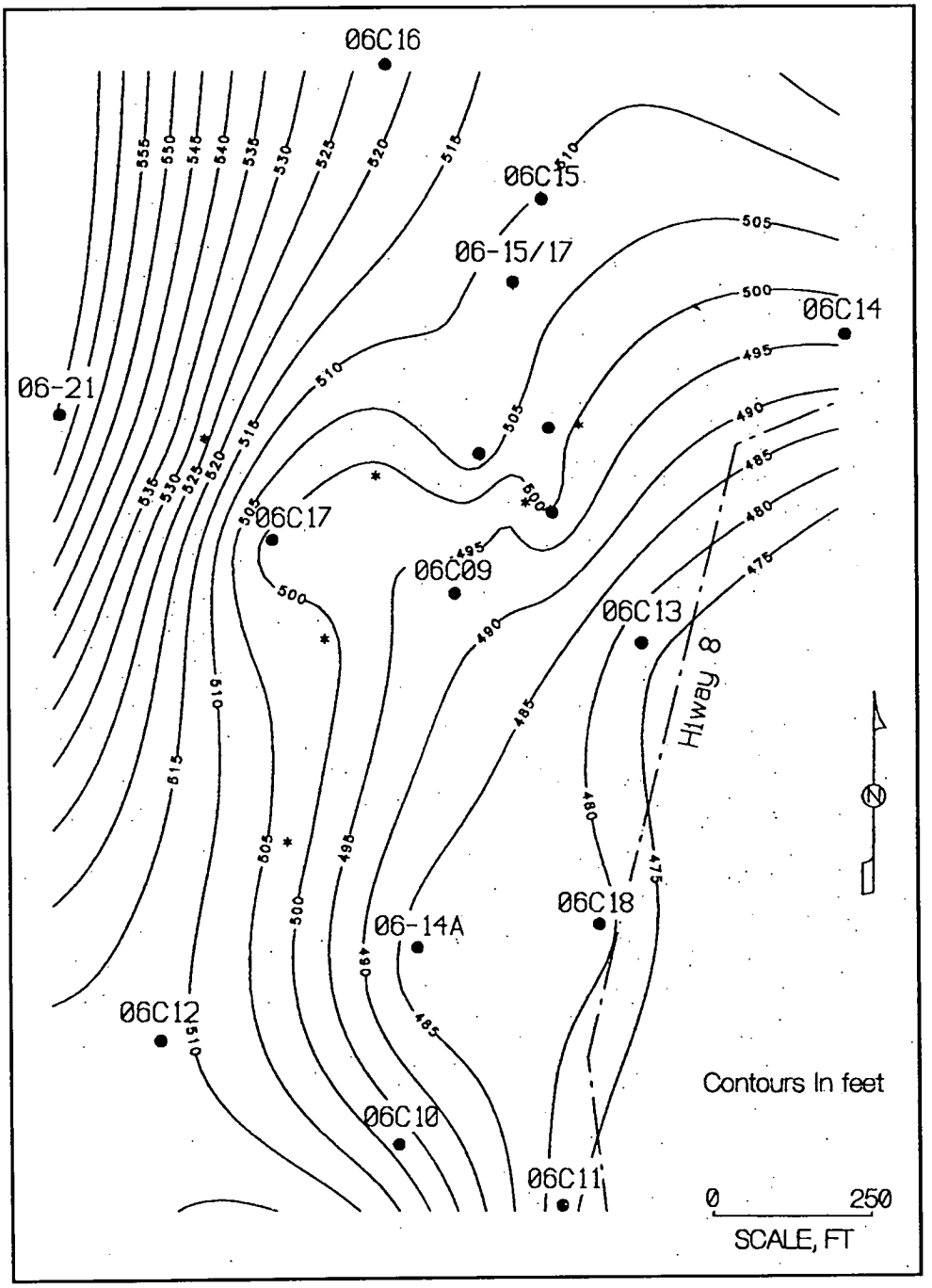


Figure 20. Elevation of top of rock from soil (*) and monitoring well borings (●), Old Rifle Range (only selected borings are labeled)

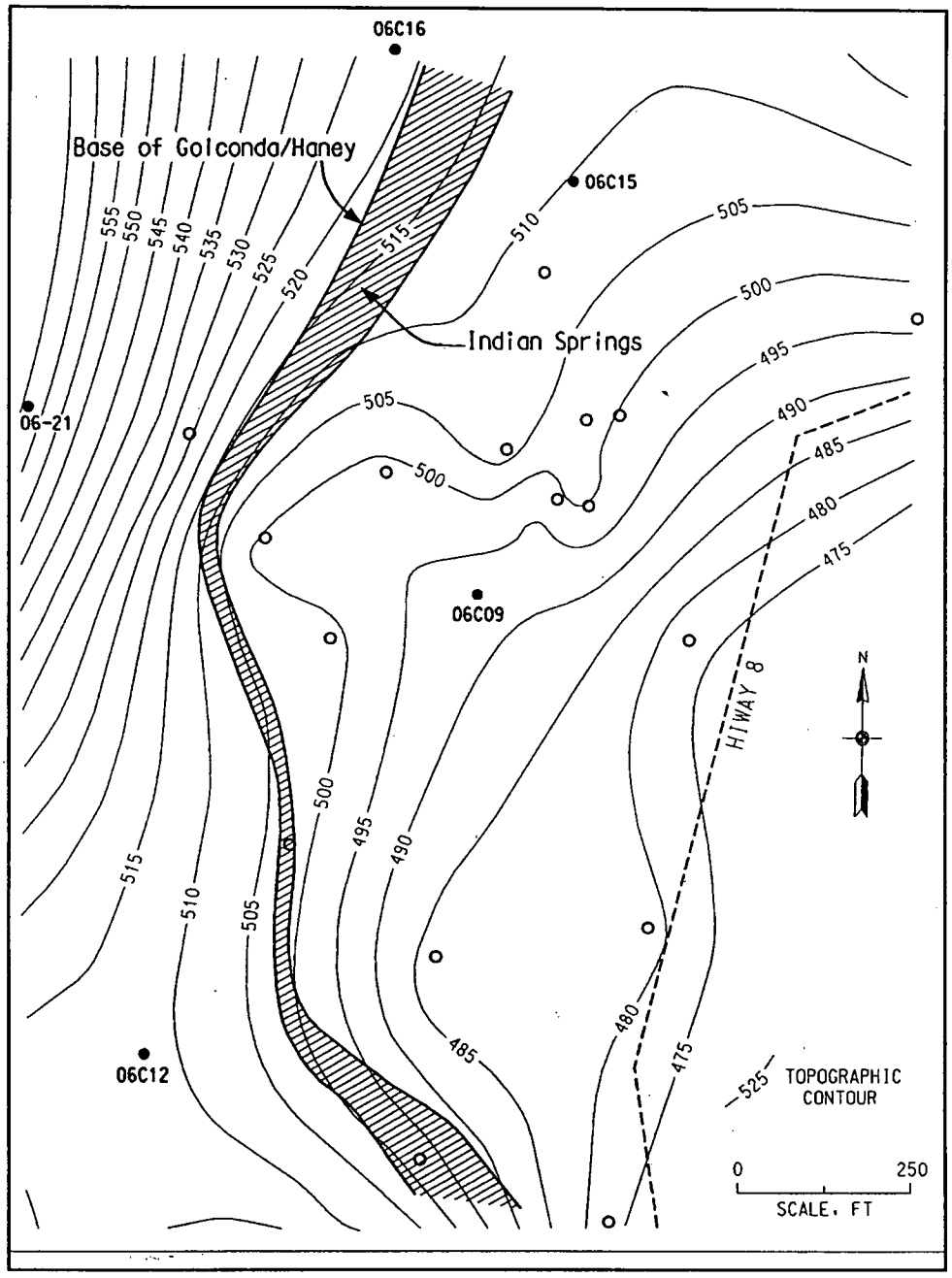


Figure 21. Subcrop map of Indian Springs and base of Golconda/Haney, Old Rifle Range

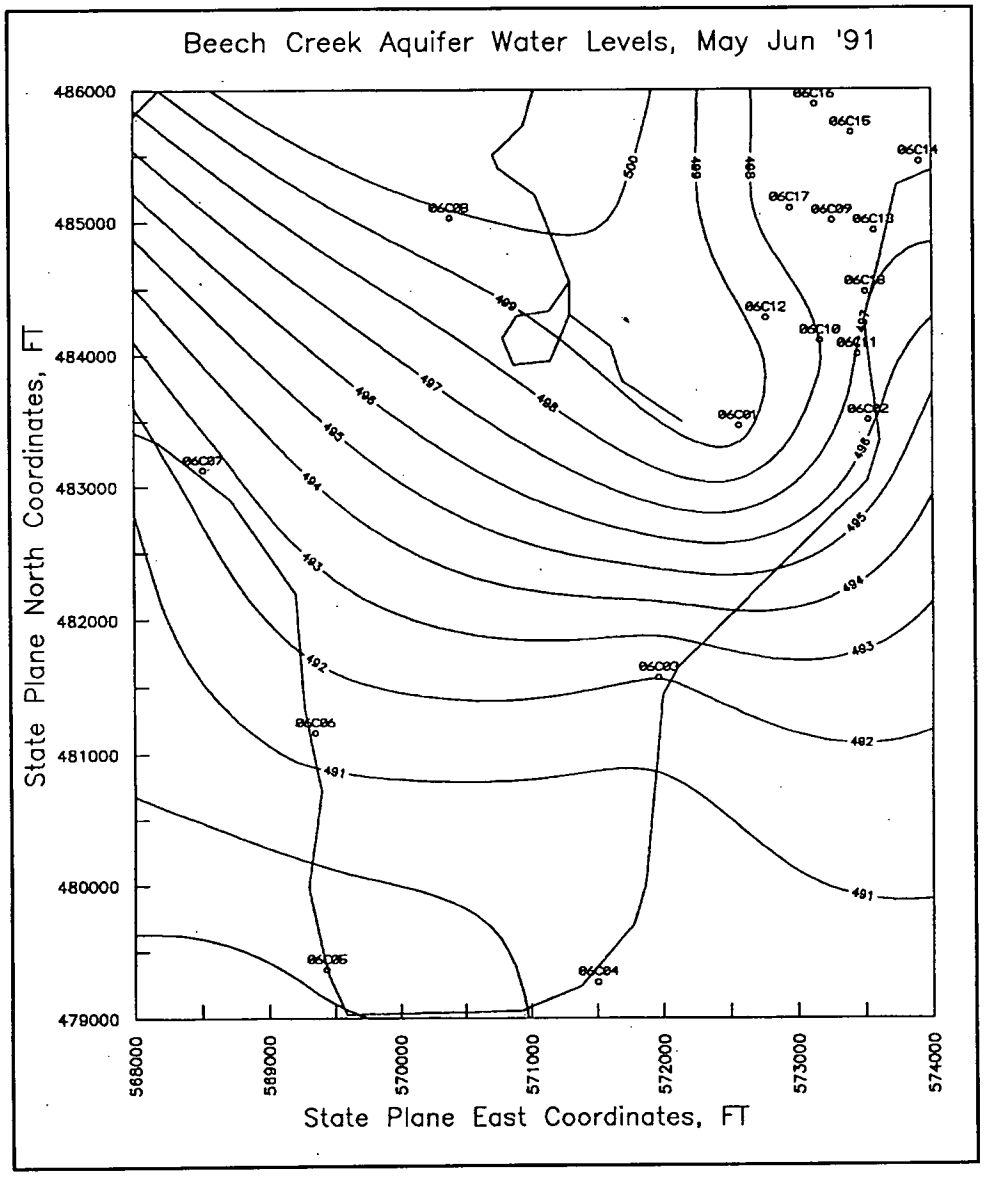


Figure 22. Piezometric surface of May-June 1991, Beech Creek aquifer, Demolition Area

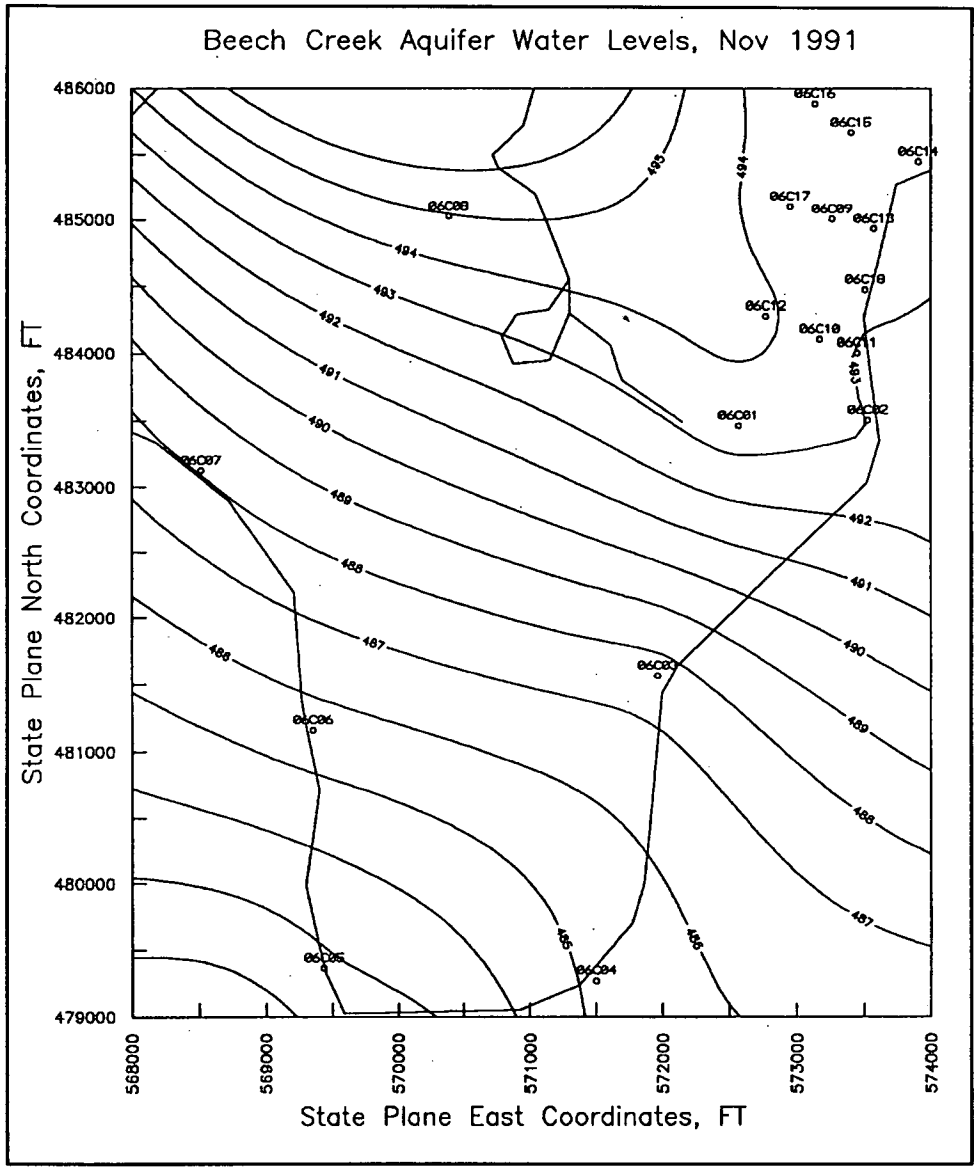


Figure 23. Piezometric surface of November 1991, Beech Creek aquifer, Demolition Area

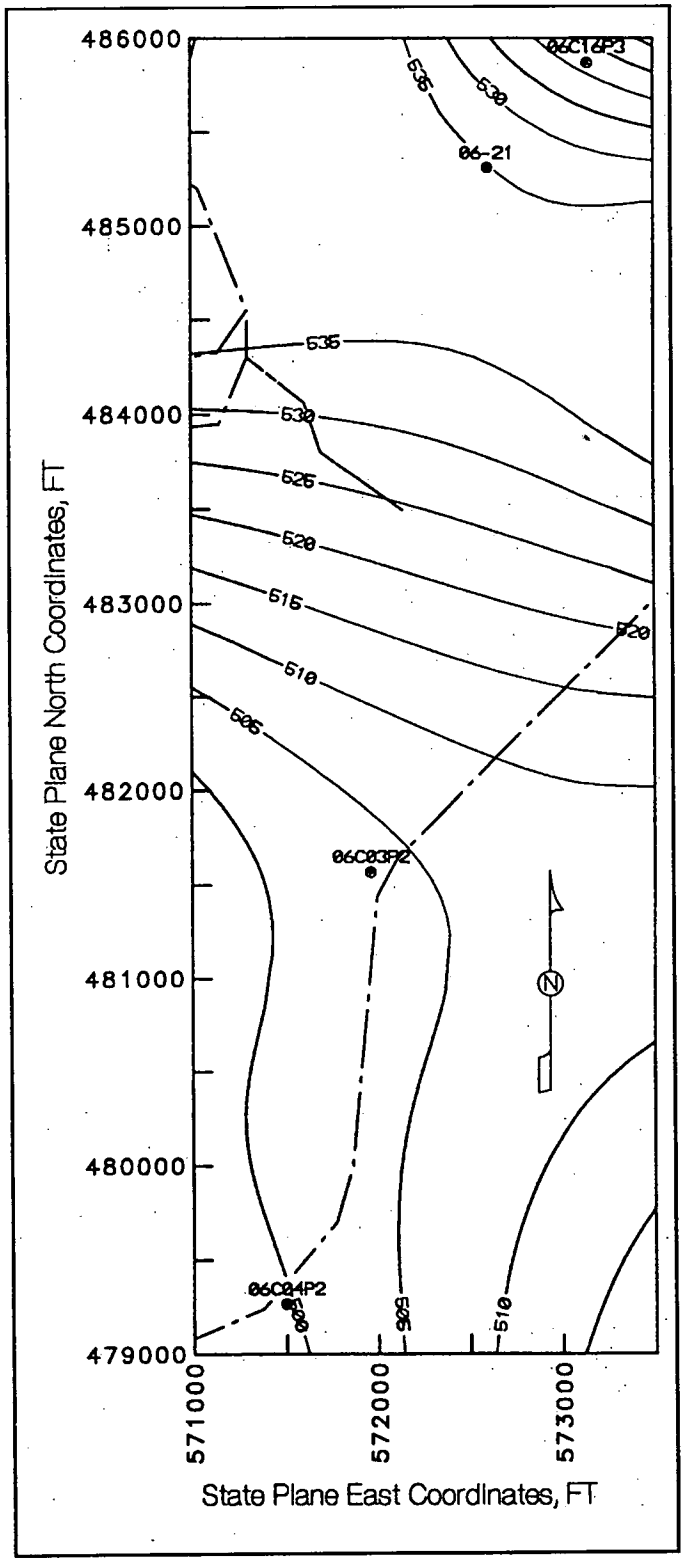


Figure 24. Piezometric surface of May-June1991, Golconda/Haney aquifer, Demolition Area/Old Rifle Range

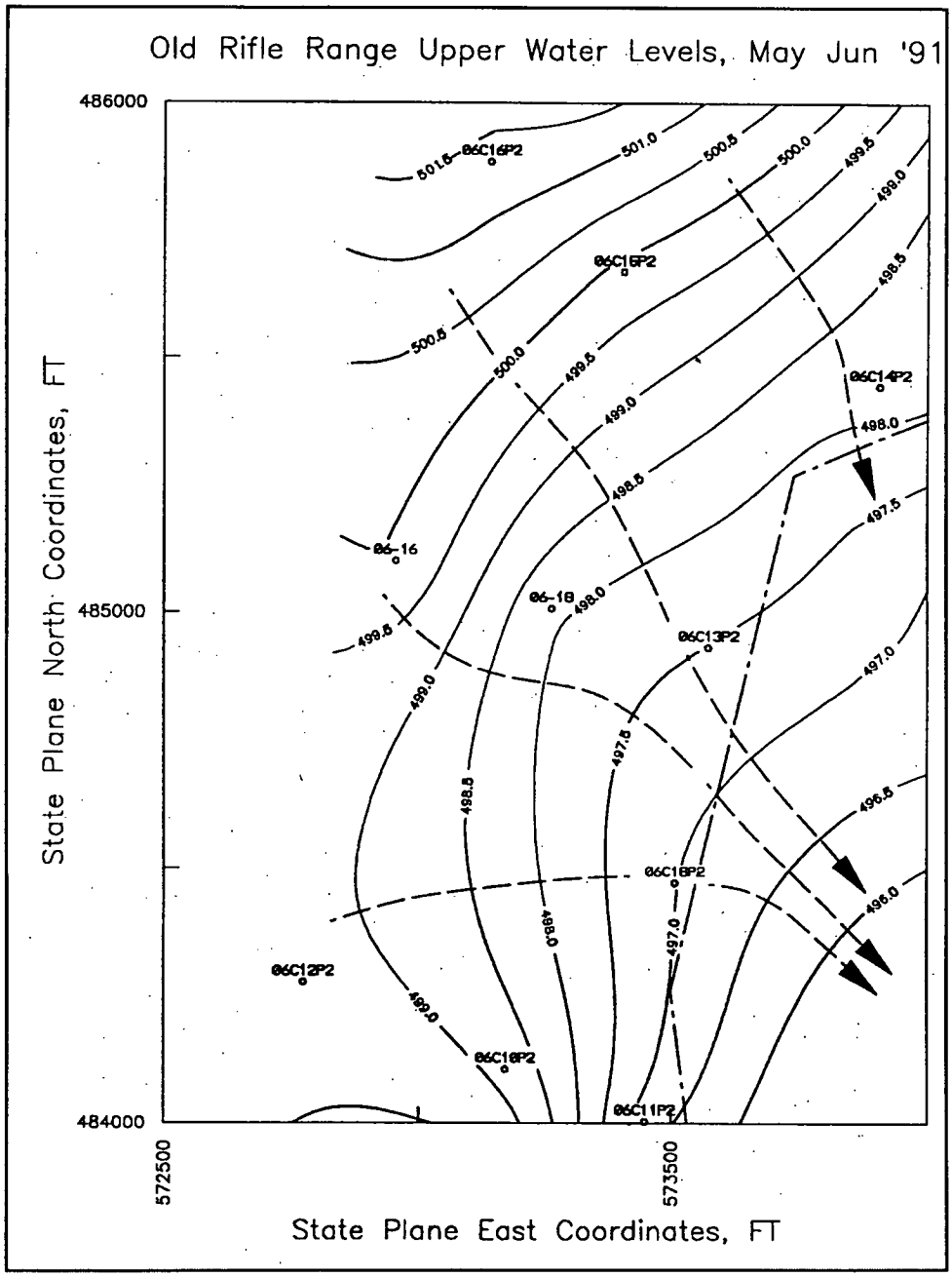


Figure 25. Piezometric surface, uppermost aquifer for May-June 1991, Old Rifle Range

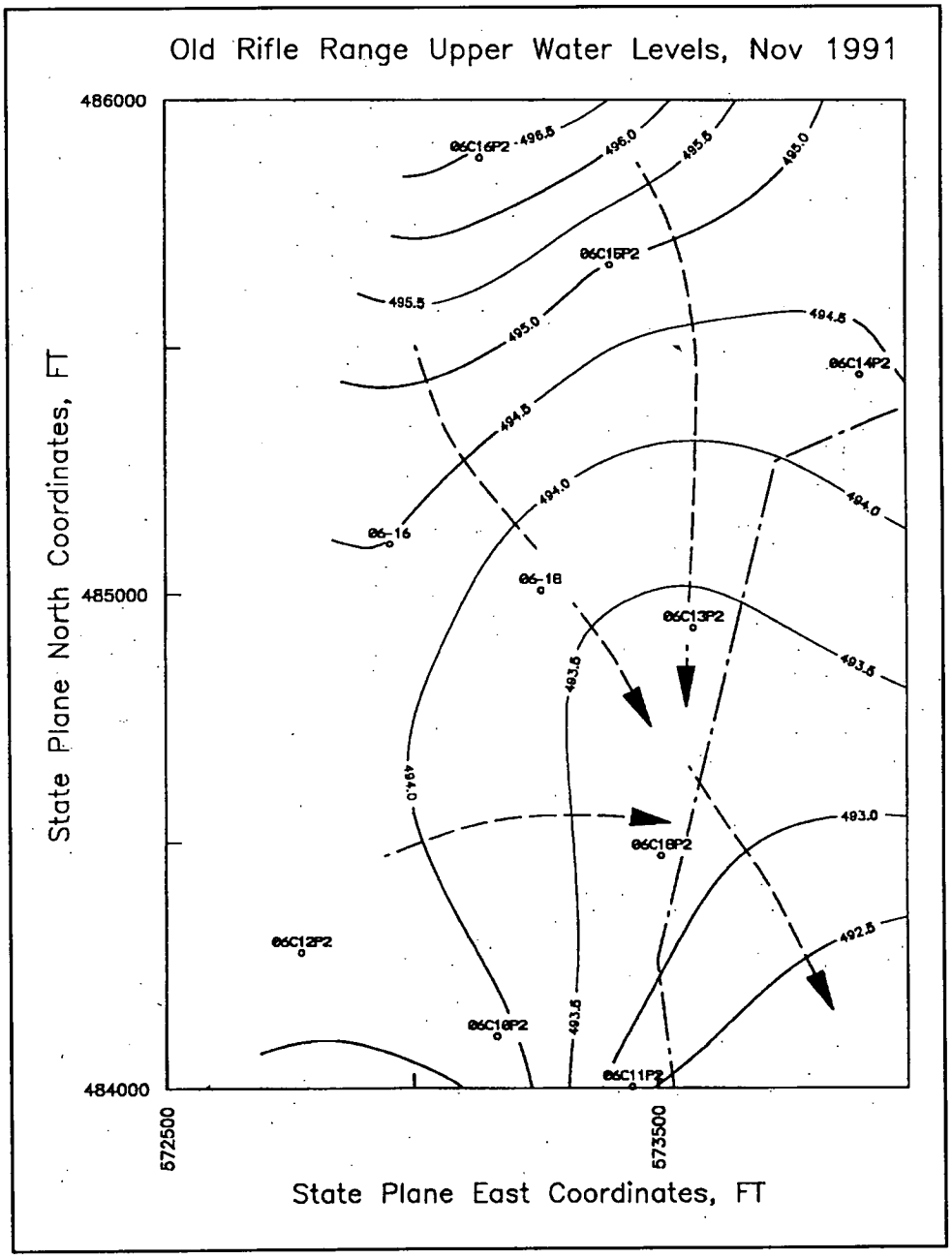


Figure 26. Piezometric surface, uppermost aquifer for November 1991, Old Rifle Range

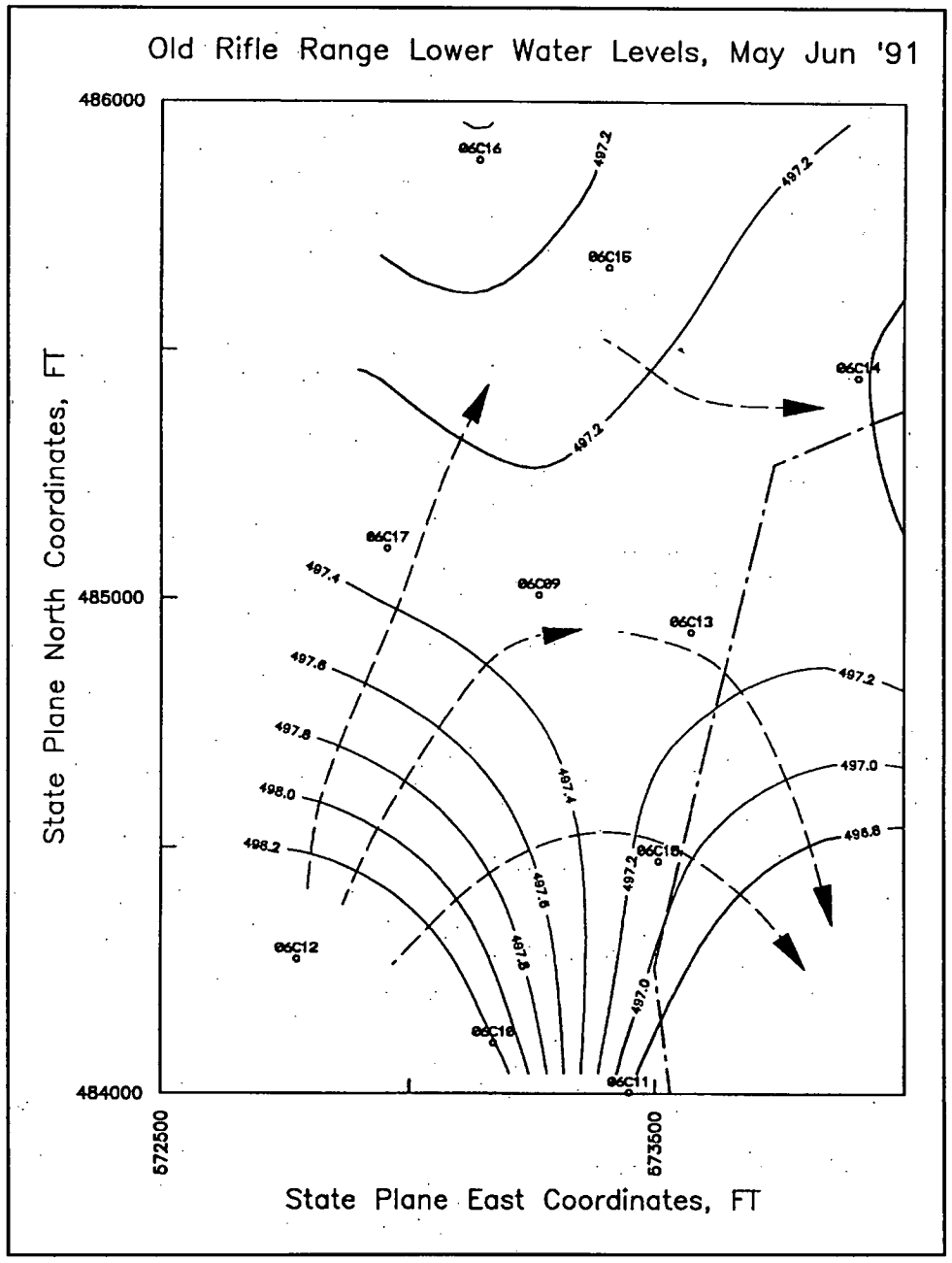


Figure 27. Piezometric surface, Big Clifty/Beech Creek aquifer (lower zone) for May-June 1991, Old Rifle Range

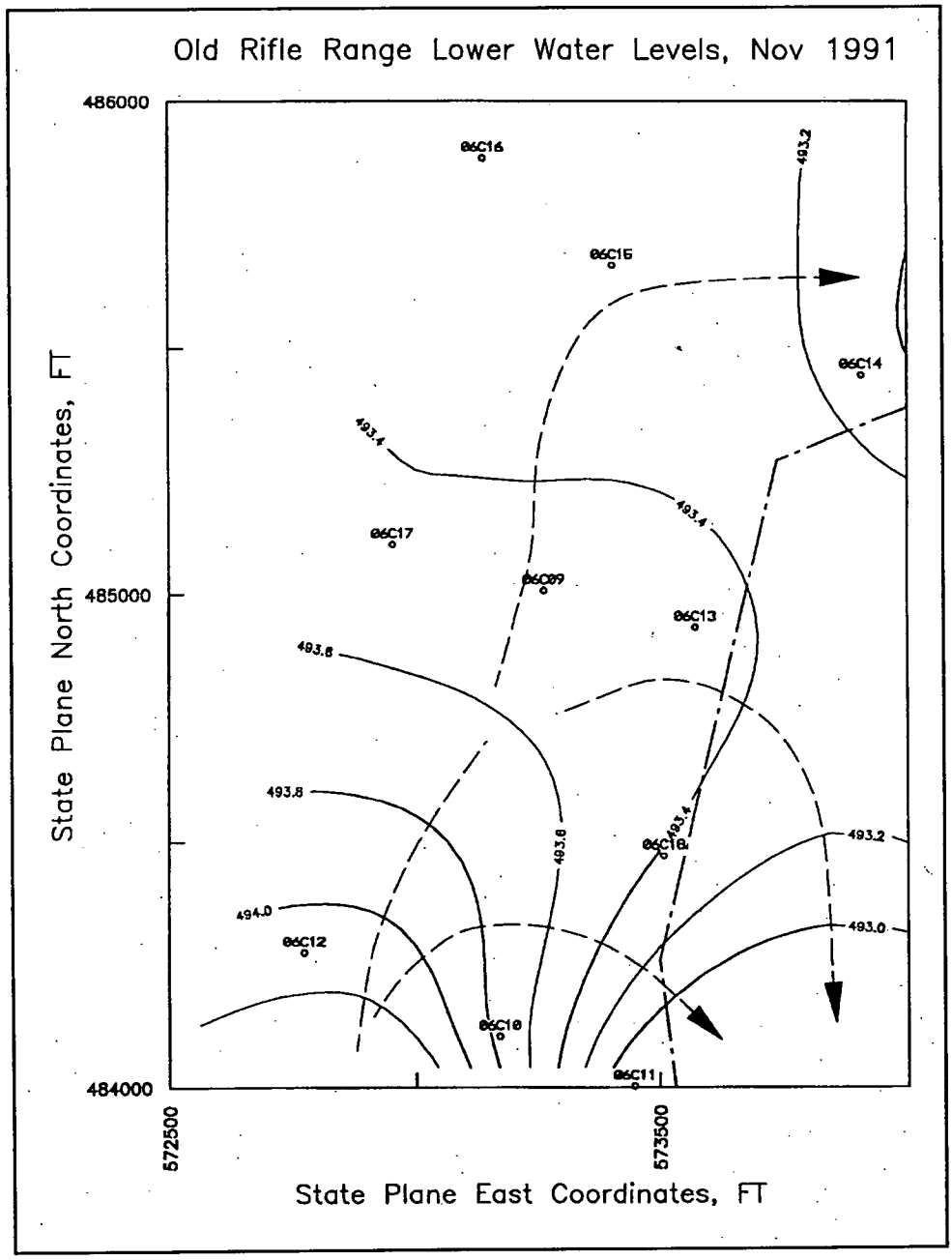


Figure 28. Piezometric surface for November 1991, Big Clifty/Beech Creek aquifer (lower zone) Old Rifle Range

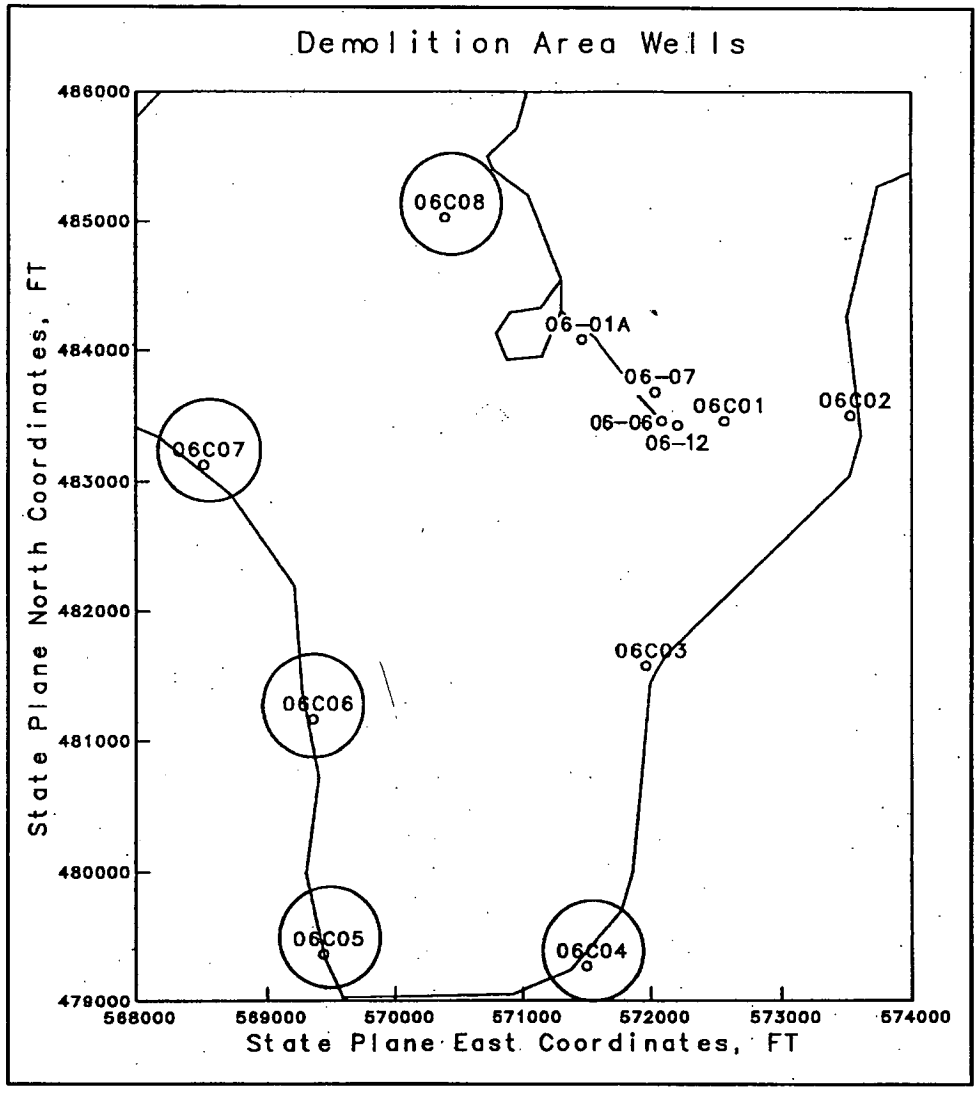


Figure 29. First group of Demolition Area wells (for metals)

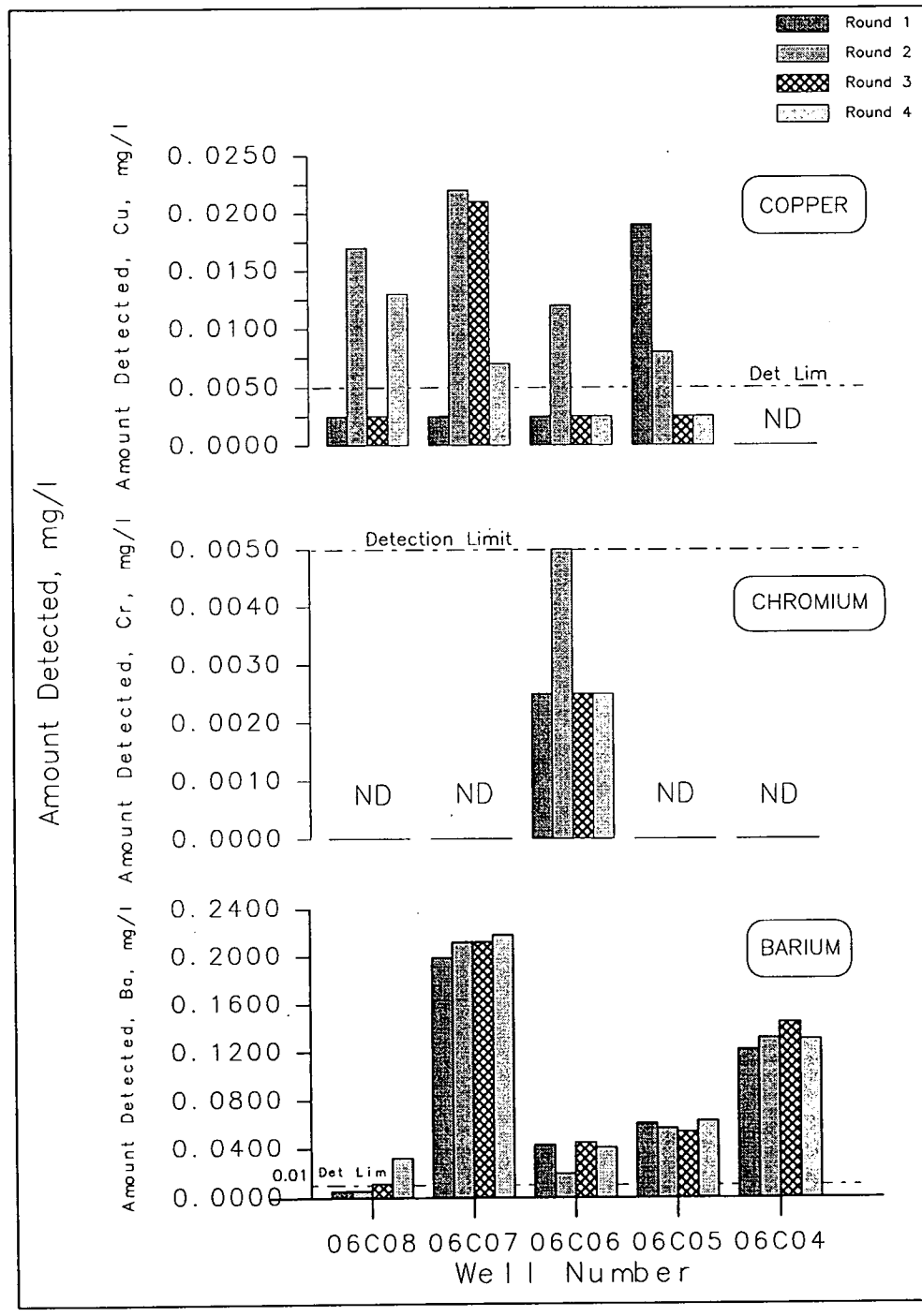


Figure 30. Levels of copper, chromium and barium detected in Demolition Area first group wells

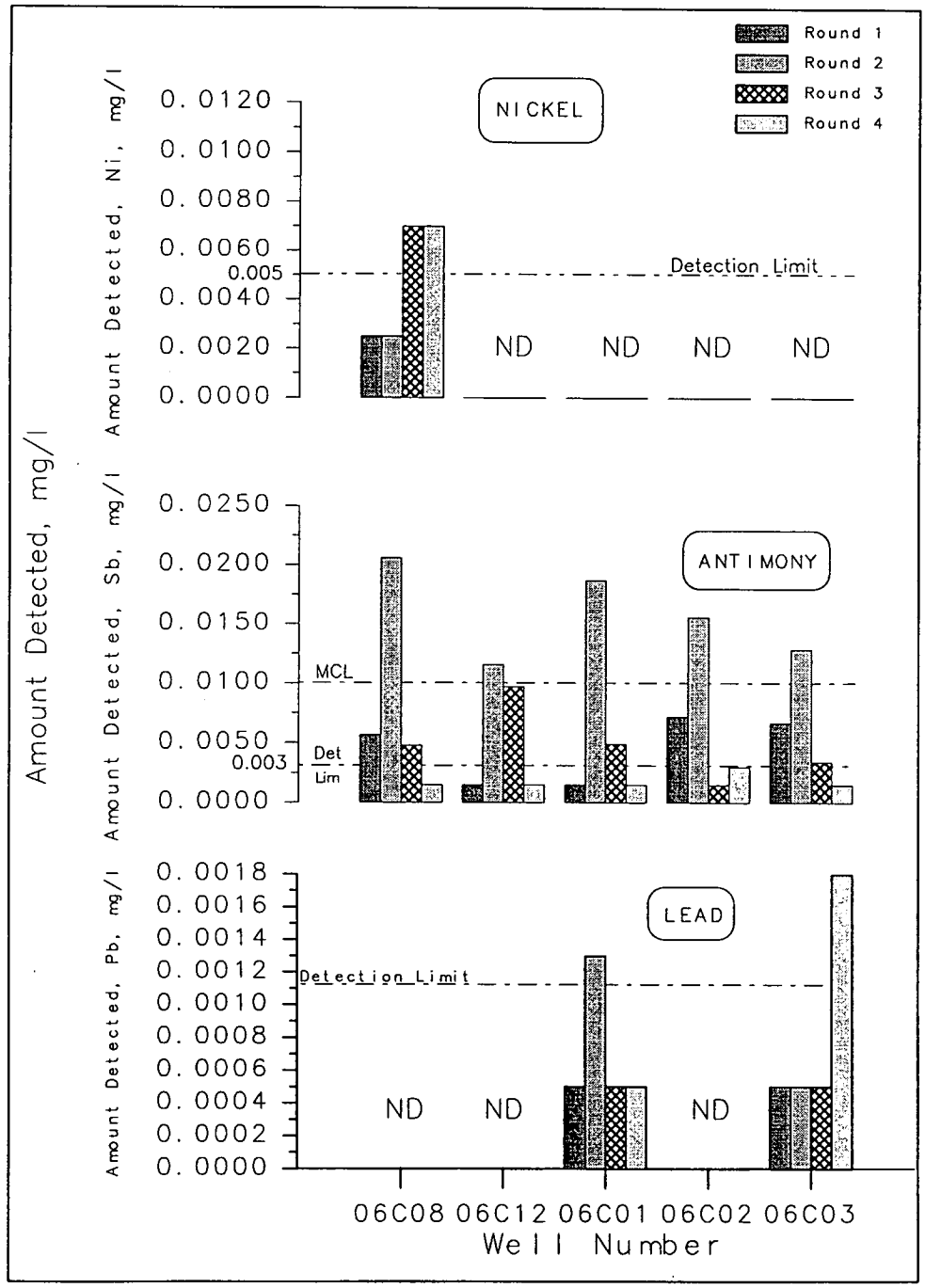


Figure 31. Levels of nickel, antimony, and lead detected in Demolition Area first group wells

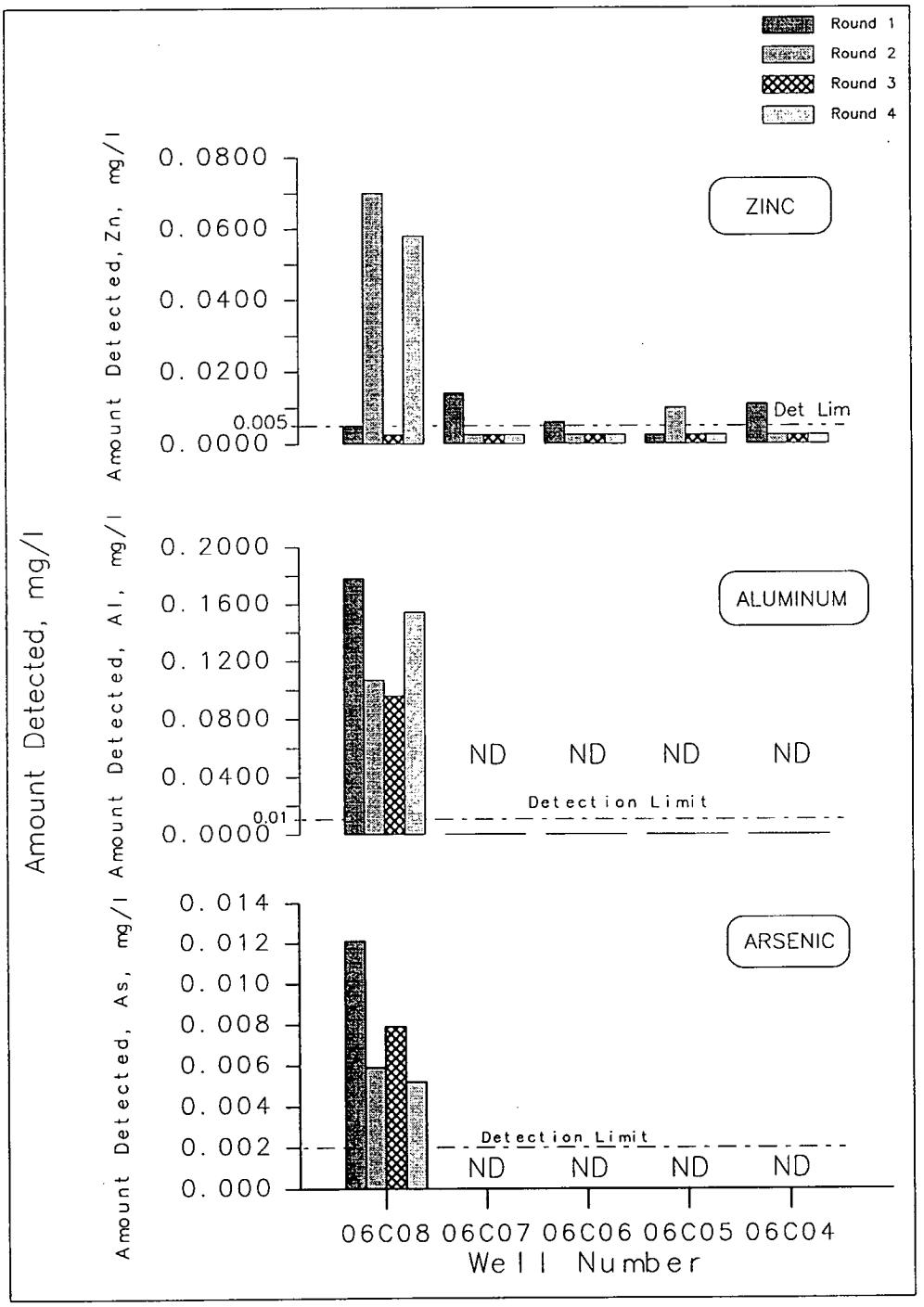


Figure 32. Levels of zinc, aluminum, and arsenic detected in Demolition Area first group wells

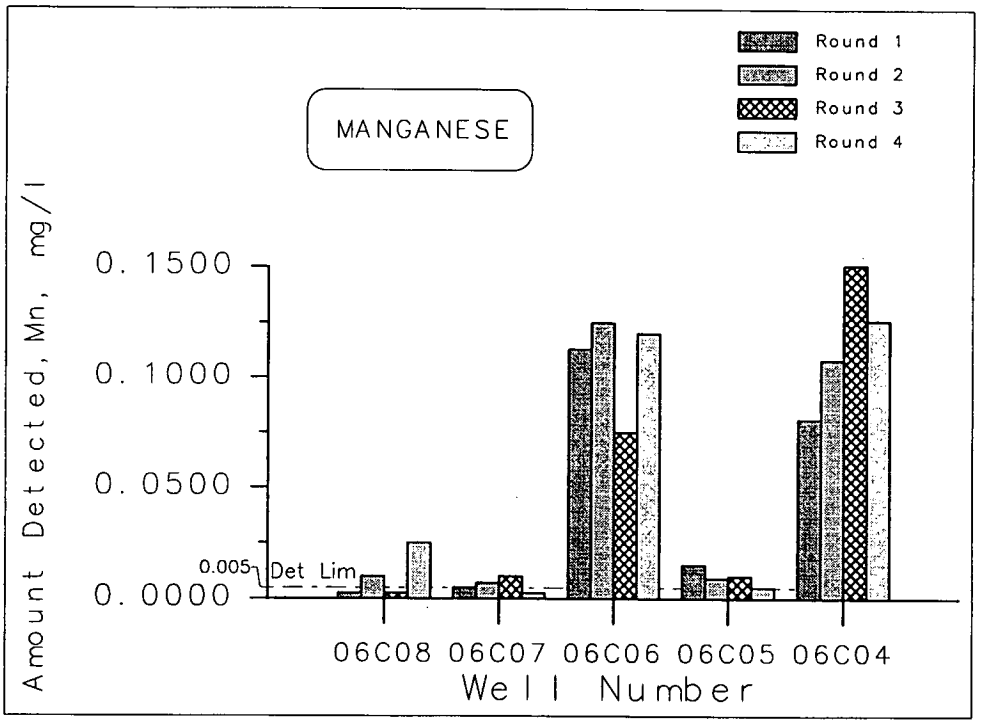


Figure 33. Levels of manganese detected in Demolition Area first group wells

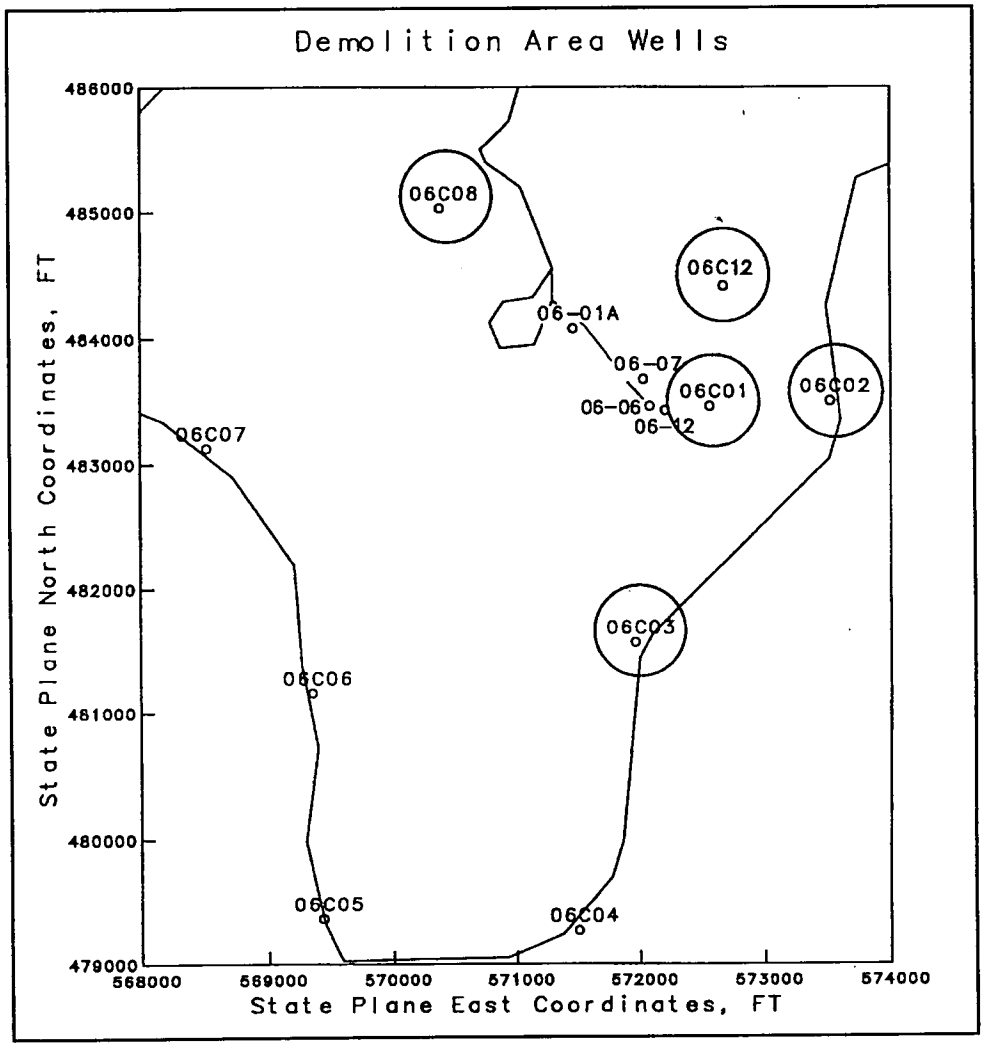


Figure 34. Second group of Demolition Area wells (for metals)

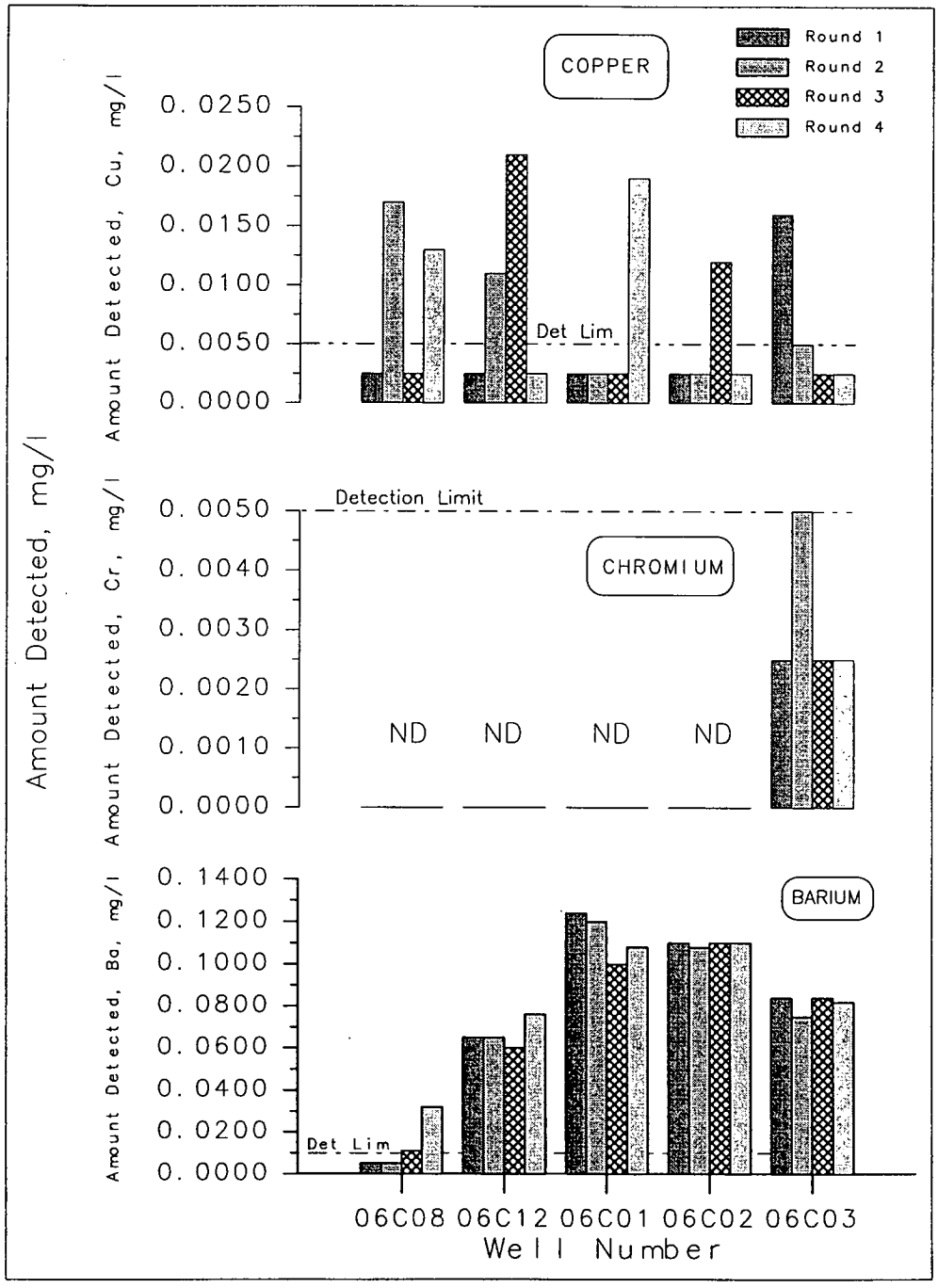


Figure 35. Levels of copper, chromium, and barium in Demolition Area second group wells

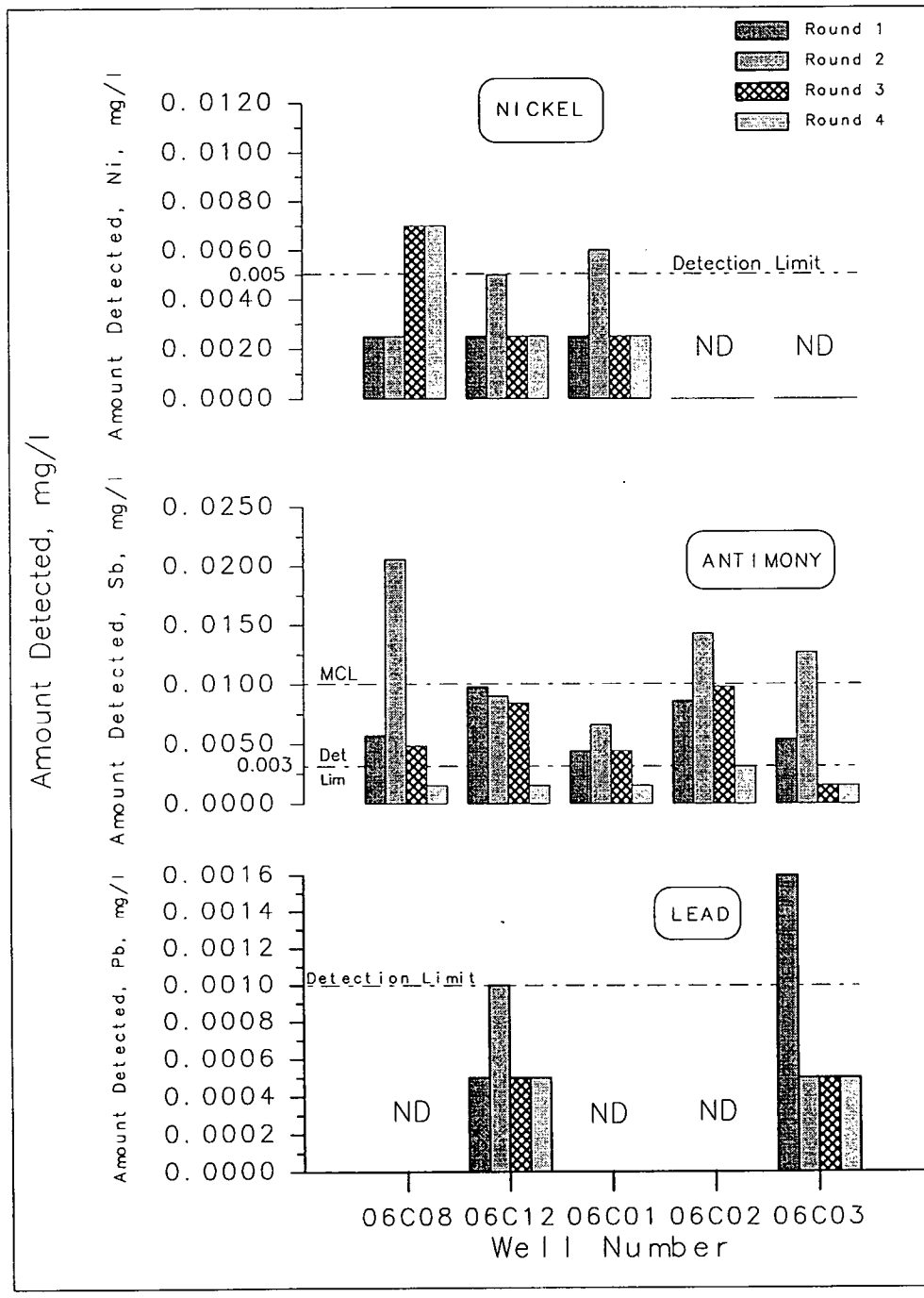


Figure 36. Levels of nickel, antimony, and lead in Demolition Area second group wells

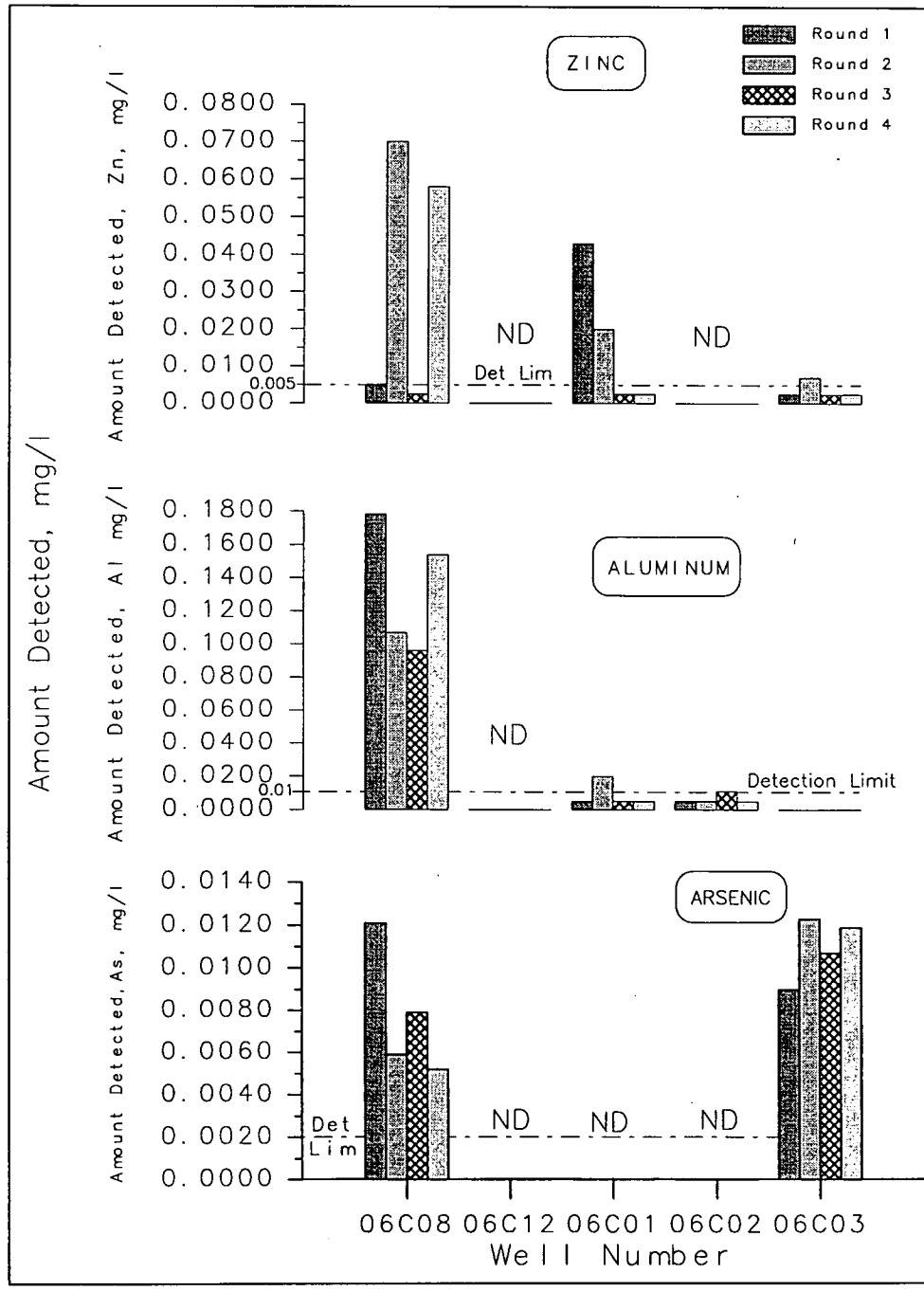


Figure 37. Levels of zinc, aluminum, and arsenic in Demolition Area second group wells

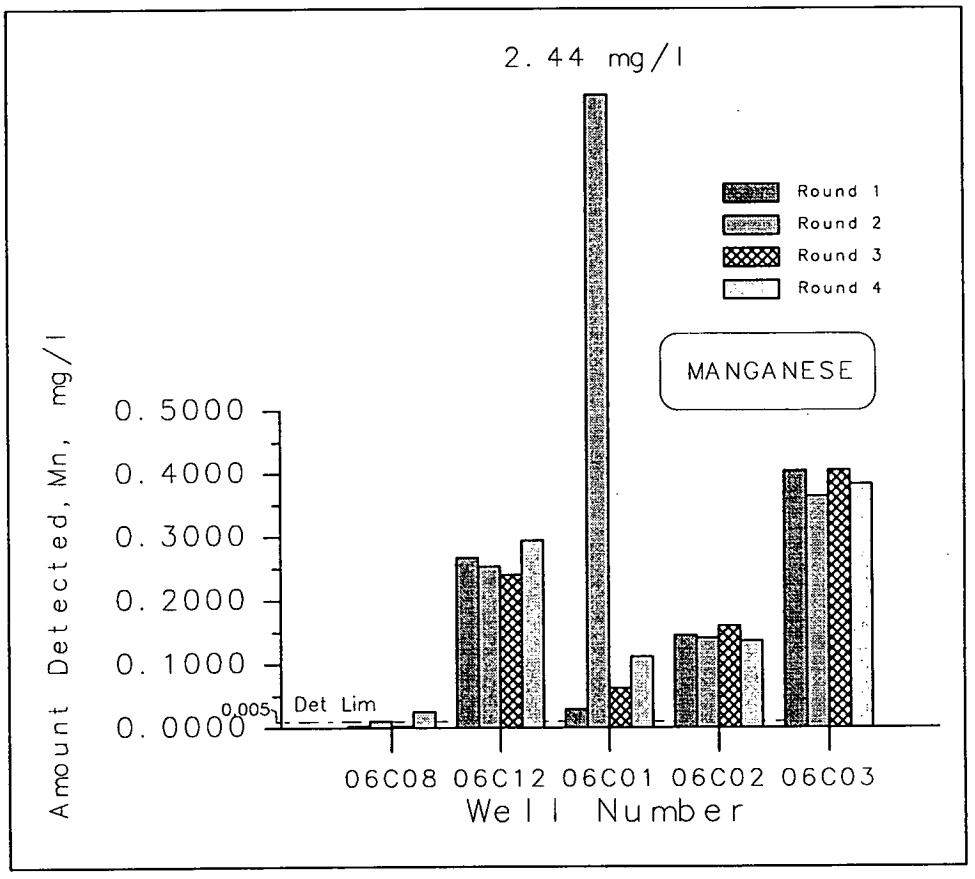


Figure 38. Levels of manganese detected in Demolition Area second group wells

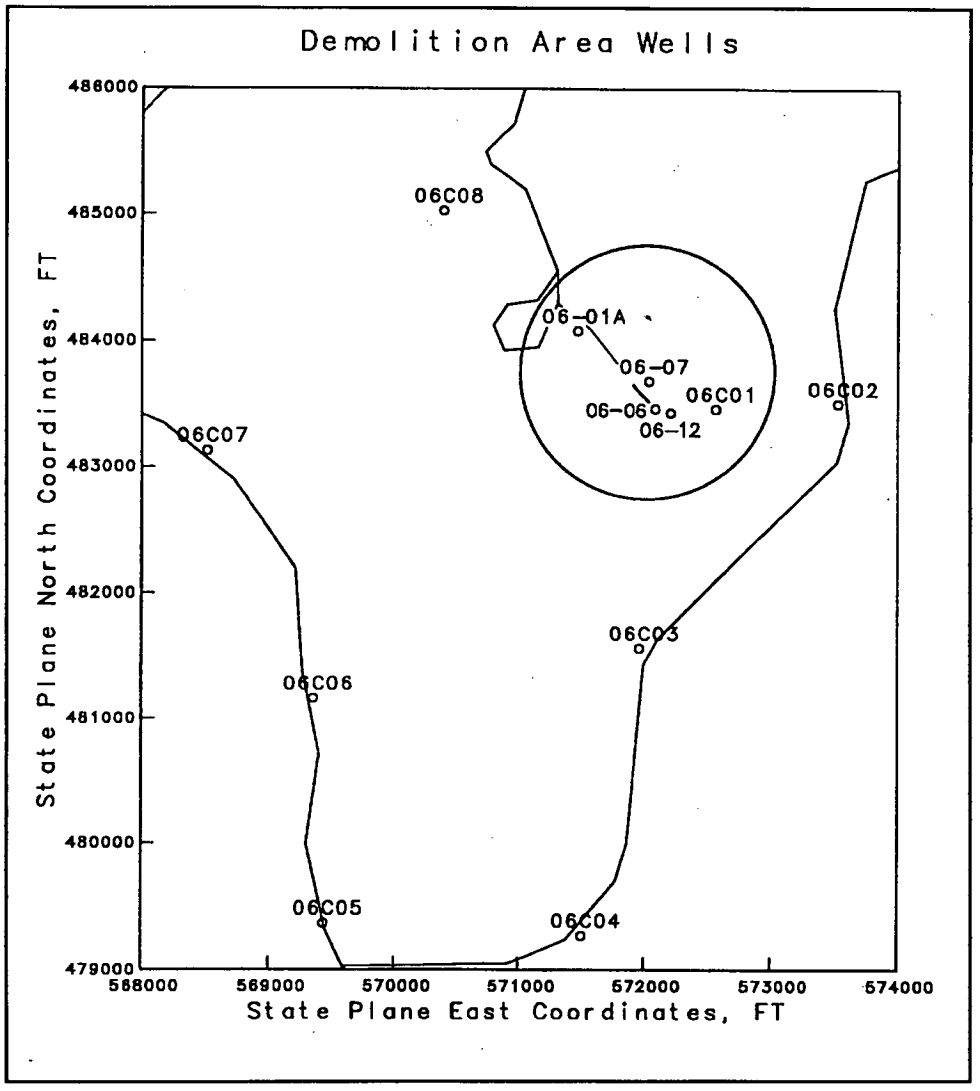


Figure 39. Third group of Demolition Area wells (for metals)

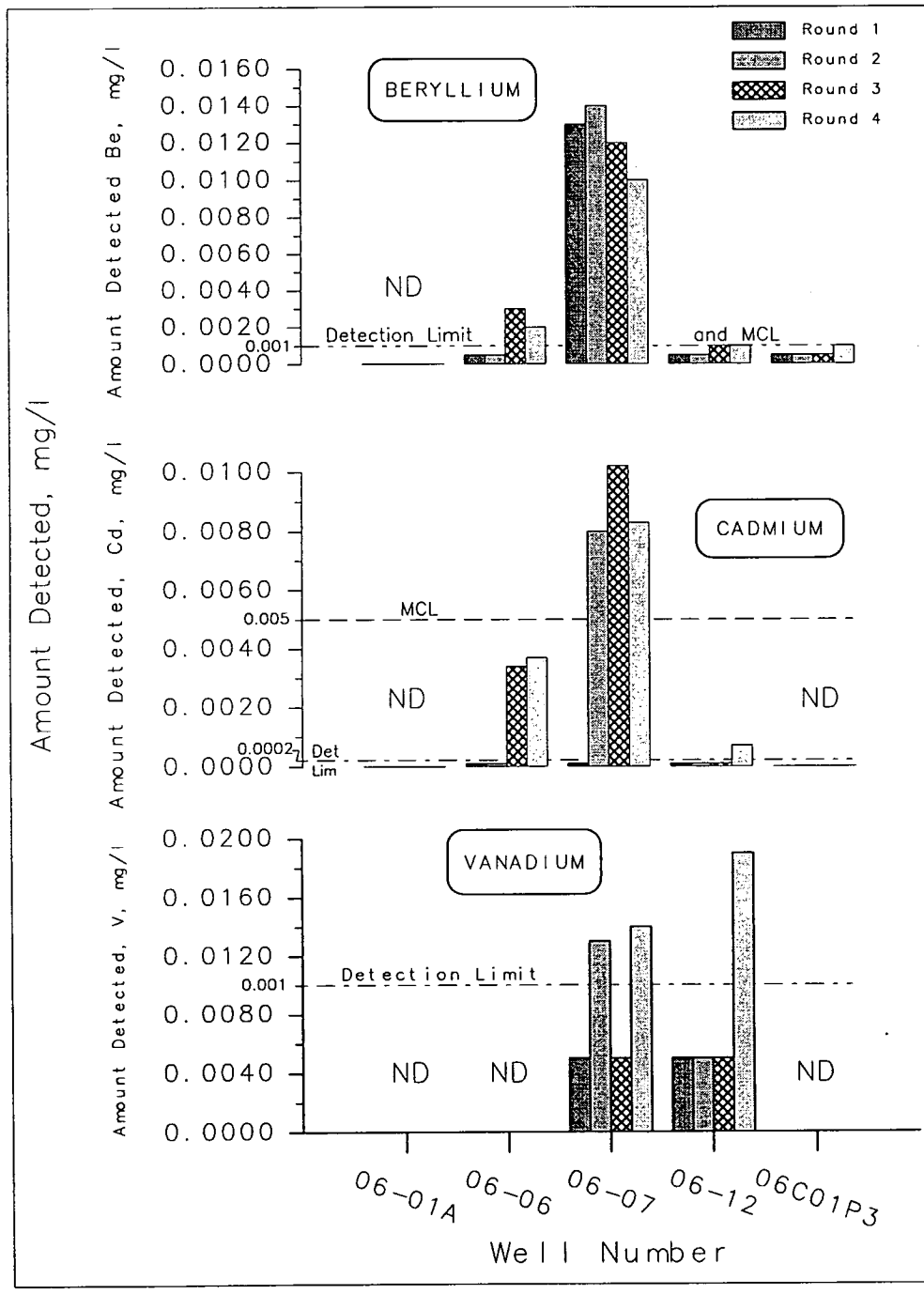


Figure 40. Levels of beryllium, cadmium, and vanadium in Demolition Area third group wells.

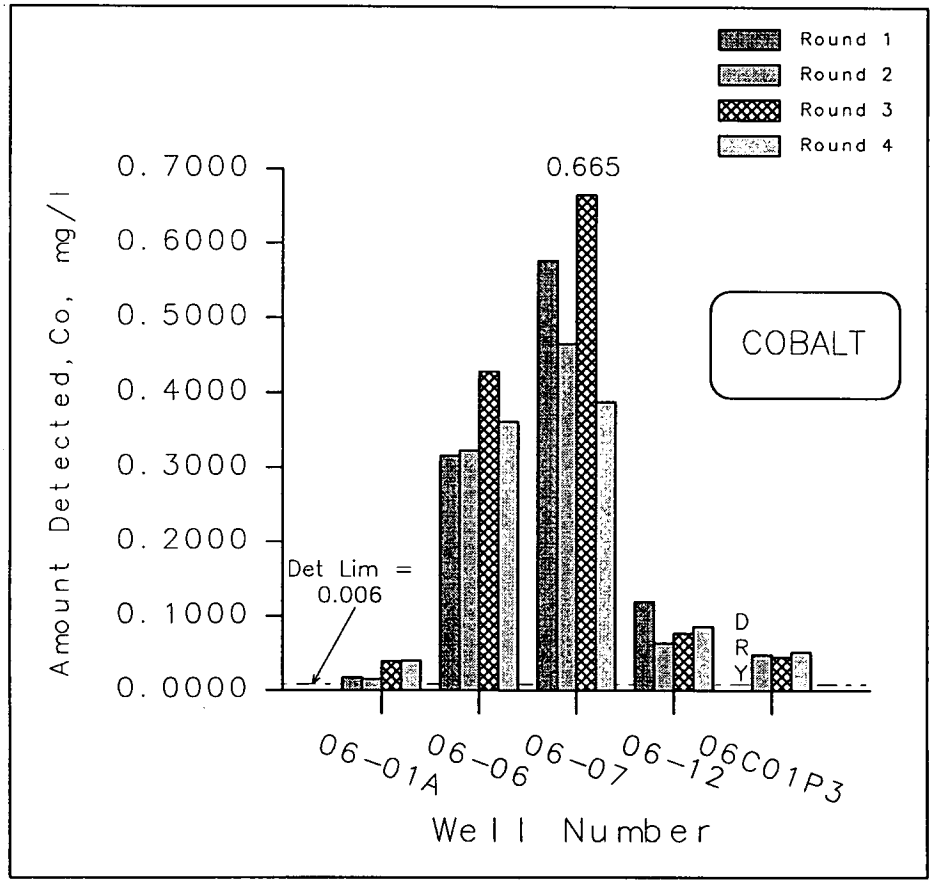


Figure 41. Levels of cobalt in Demolition Area third group wells

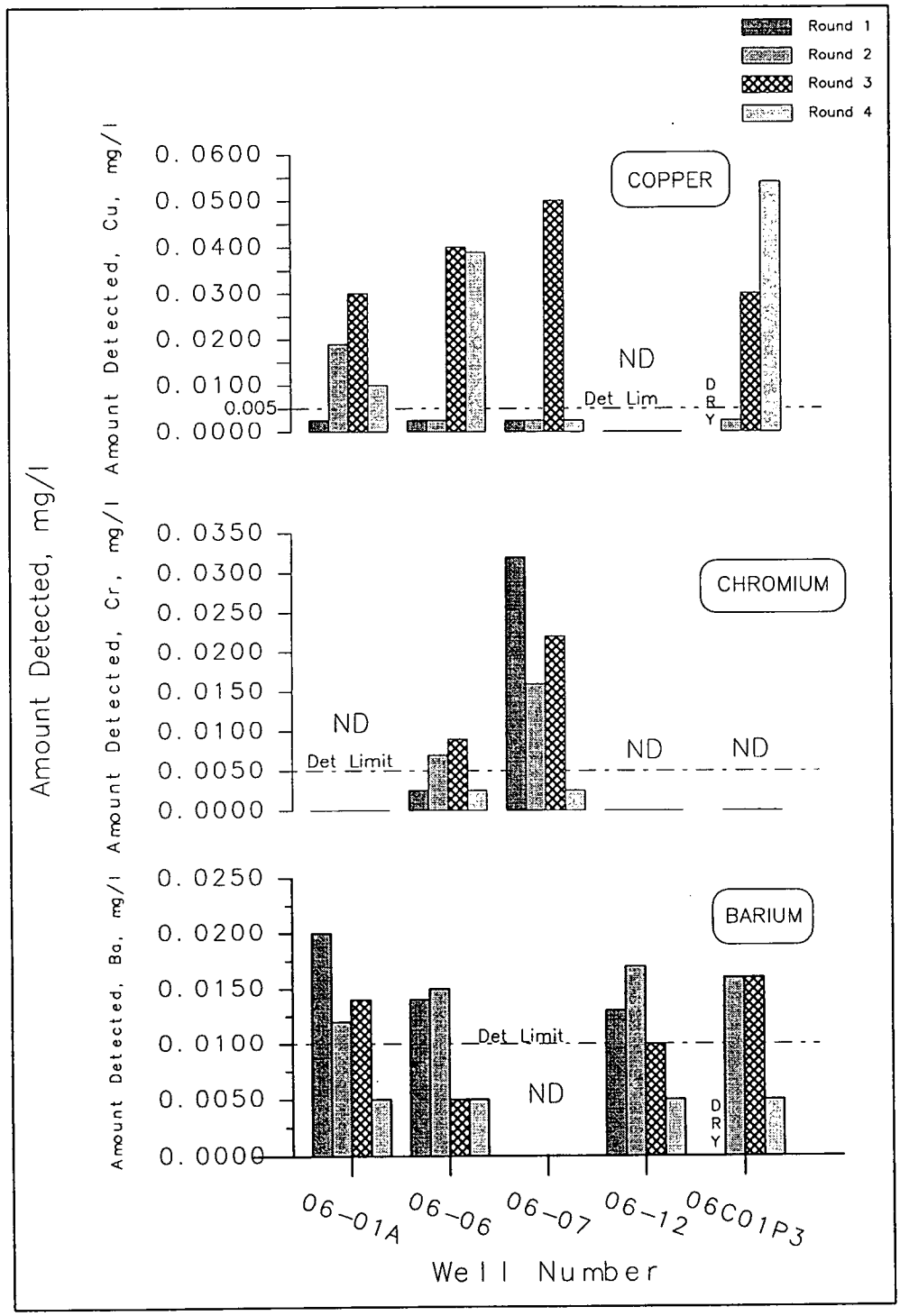


Figure 42. Levels of copper, chromium, and barium in Demolition Area third group wells

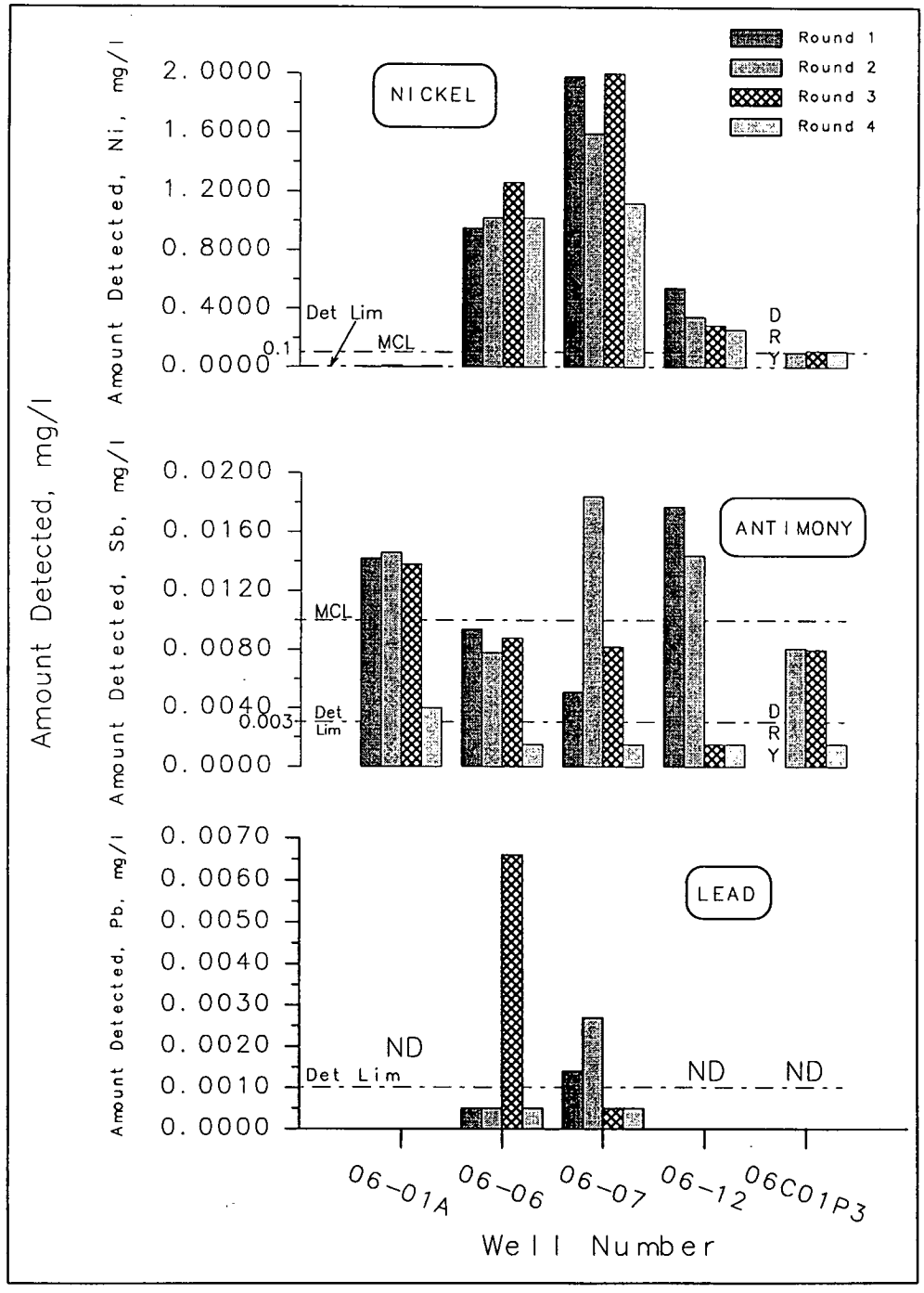


Figure 43. Levels of nickel, antimony, and lead in Demolition Area third group wells

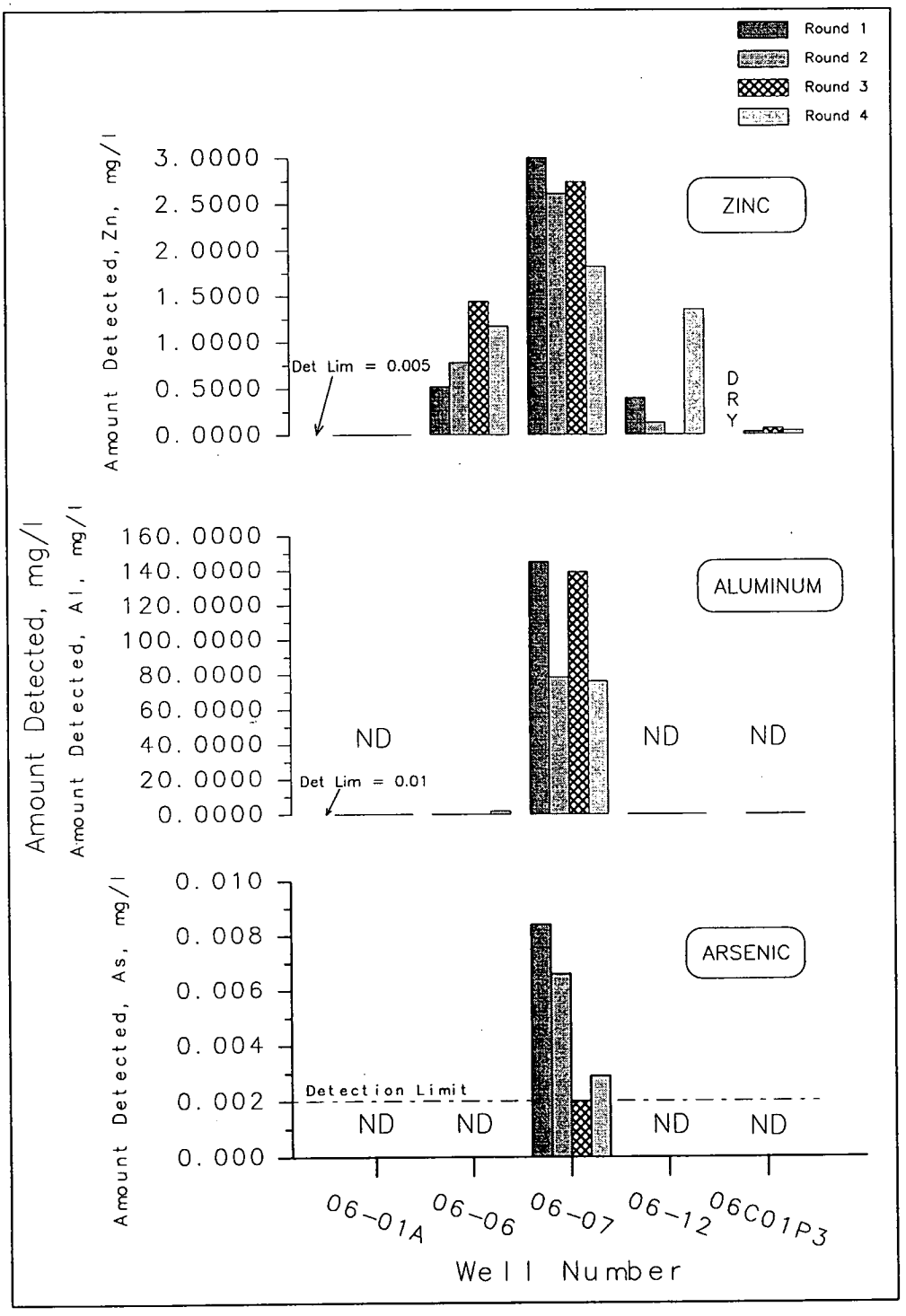


Figure 44. Levels of zinc, aluminum, and arsenic in Demolition Area third group wells

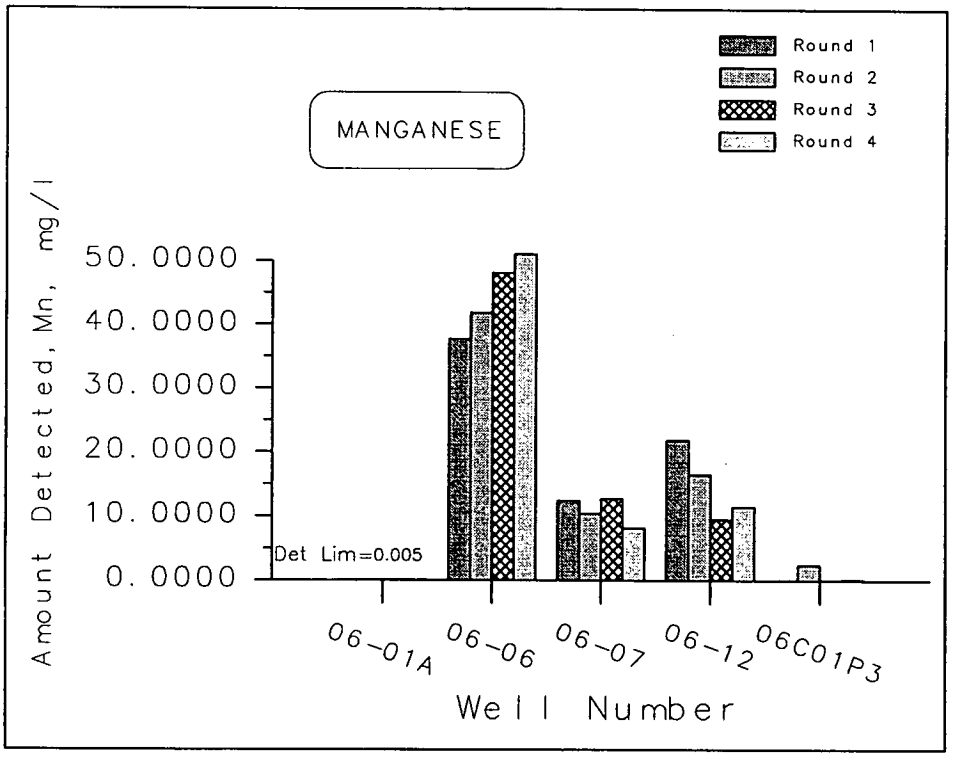


Figure 45. Levels of manganese detected in Demolition Area third group wells

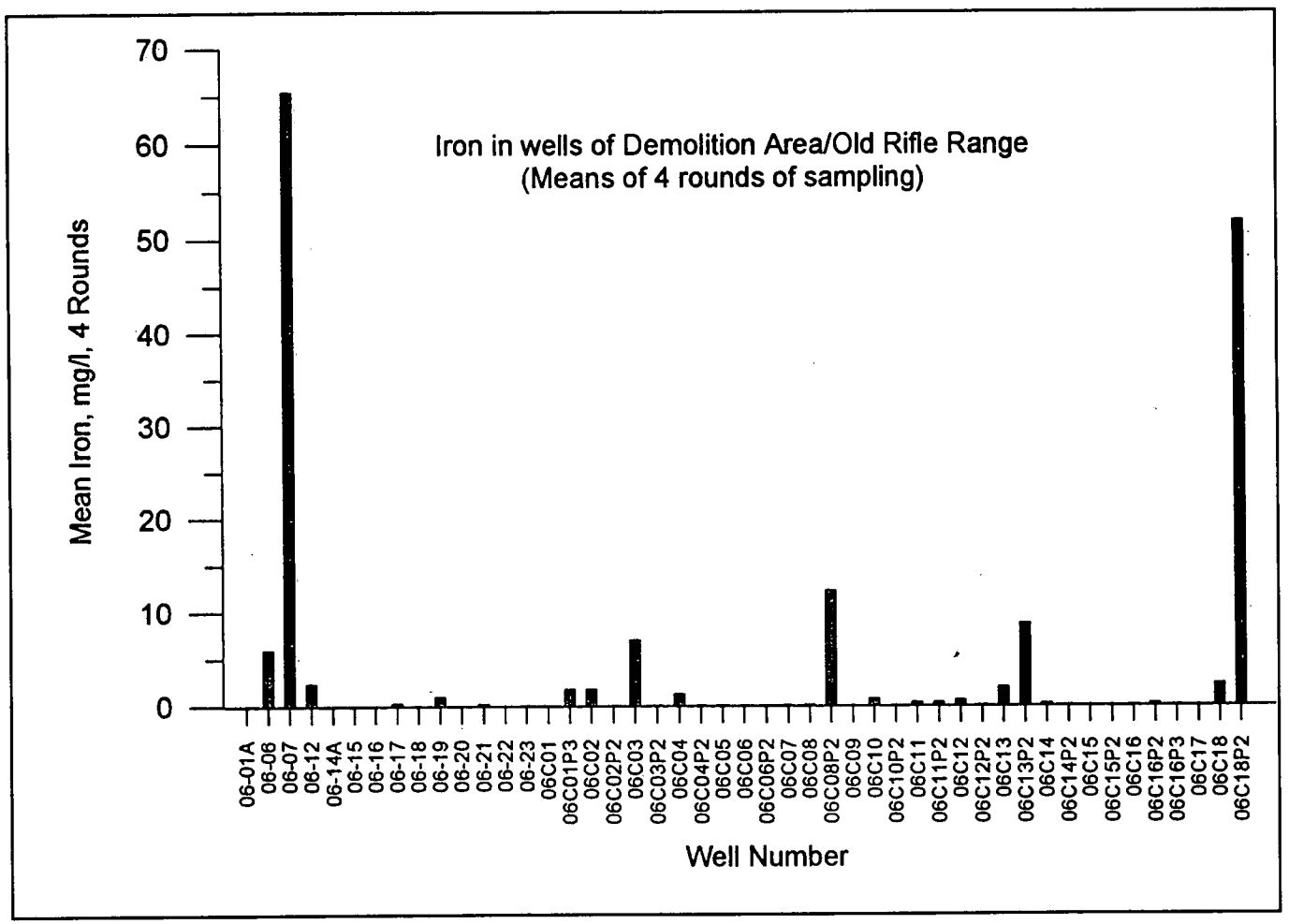


Figure 46. Mean levels of iron for four rounds of sampling, all wells, Demolition Area/Old Rifle Range

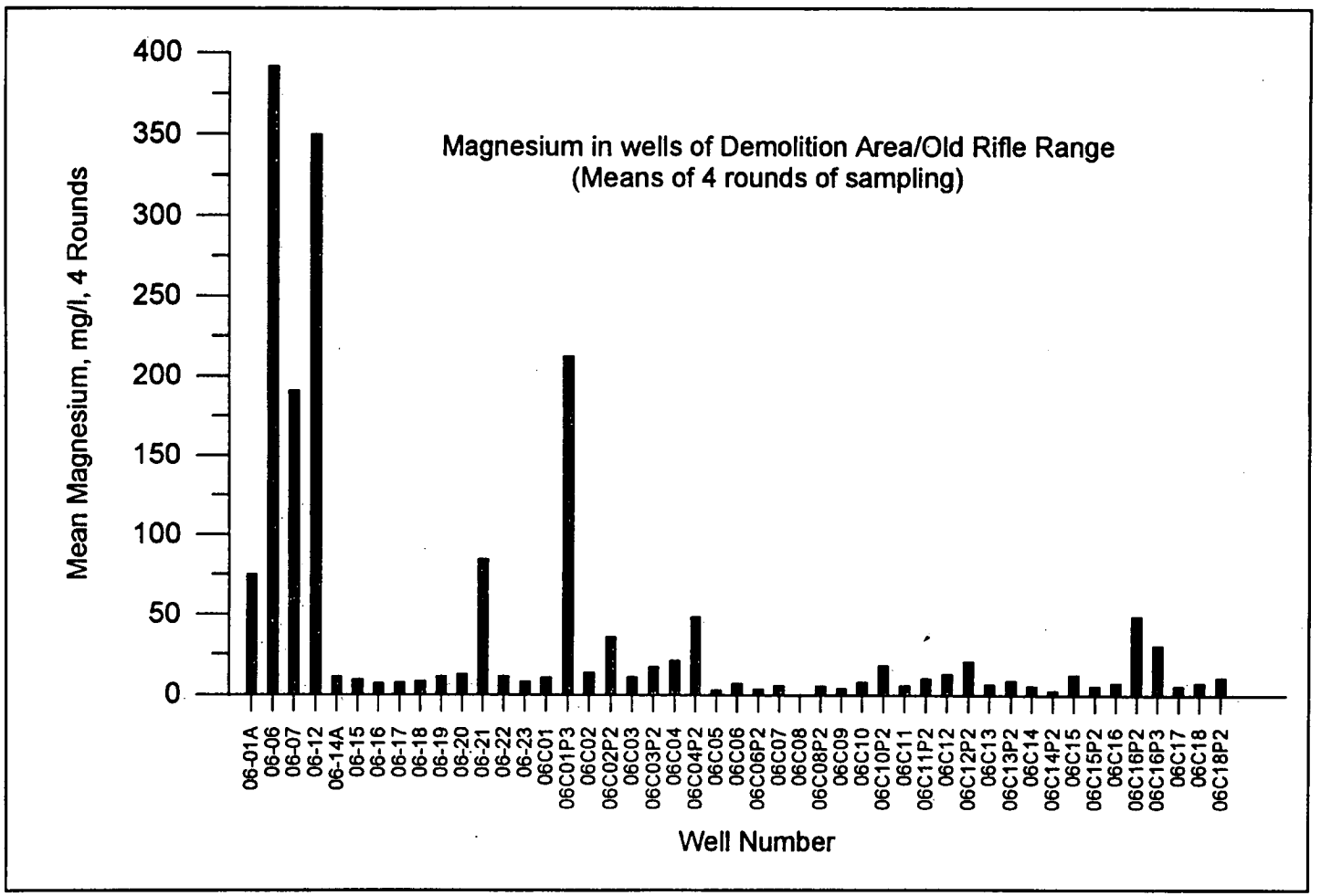


Figure 47. Mean levels of magnesium for four rounds of sampling, all wells, Demolition Area/Old Rifle Range

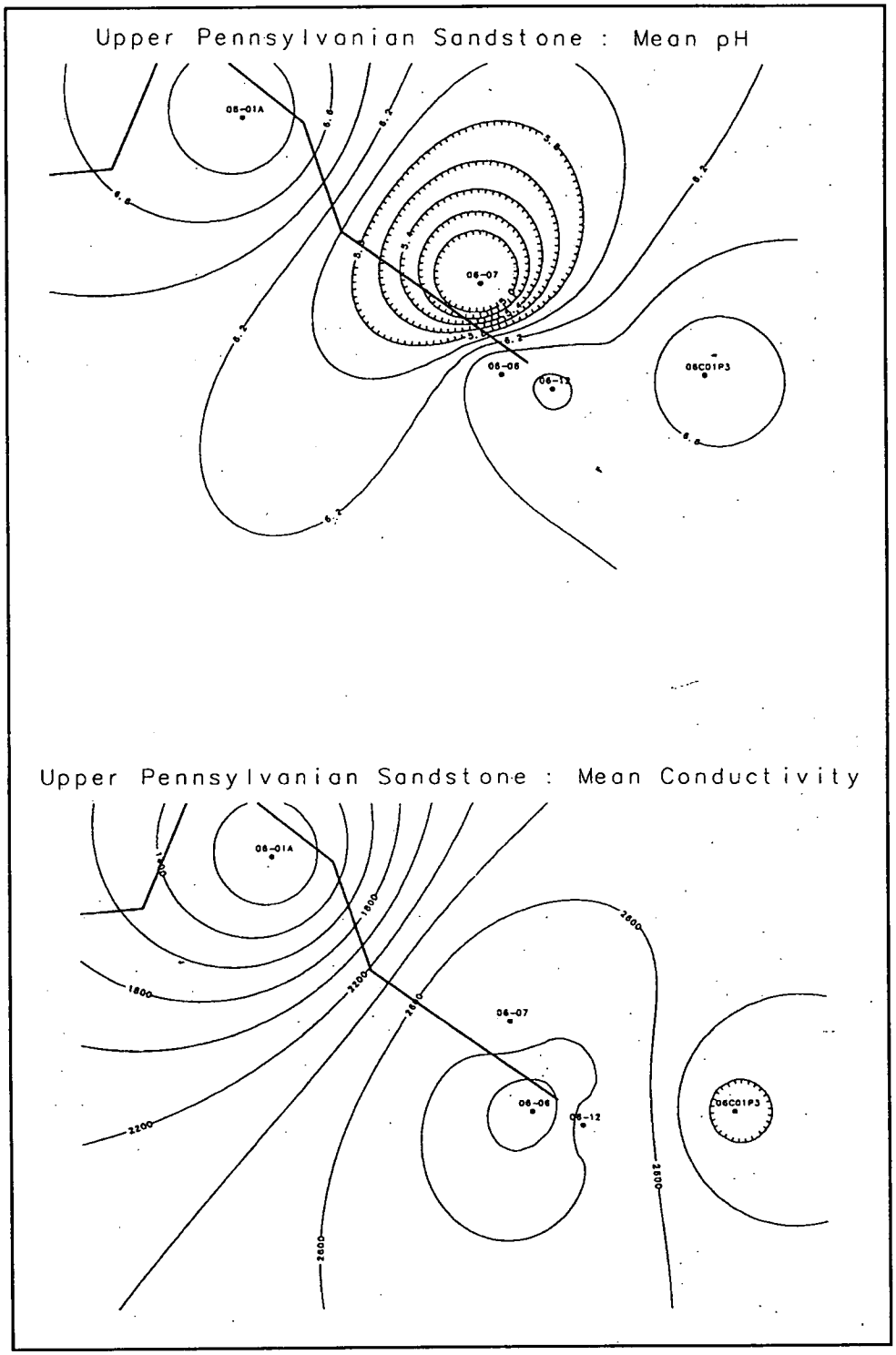


Figure 48. Mean field-measured pH and conductivity in four rounds of sampling, third group wells, Demolition Area

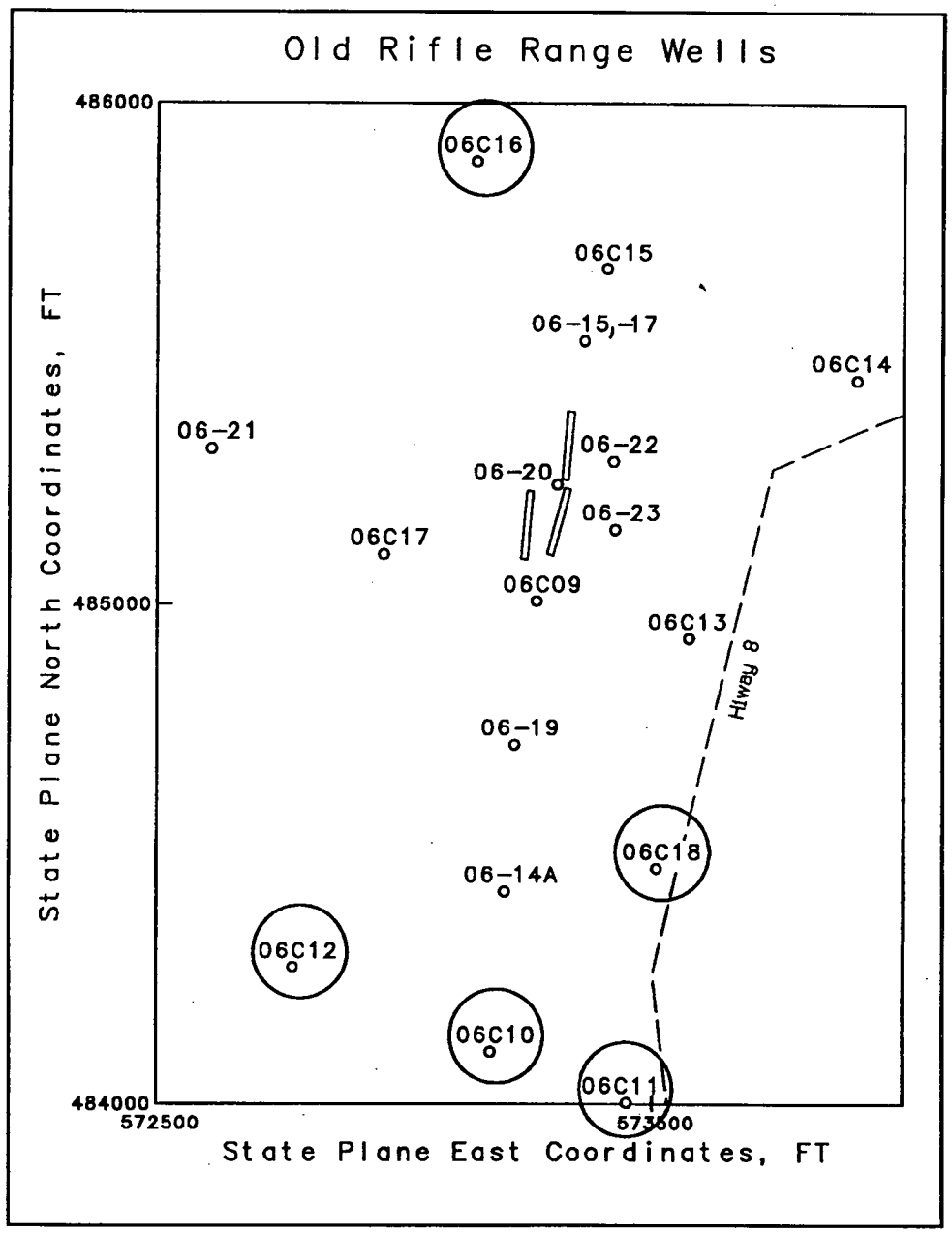


Figure 49. First group of lower zone wells, Old Rifle Range

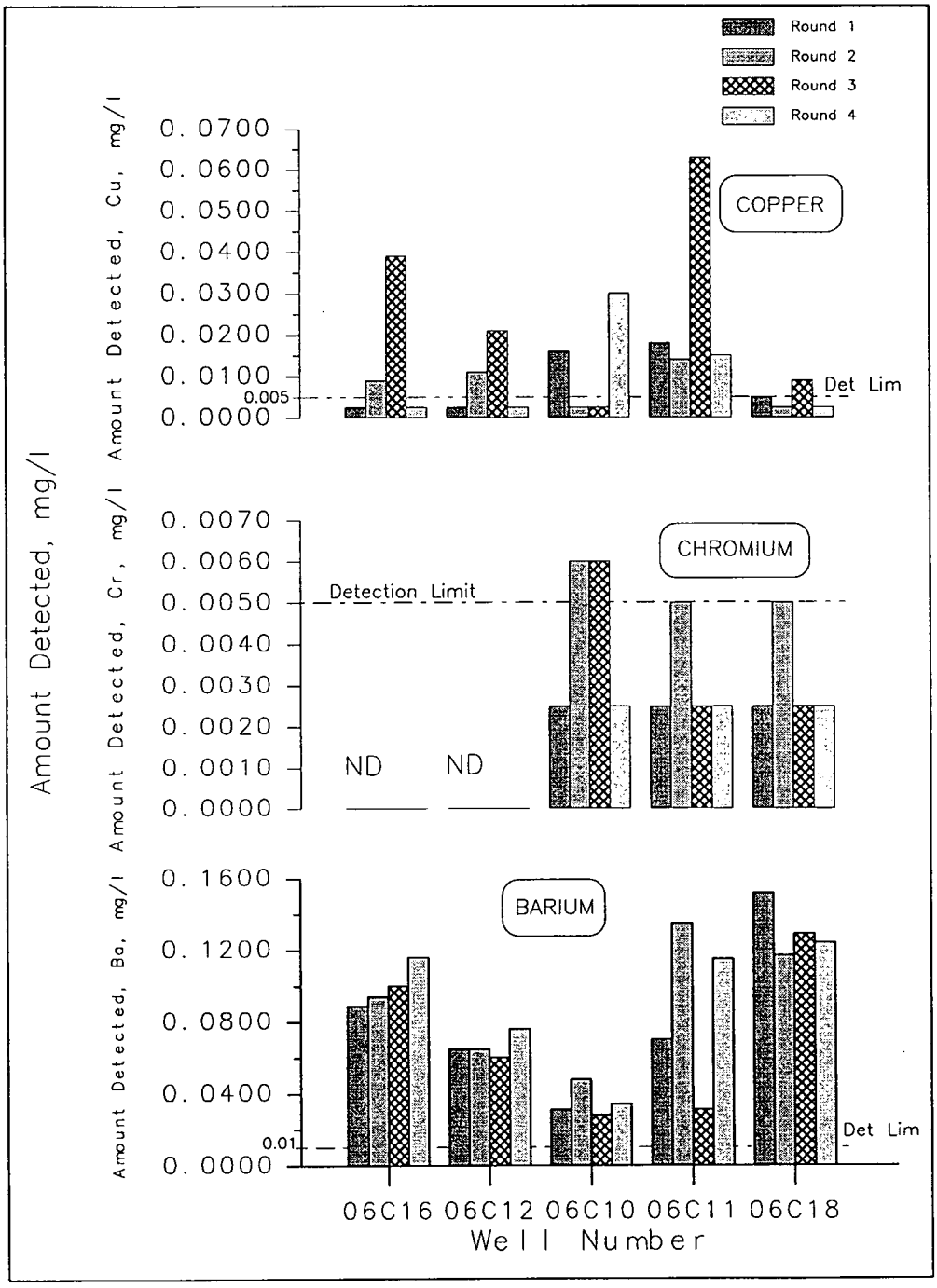


Figure 50. Levels of copper, chromium, and barium in first group of lower zone wells, Old Rifle Range

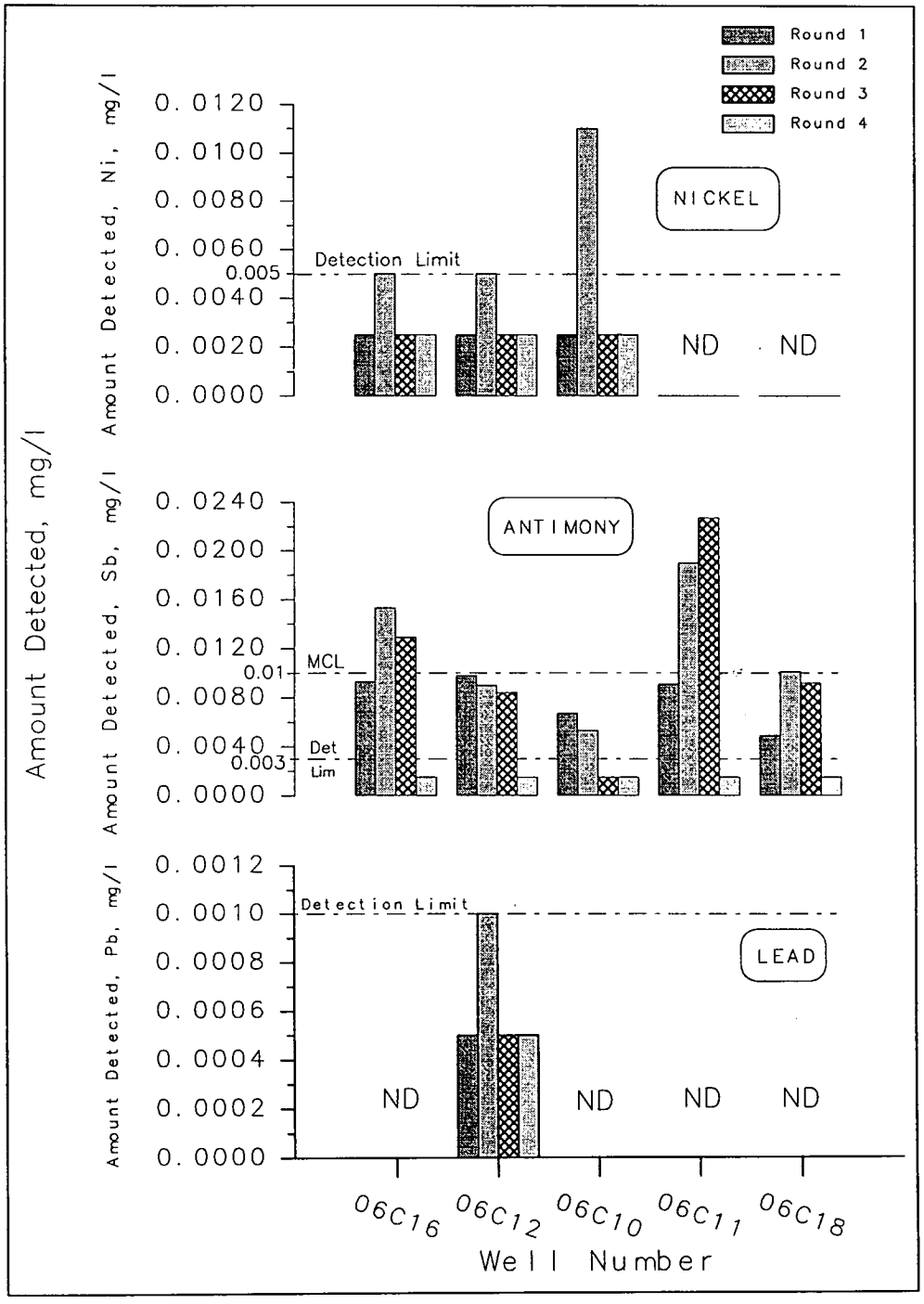


Figure 51. Levels of nickel, antimony, and lead in first group of lower zone wells, Old Rifle Range

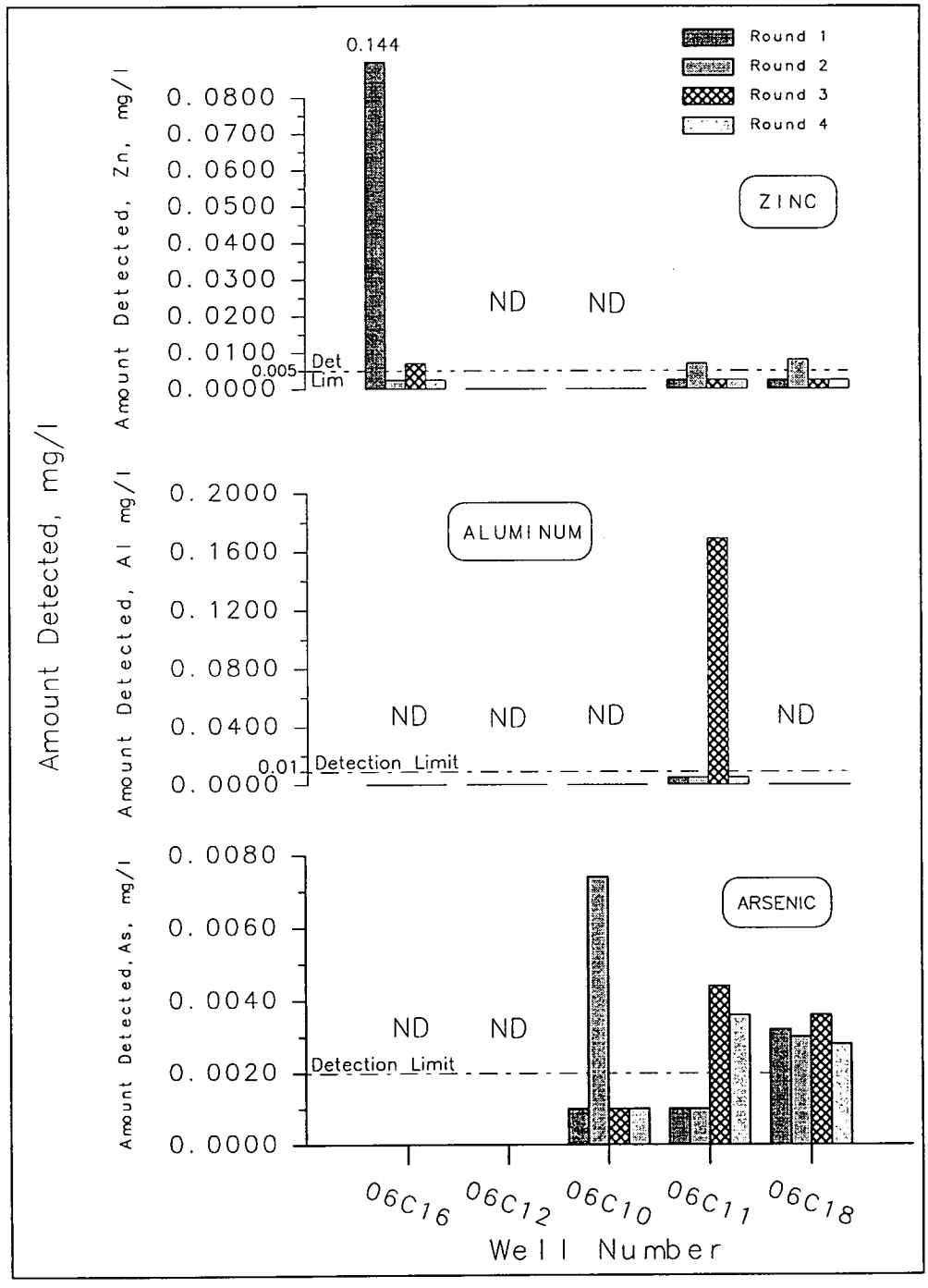


Figure 52. Levels of zinc, aluminum, and arsenic in first group of lower zone wells, Old Rifle Range

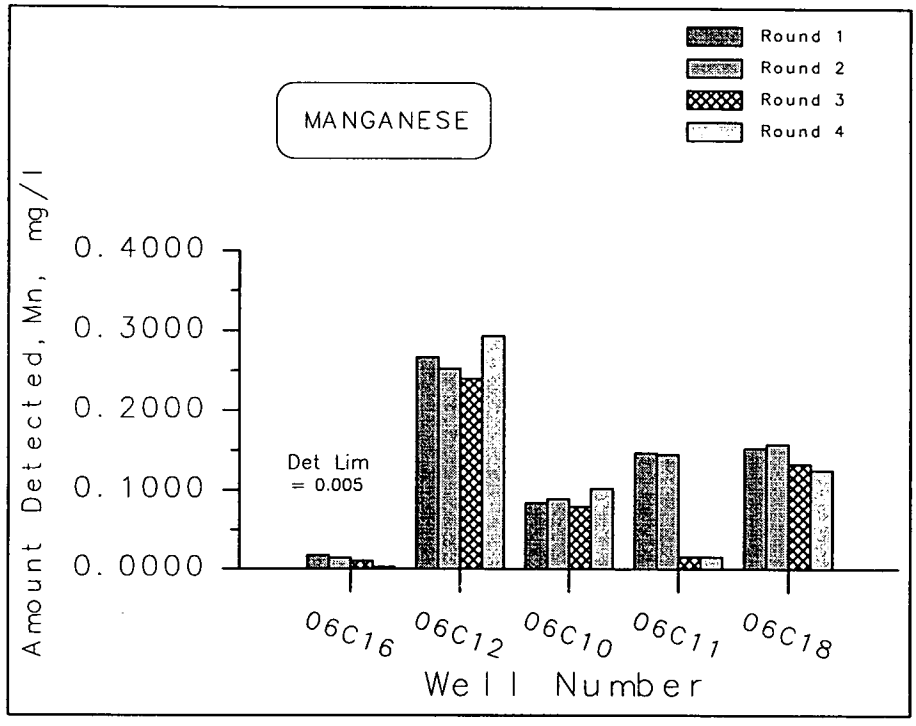


Figure 53. Levels of manganese detected in first group of lower zone wells, Old Rifle Range

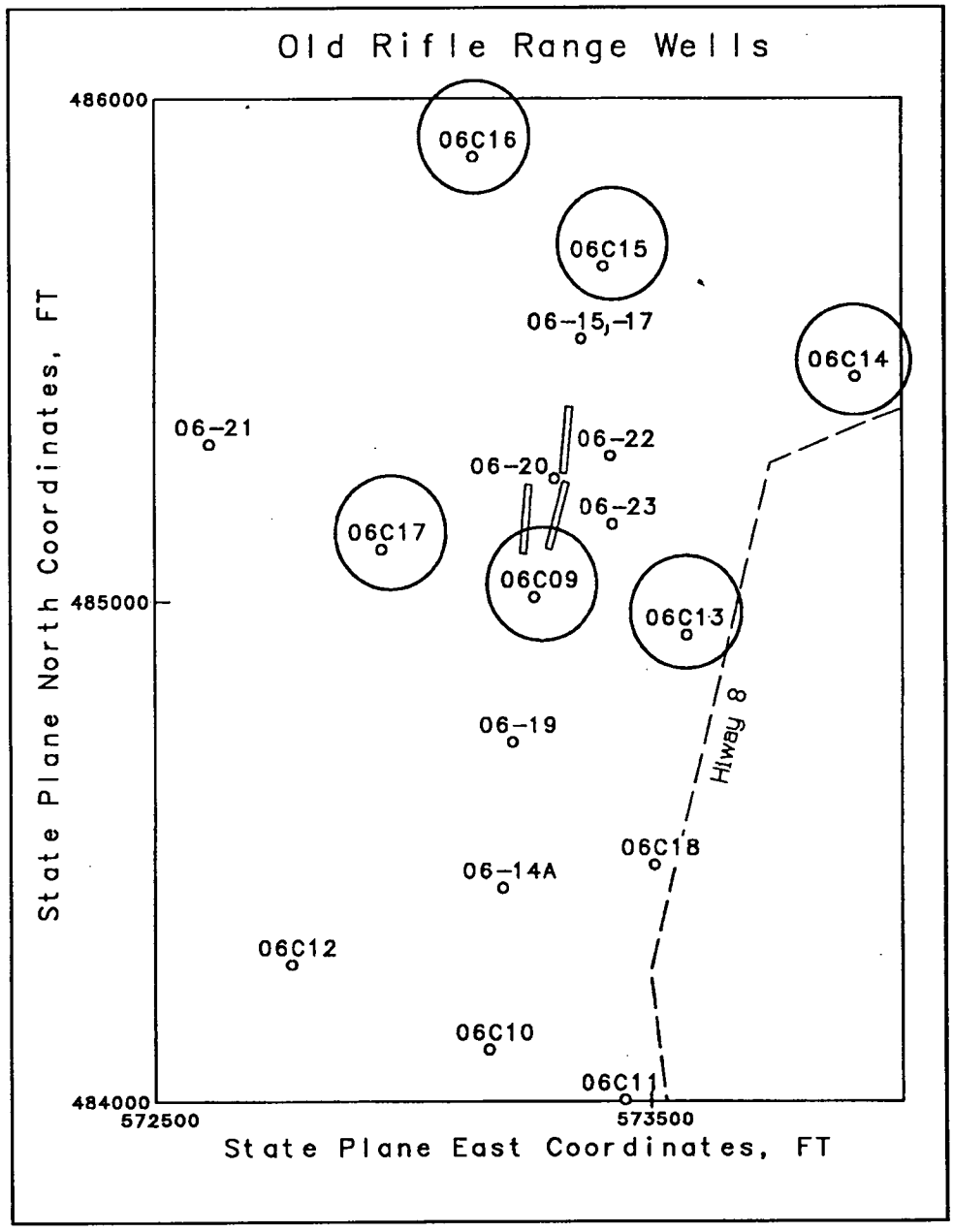


Figure 54. Second group of lower zone wells, Old Rifle Range

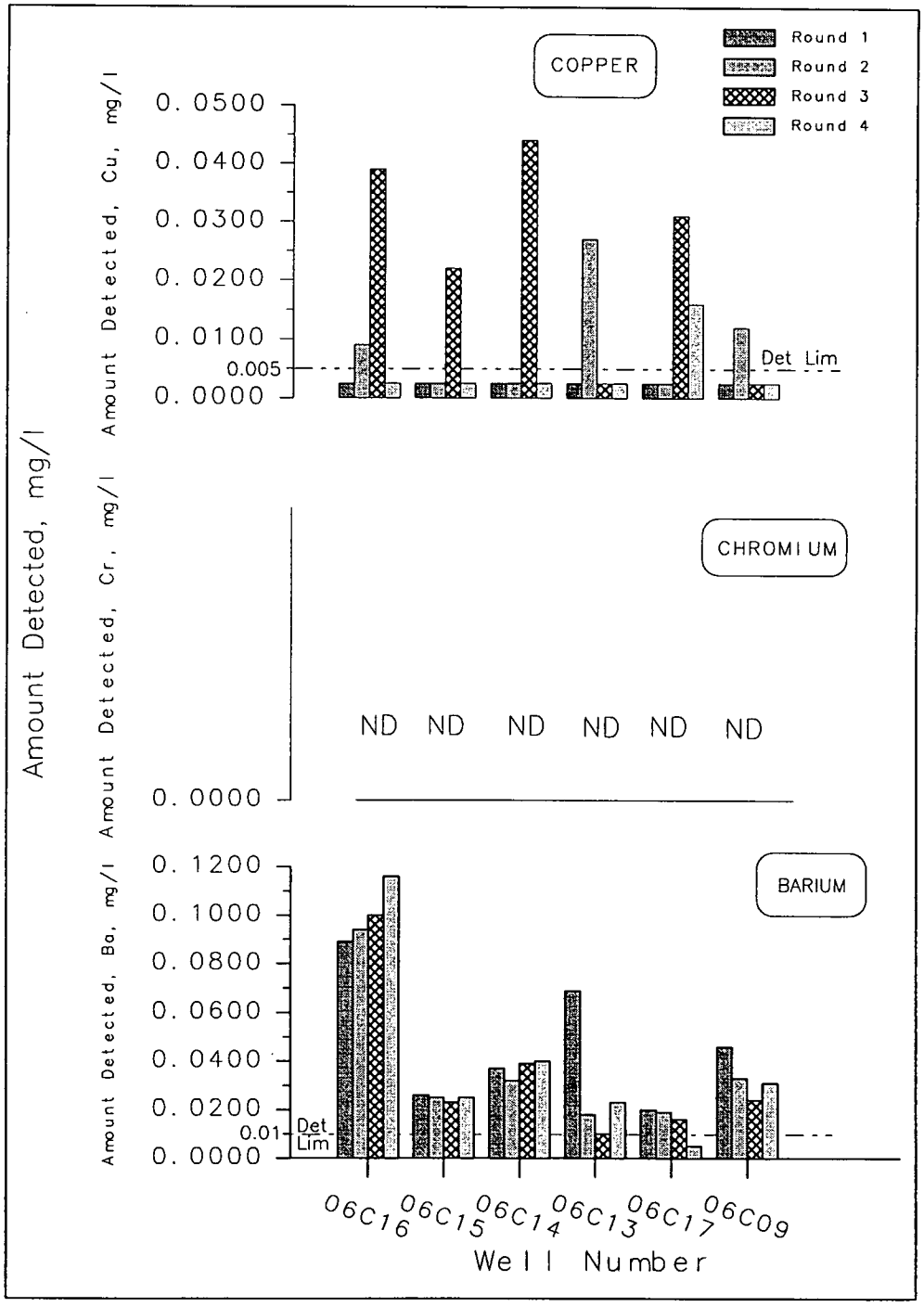


Figure 55. Levels of copper, chromium, and barium in second group of lower zone wells, Old Rifle Range

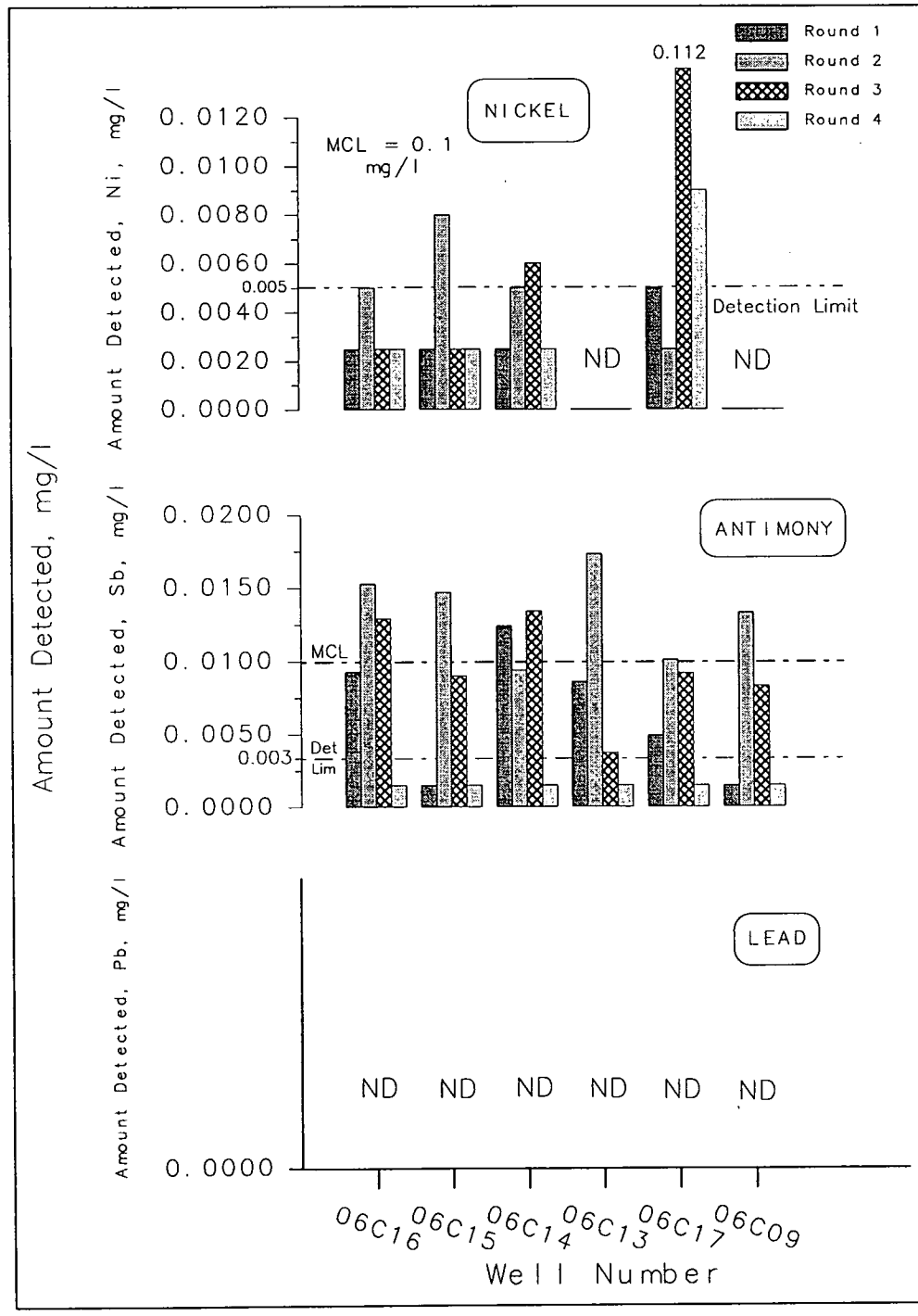


Figure 56. Levels of nickel, antimony, and lead in second group of lower zone wells, Old Rifle Range

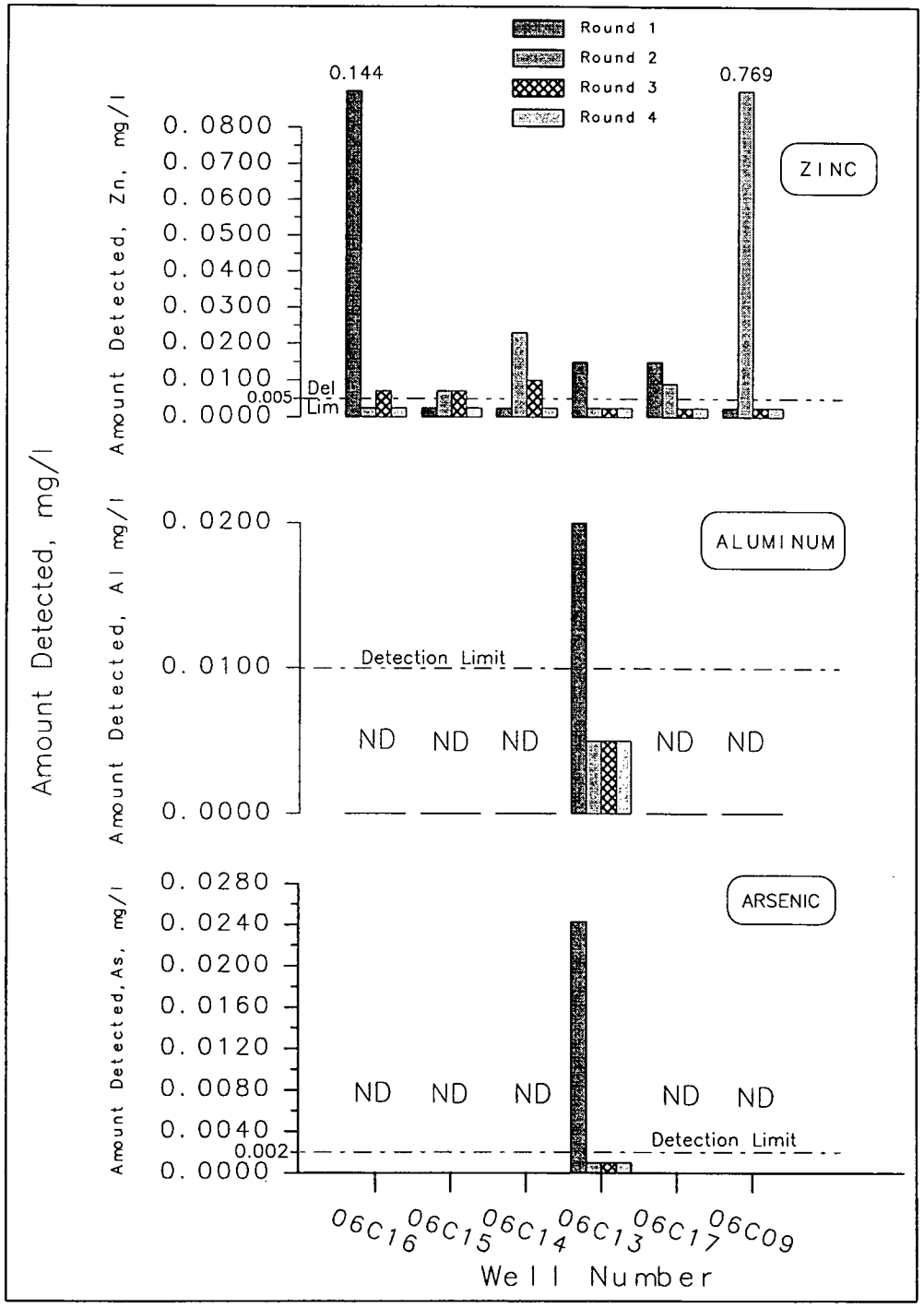


Figure 57. Levels of zinc, aluminum, and arsenic in second group of lower zone wells, Old Rifle Range

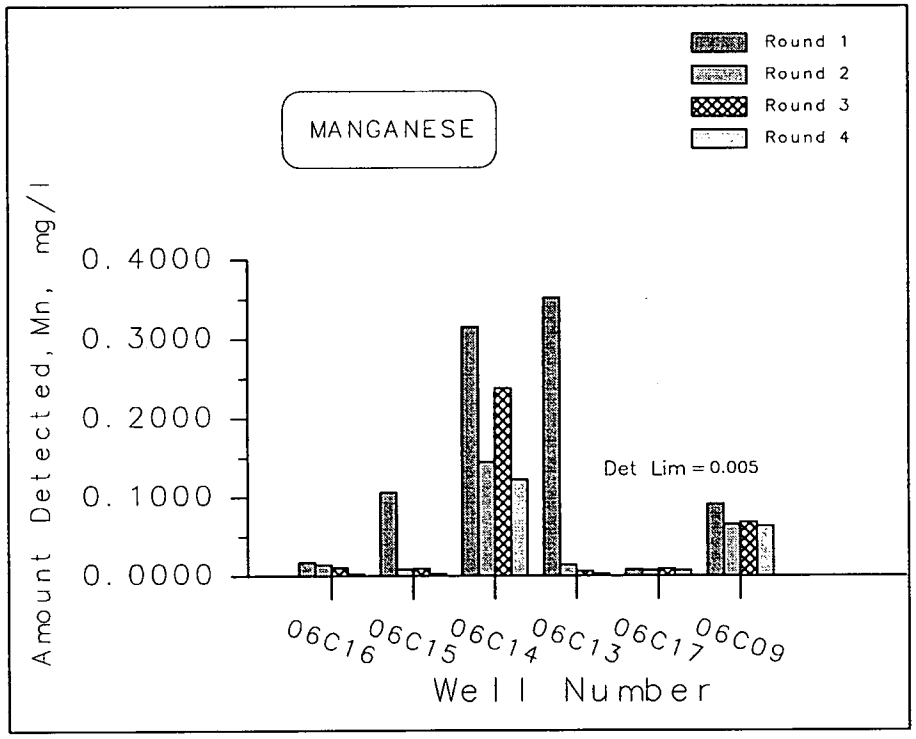


Figure 58. Levels of manganese detected in second group of lower zone wells, Old Rifle Range

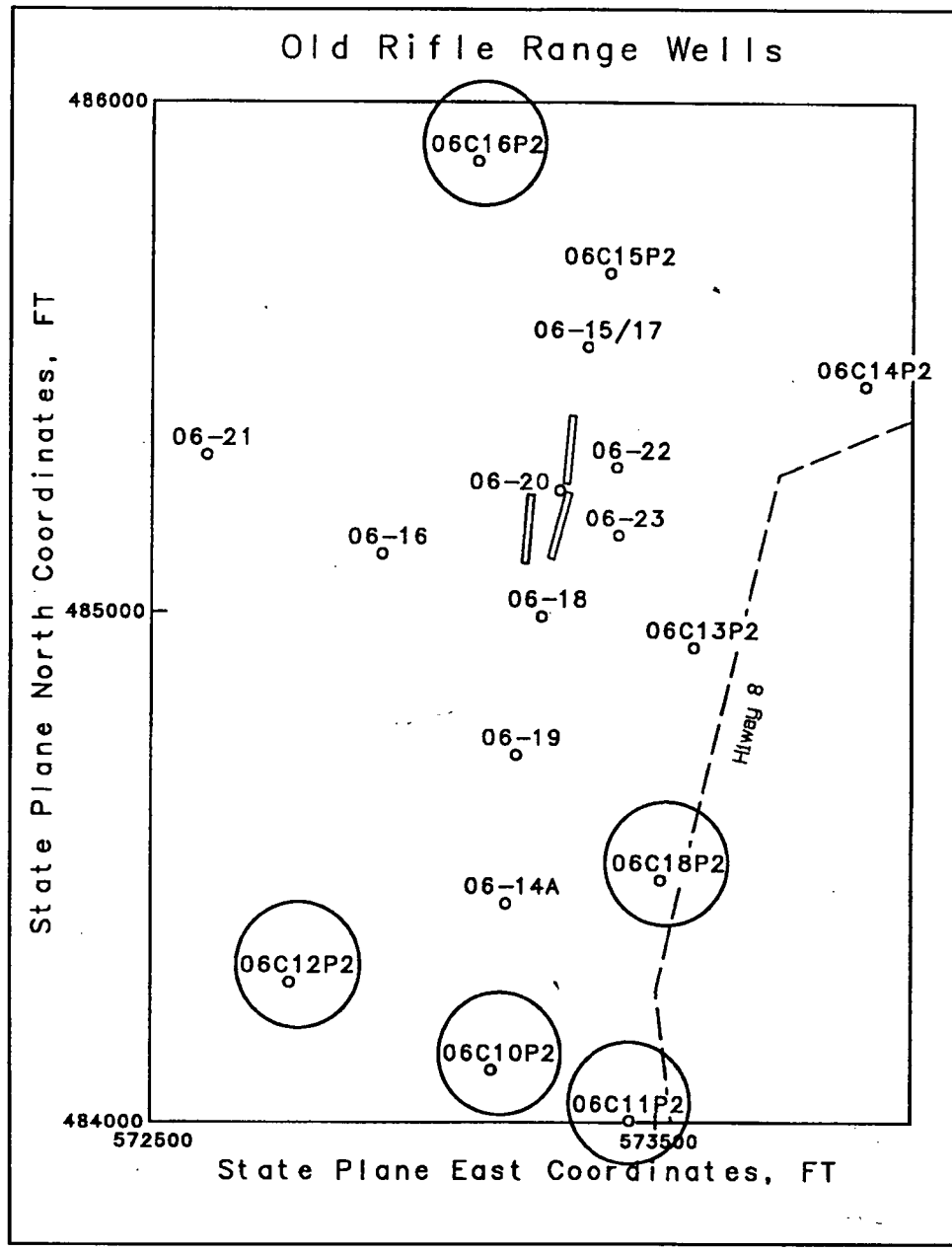


Figure 59. First group of upper zone wells, Old Rifle Range

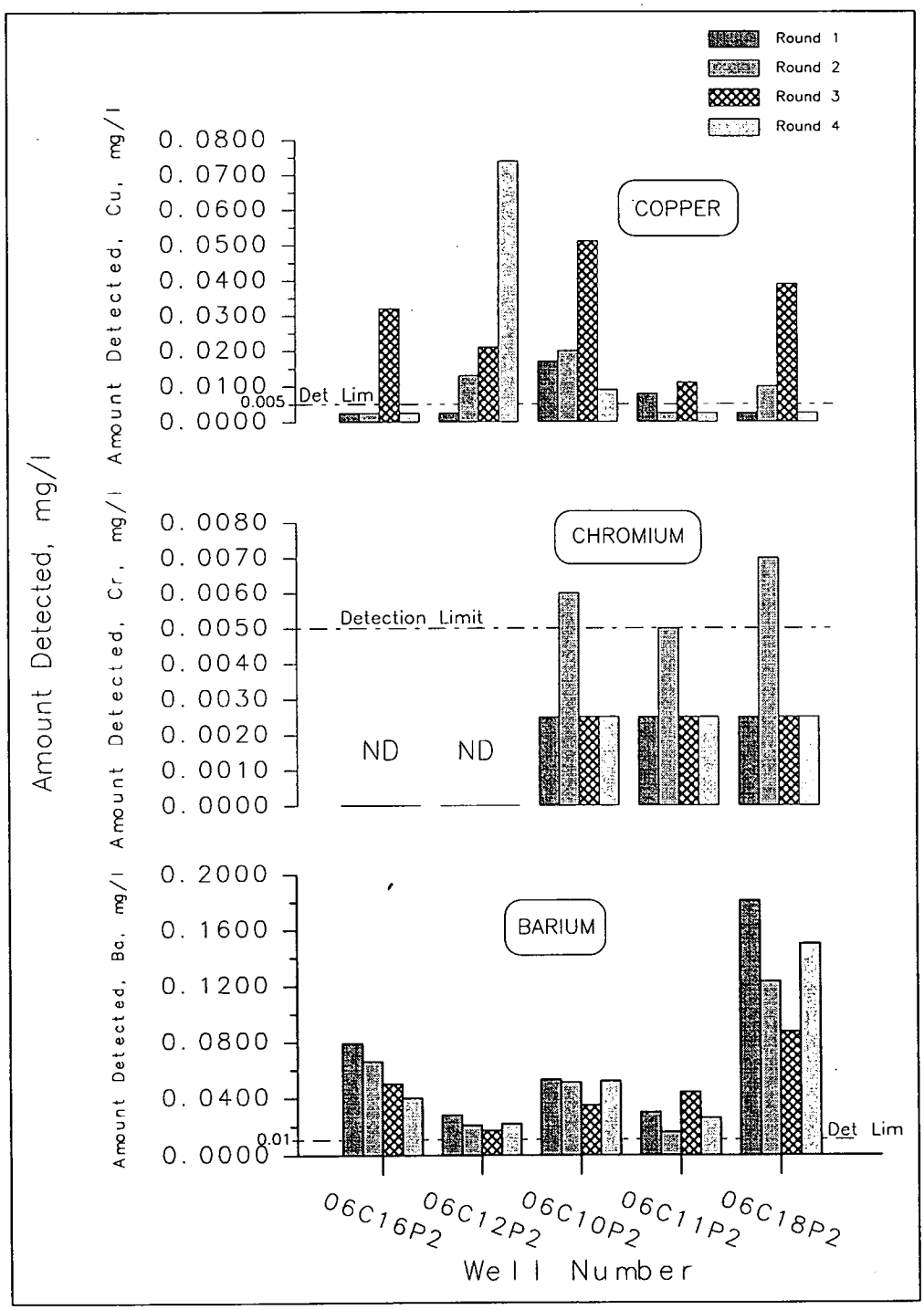


Figure 60. Levels of copper, chromium, and barium in first group of upper zone wells, Old Rifle Range

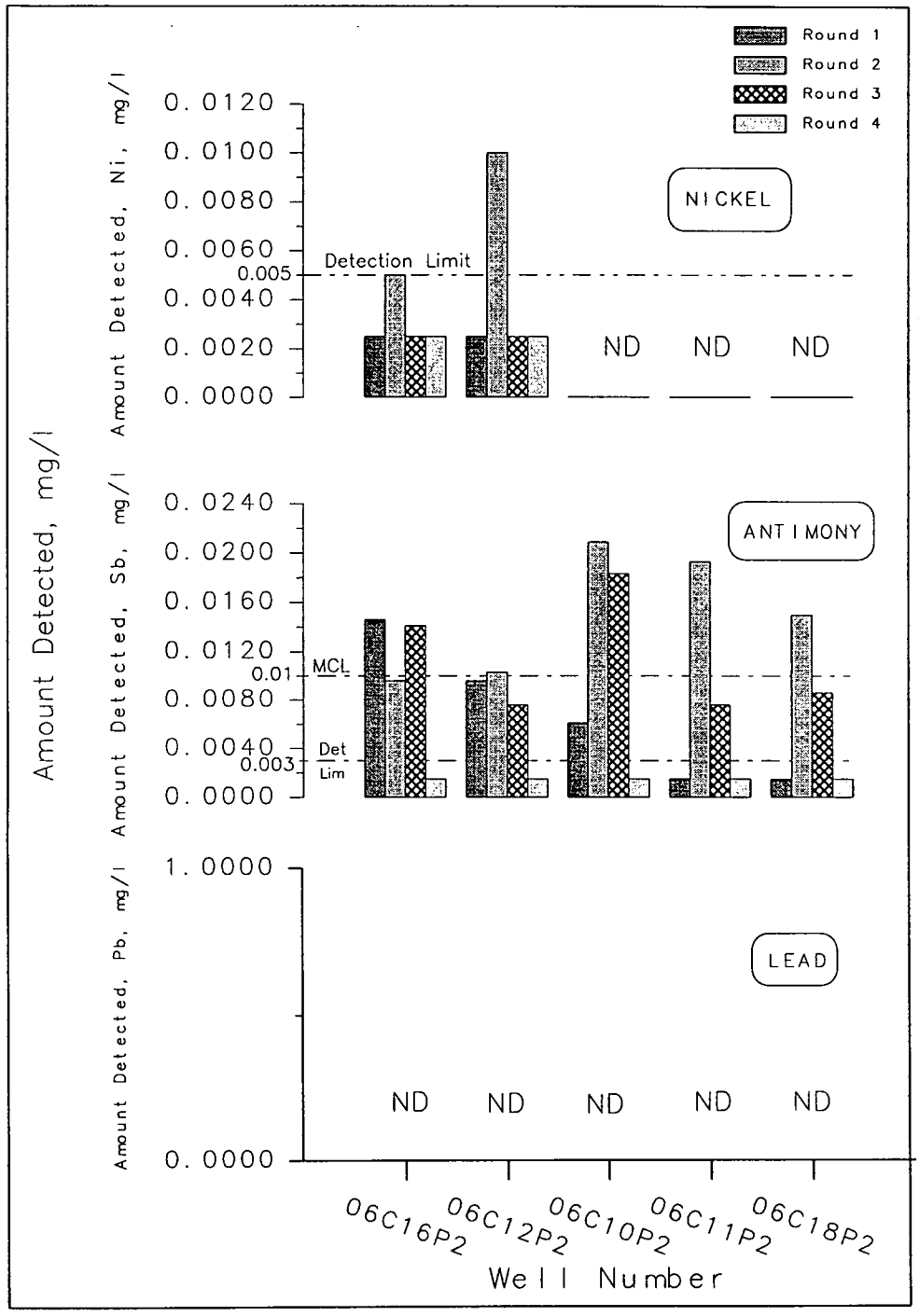


Figure 61. Levels of nickel, antimony, and lead in first group of upper zone wells, Old Rifle Range

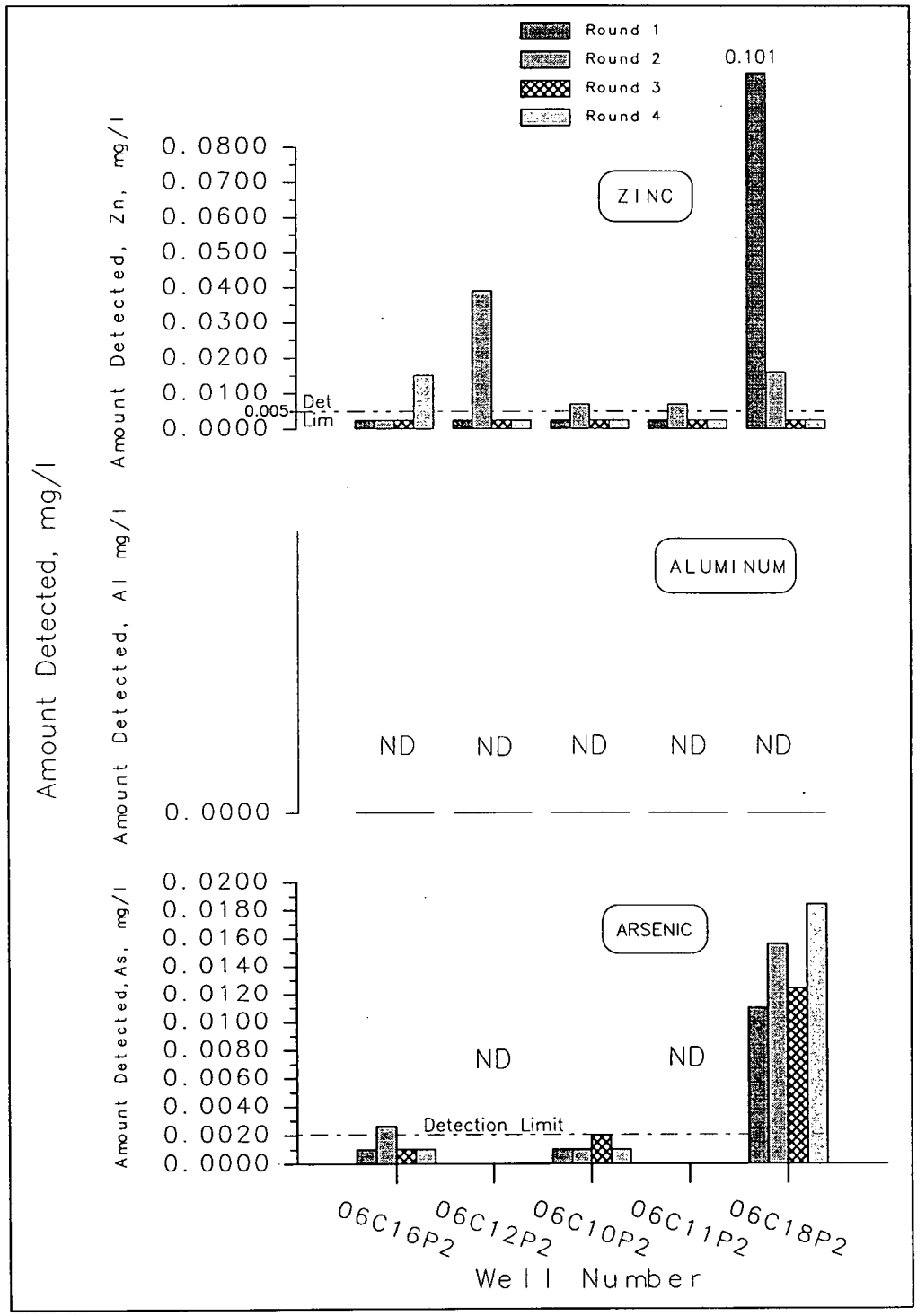


Figure 62. Levels of zinc, aluminum, and arsenic in first group of upper zone wells, Old Rifle Range

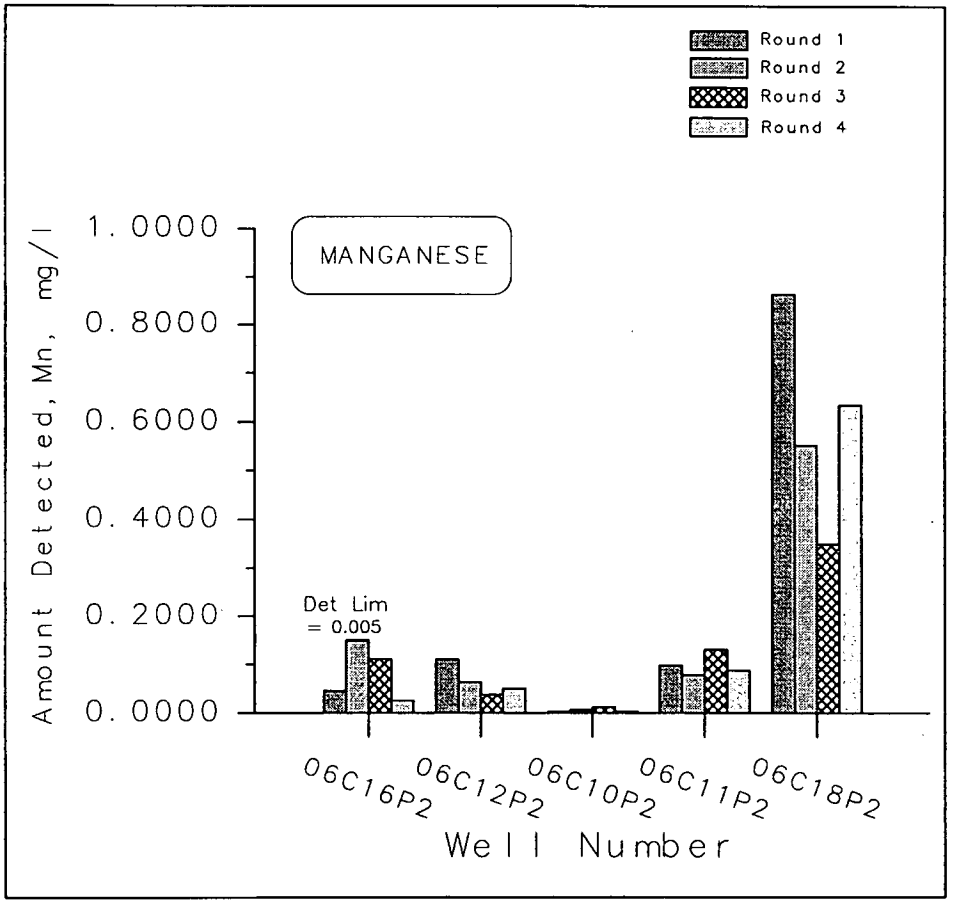


Figure 63. Levels of manganese detected in first group of upper zone wells, Old Rifle Range

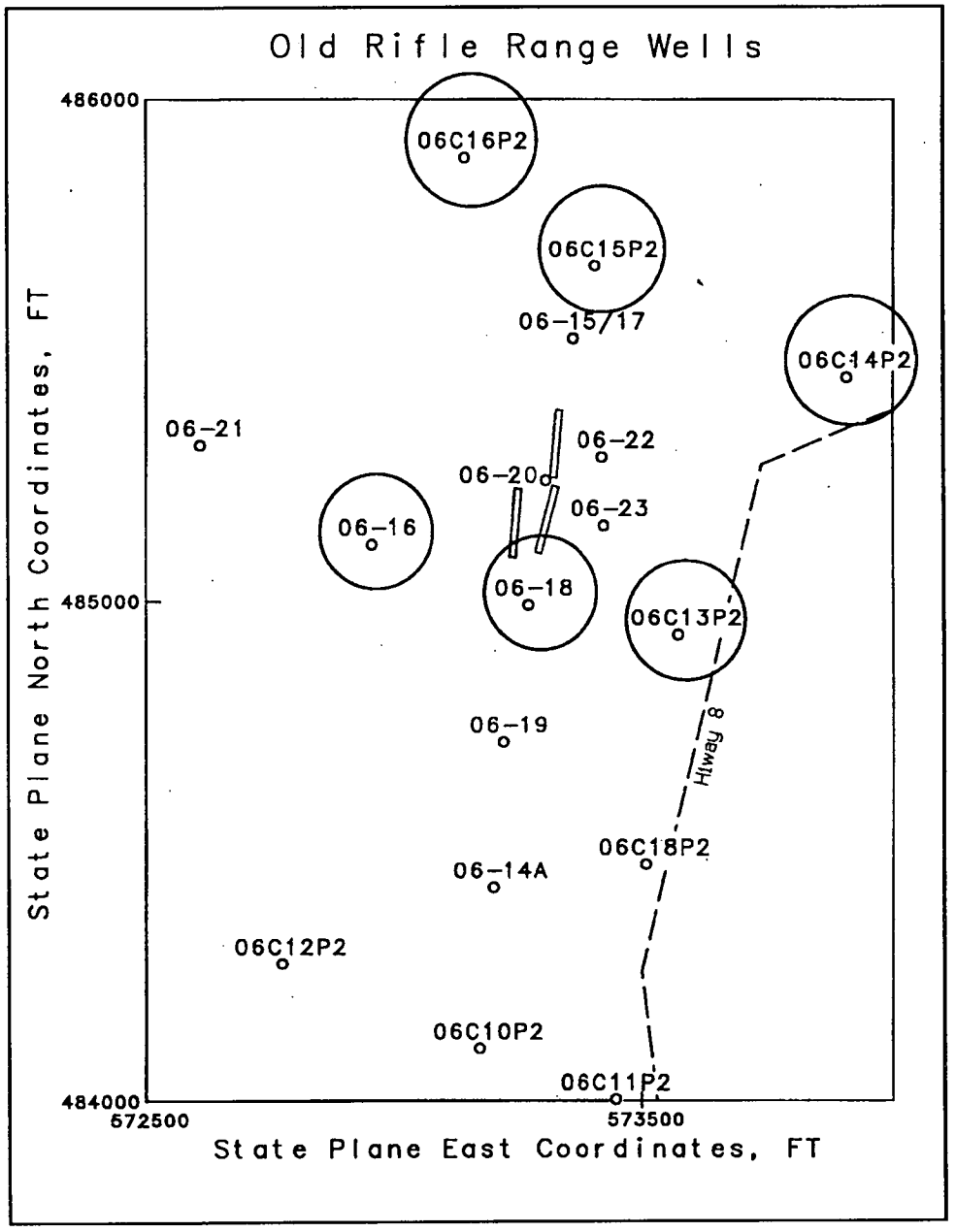


Figure 64. Second group of upper zone wells, Old Rifle Range

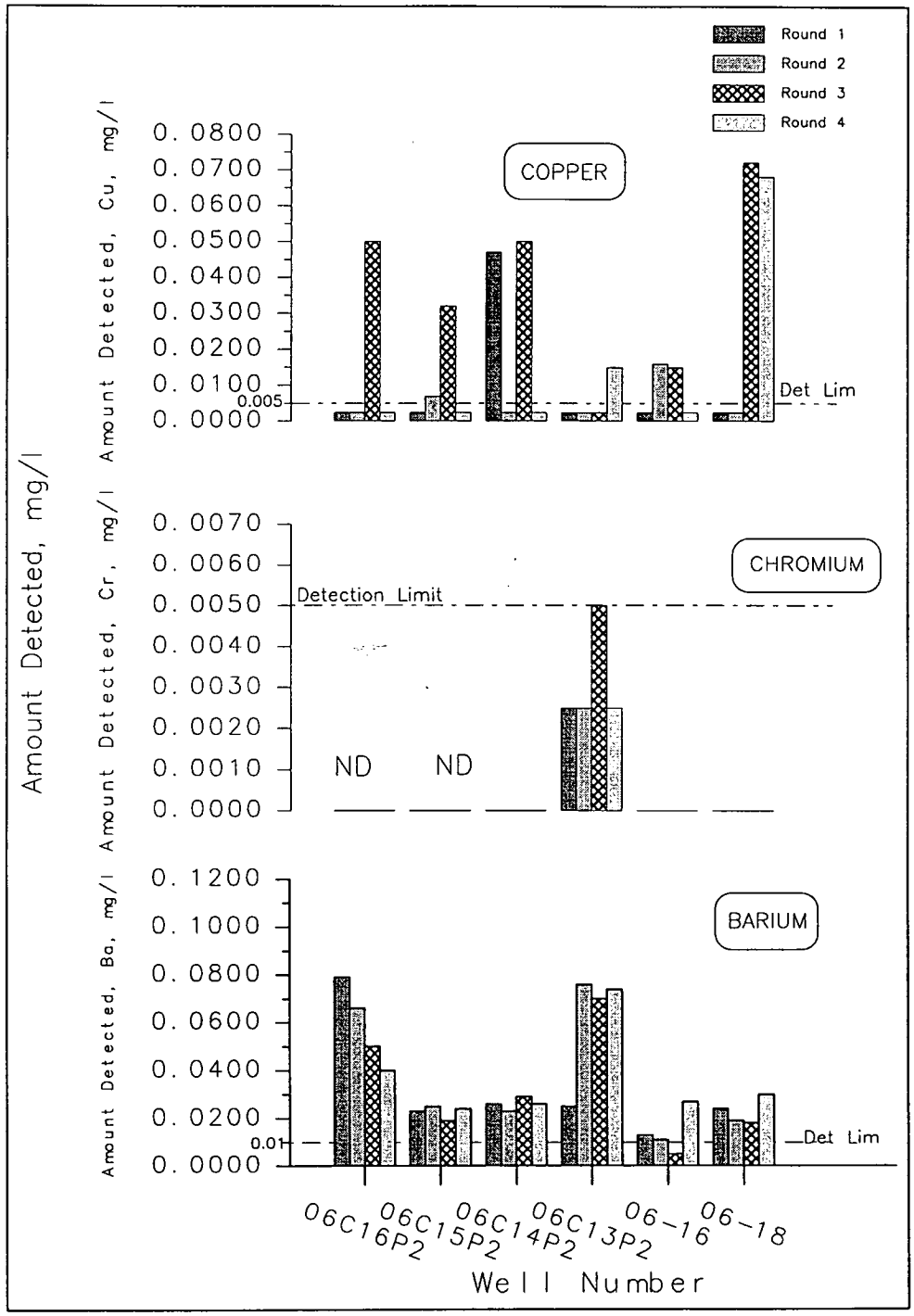


Figure 65. Levels of copper, chromium, and barium in upper zone wells, Old Rifle Range

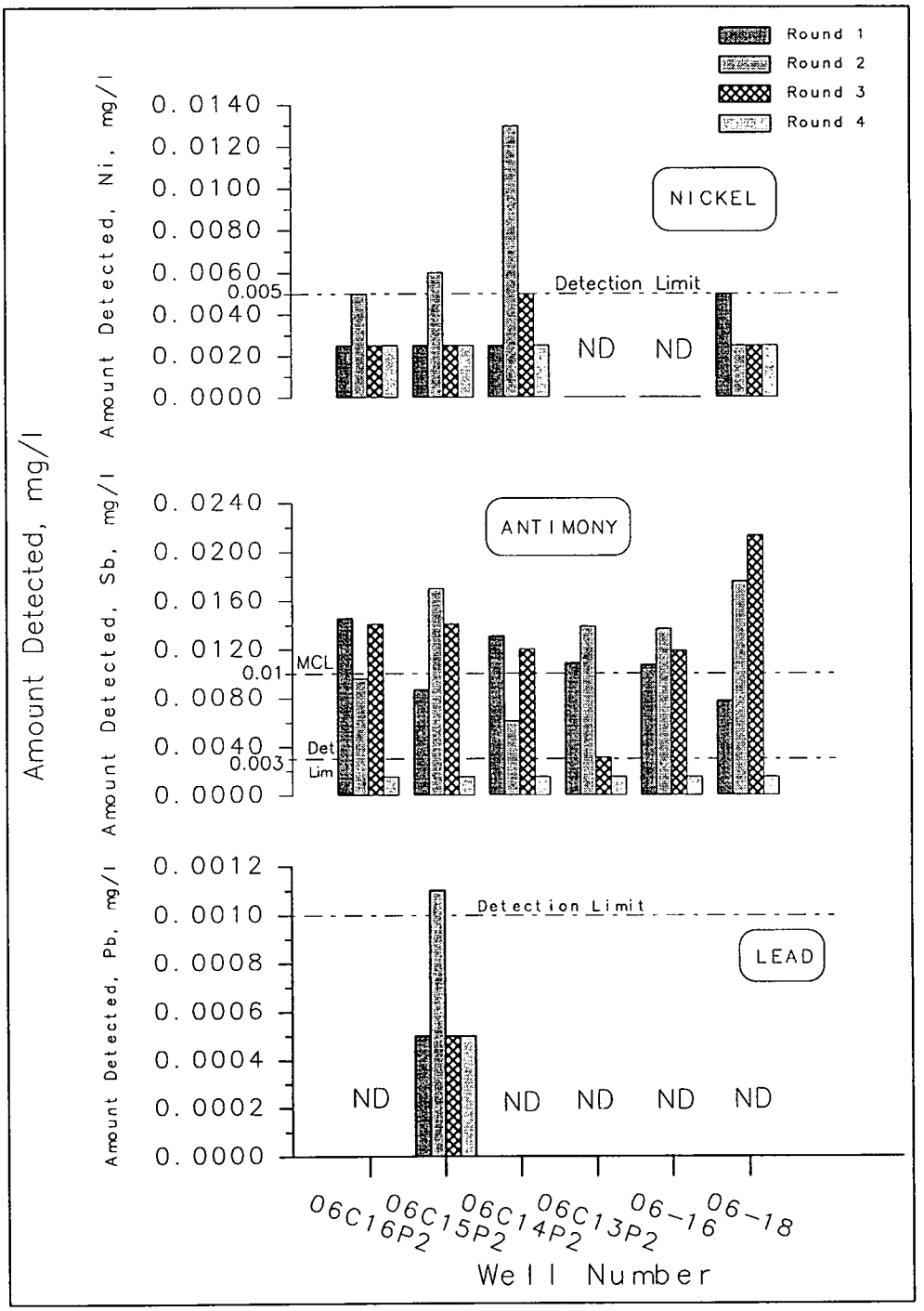


Figure 66. Levels of nickel, antimony, and lead in upper zone wells, Old Rifle Range

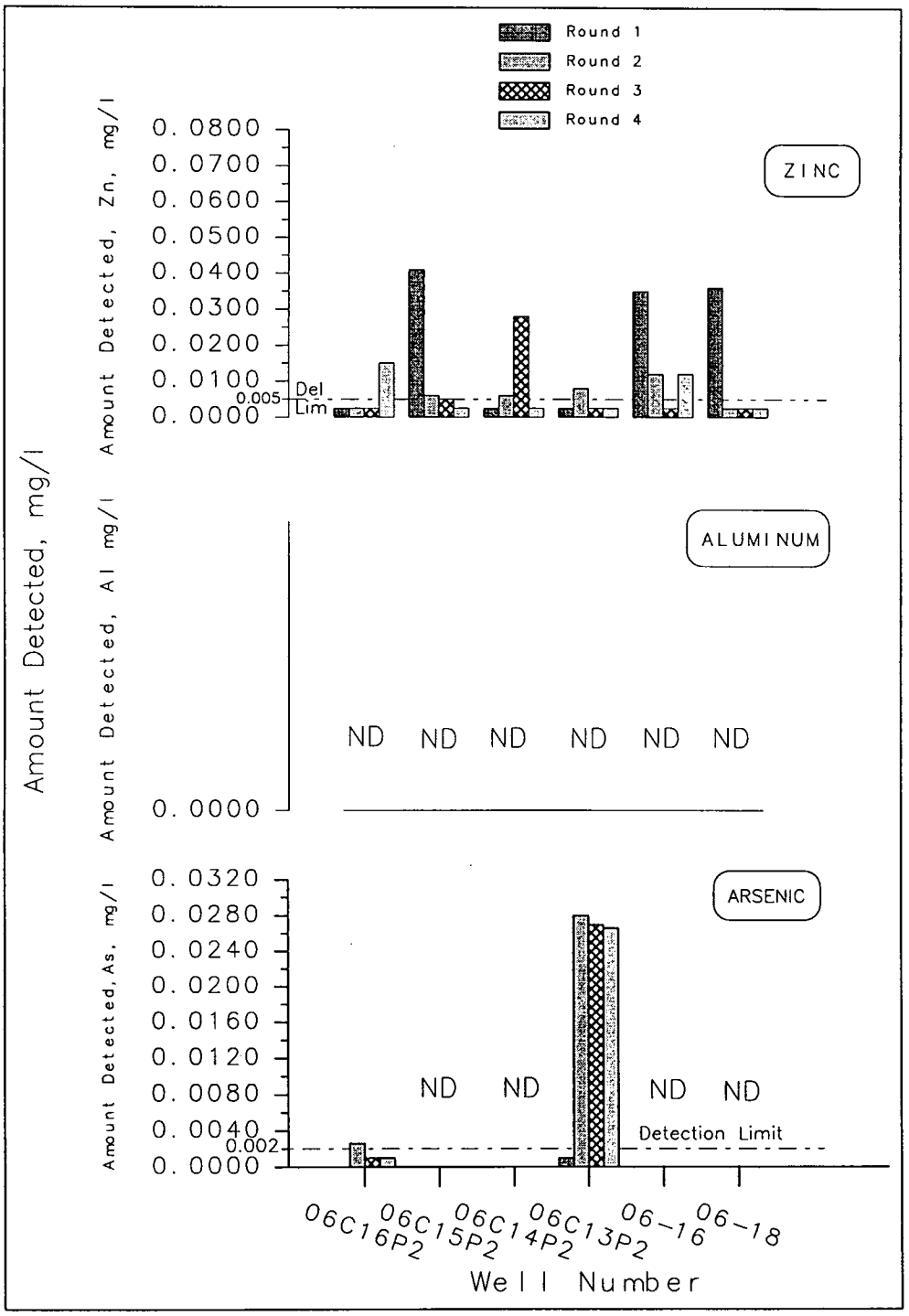


Figure 67. Levels of zinc, aluminum, and arsenic in upper zone wells, Old Rifle Range

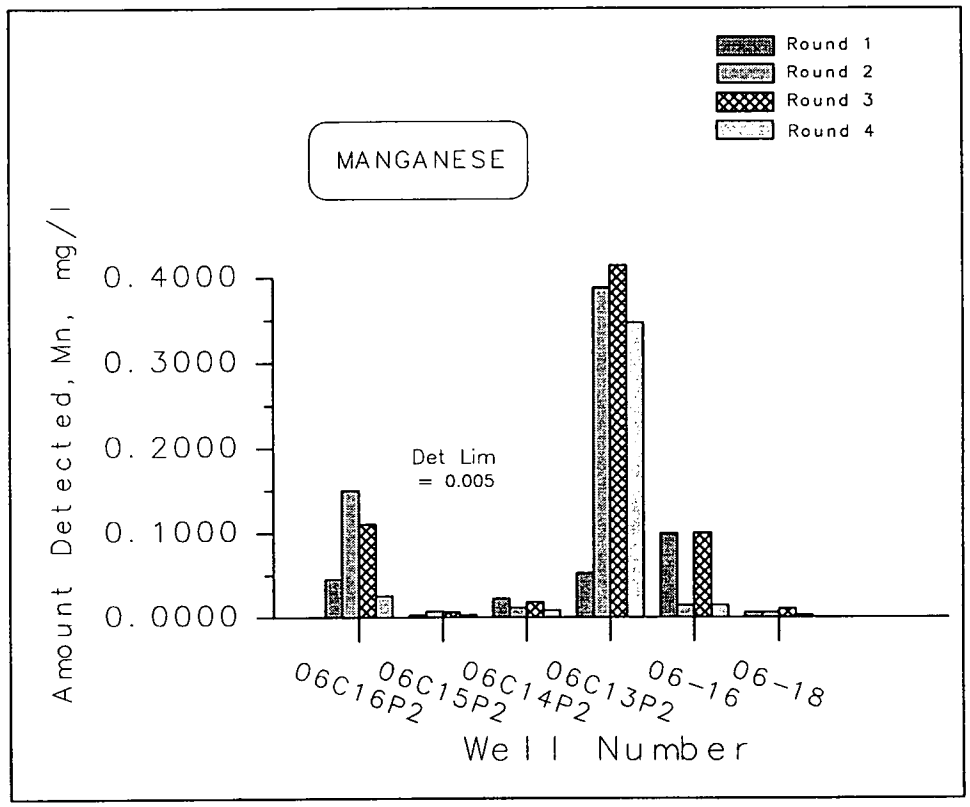


Figure 68. Levels of manganese detected in second group of upper zone wells, Old Rifle Range

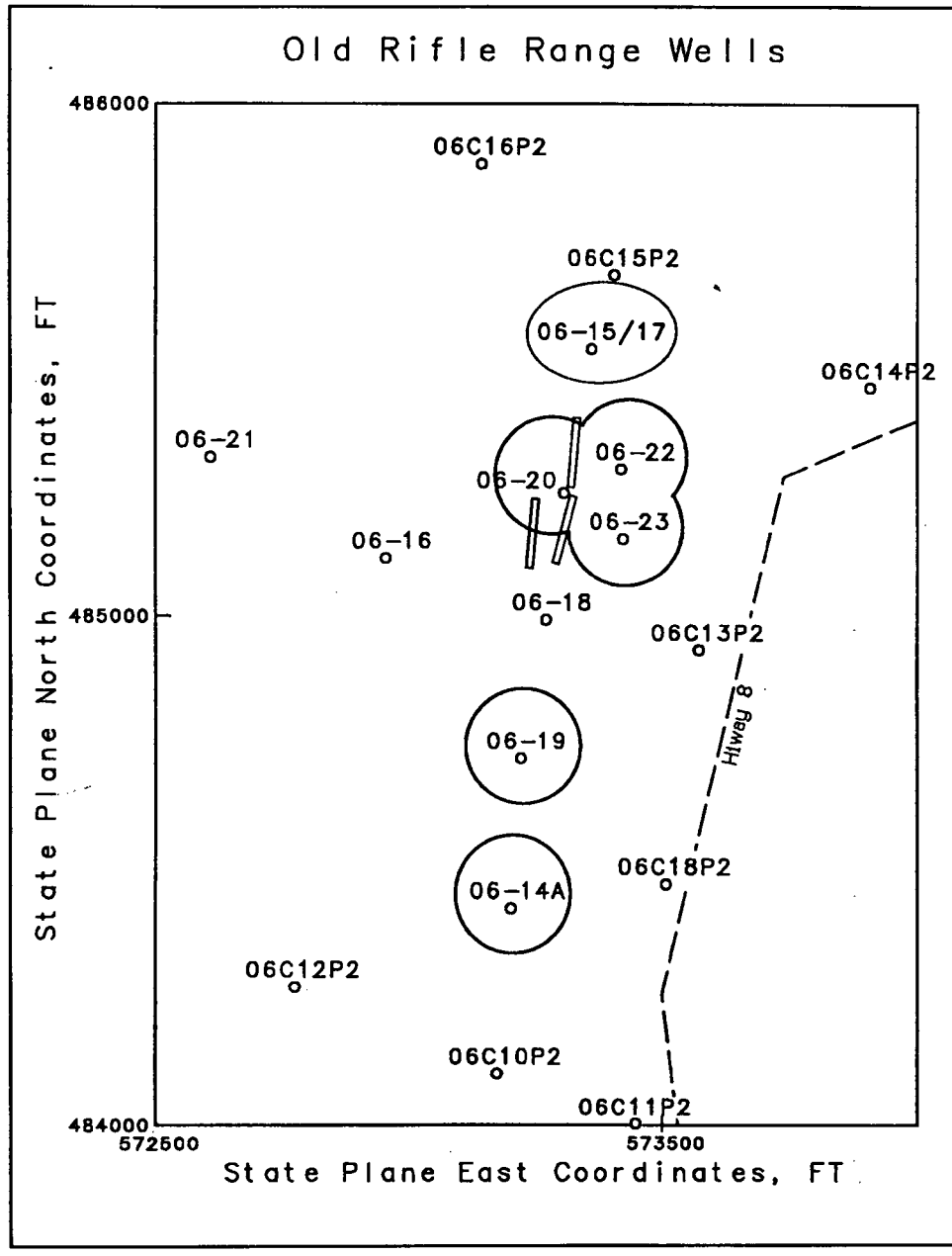


Figure 69. Third group of upper zone wells, Old Rifle Range

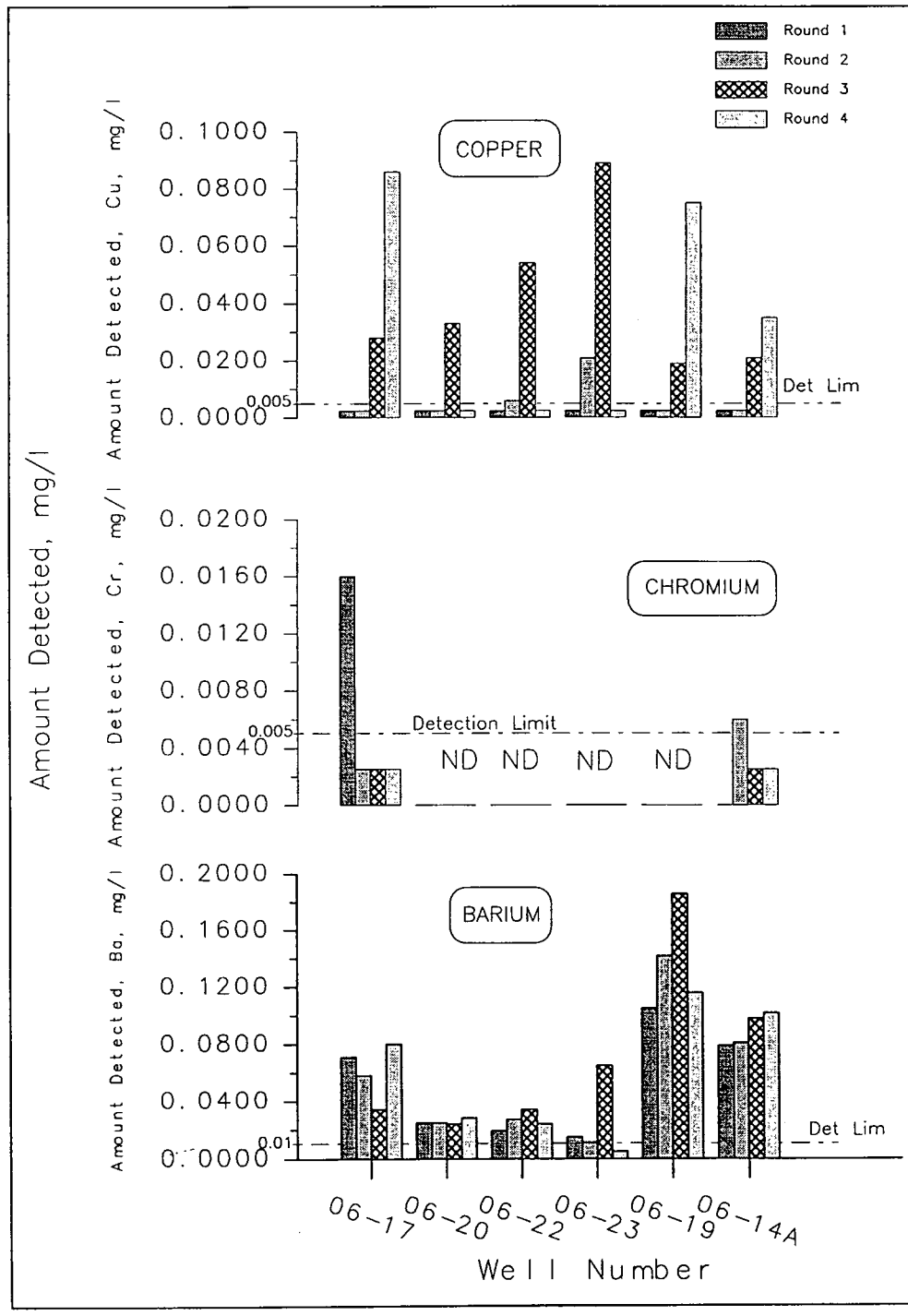


Figure 70. Levels of copper, chromium, and barium in third group of upper zone wells, Old Rifle Range

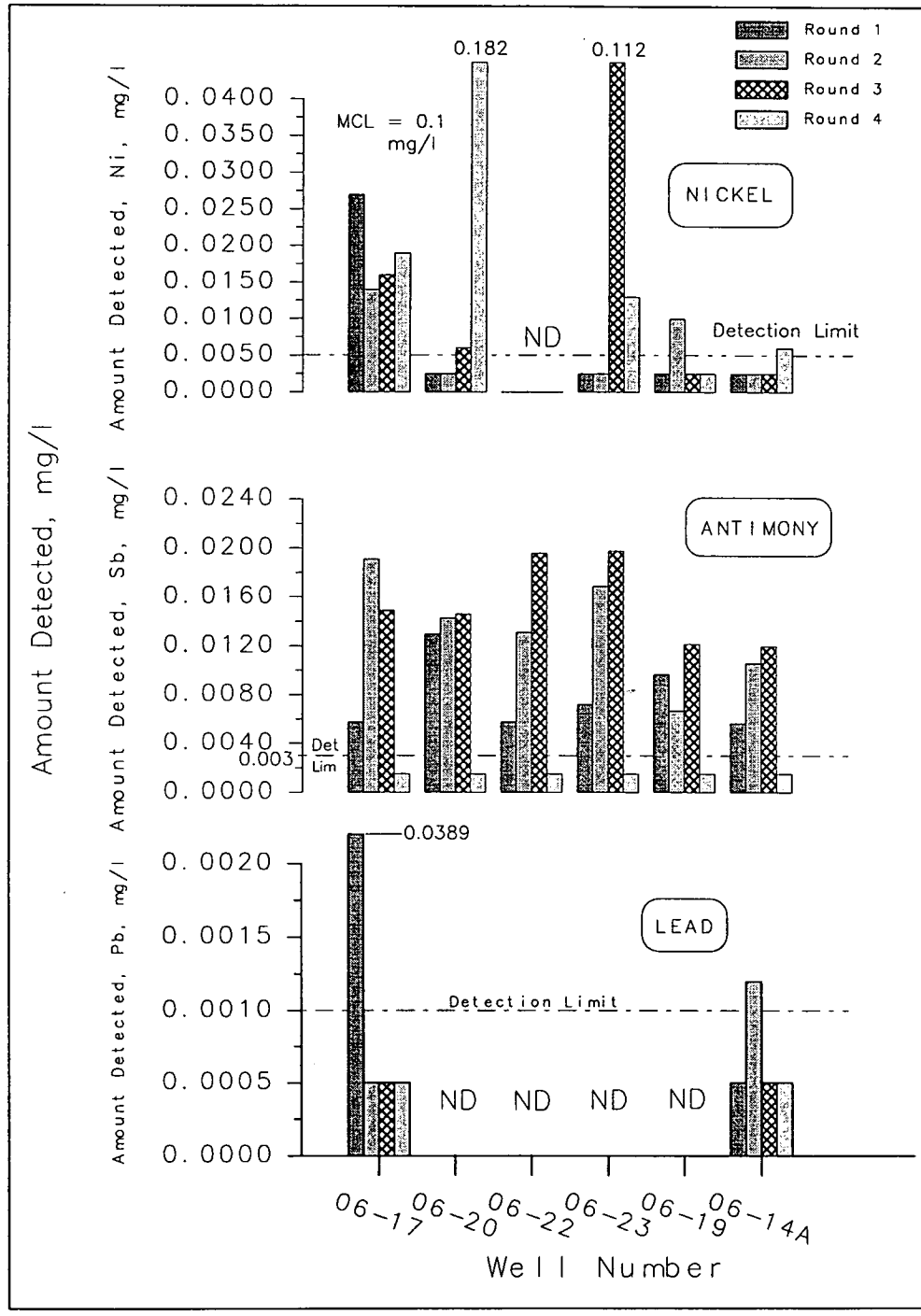


Figure 71. Levels of nickel, antimony, and lead in third group of upper zone wells, Old Rifle Range

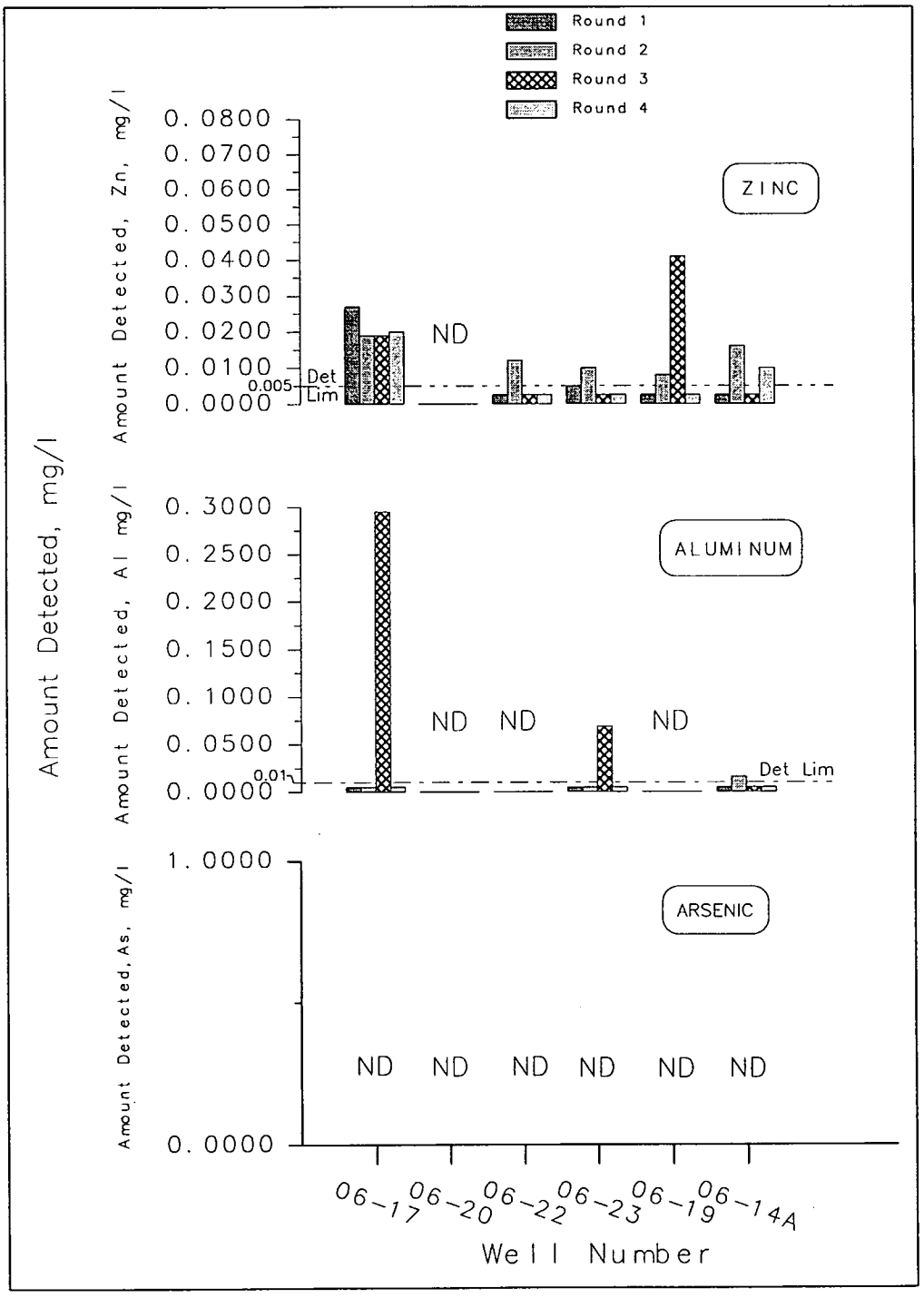


Figure 72. Levels of zinc, aluminum, and arsenic in third group of upper zone wells, Old Rifle Range

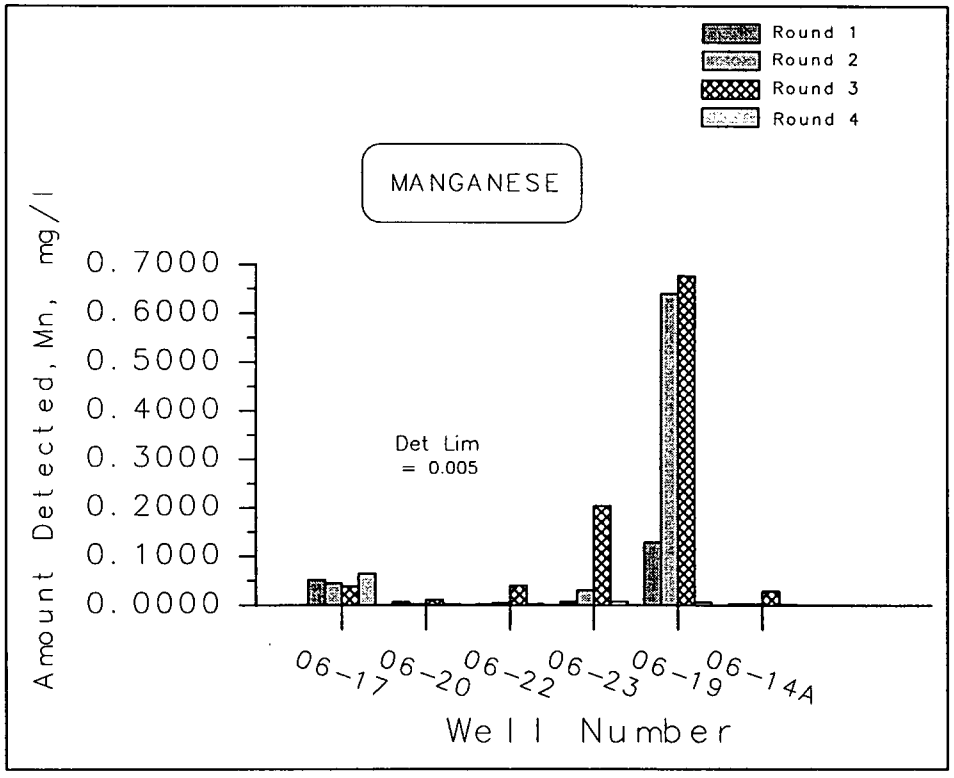


Figure 73. Levels of manganese detected in third group of upper zone wells, Old Rifle Range

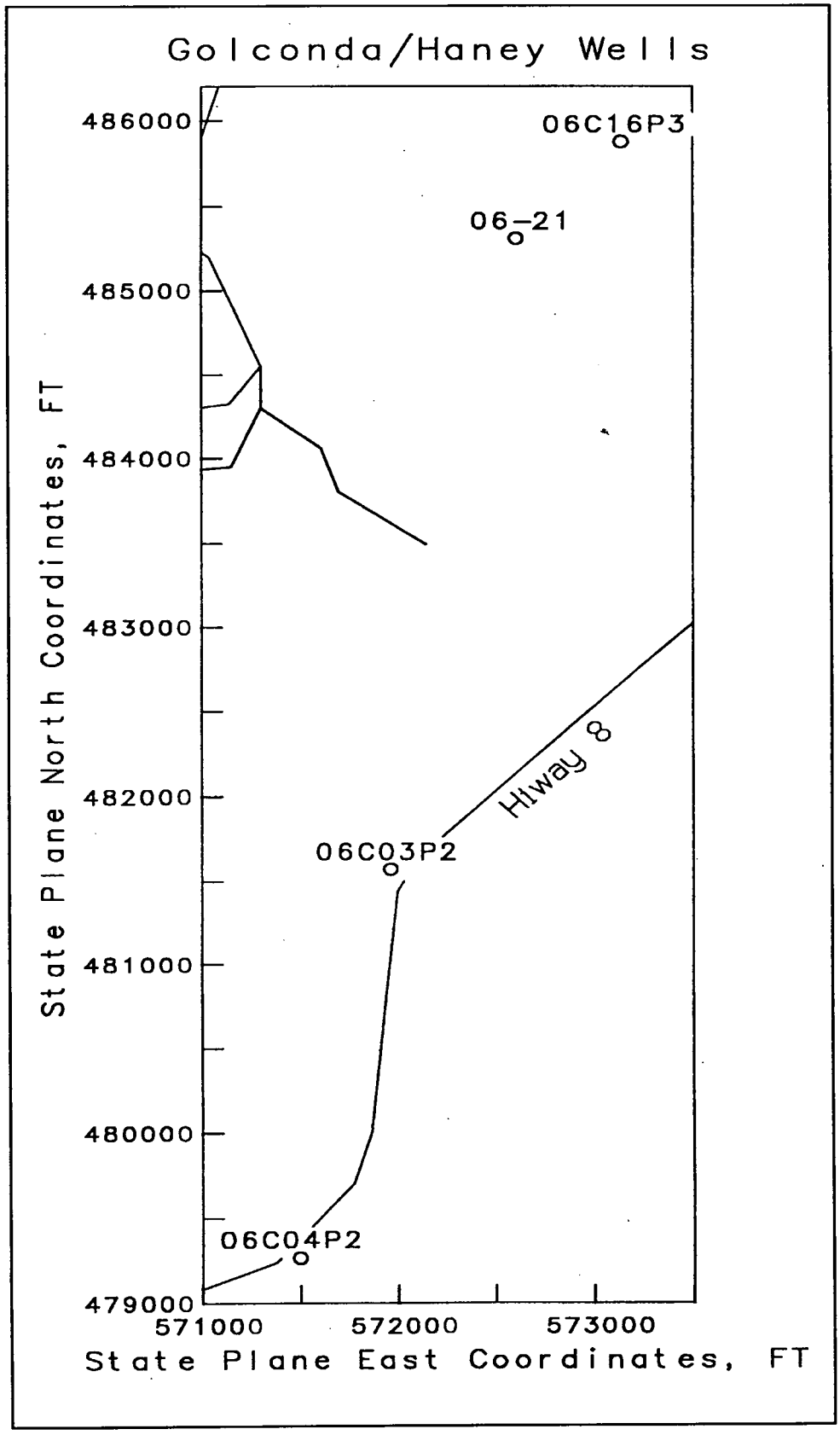


Figure 74. Location of Golconda/Haney wells

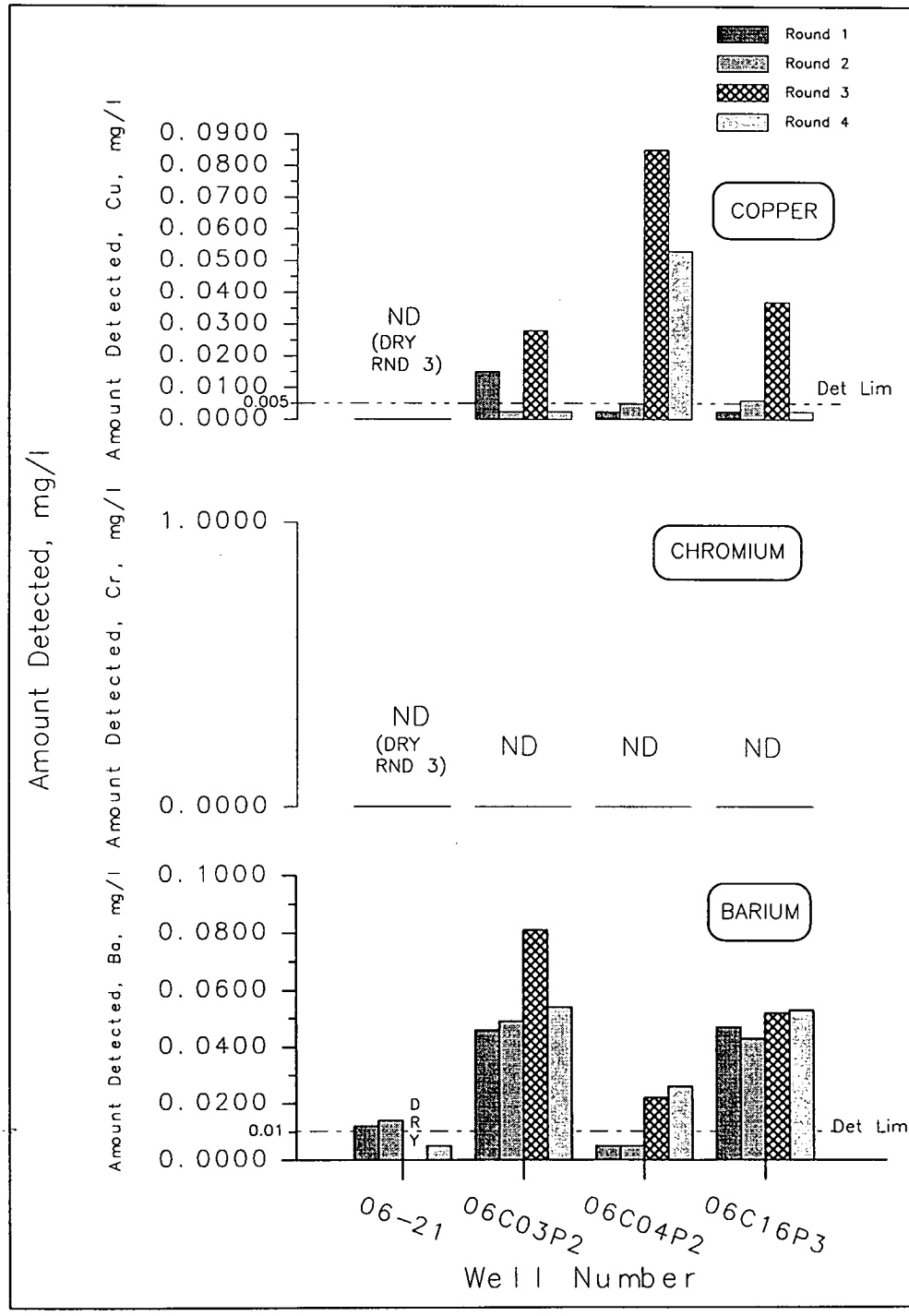


Figure 75. Levels of copper, chromium, and barium in Golconda/Haney wells

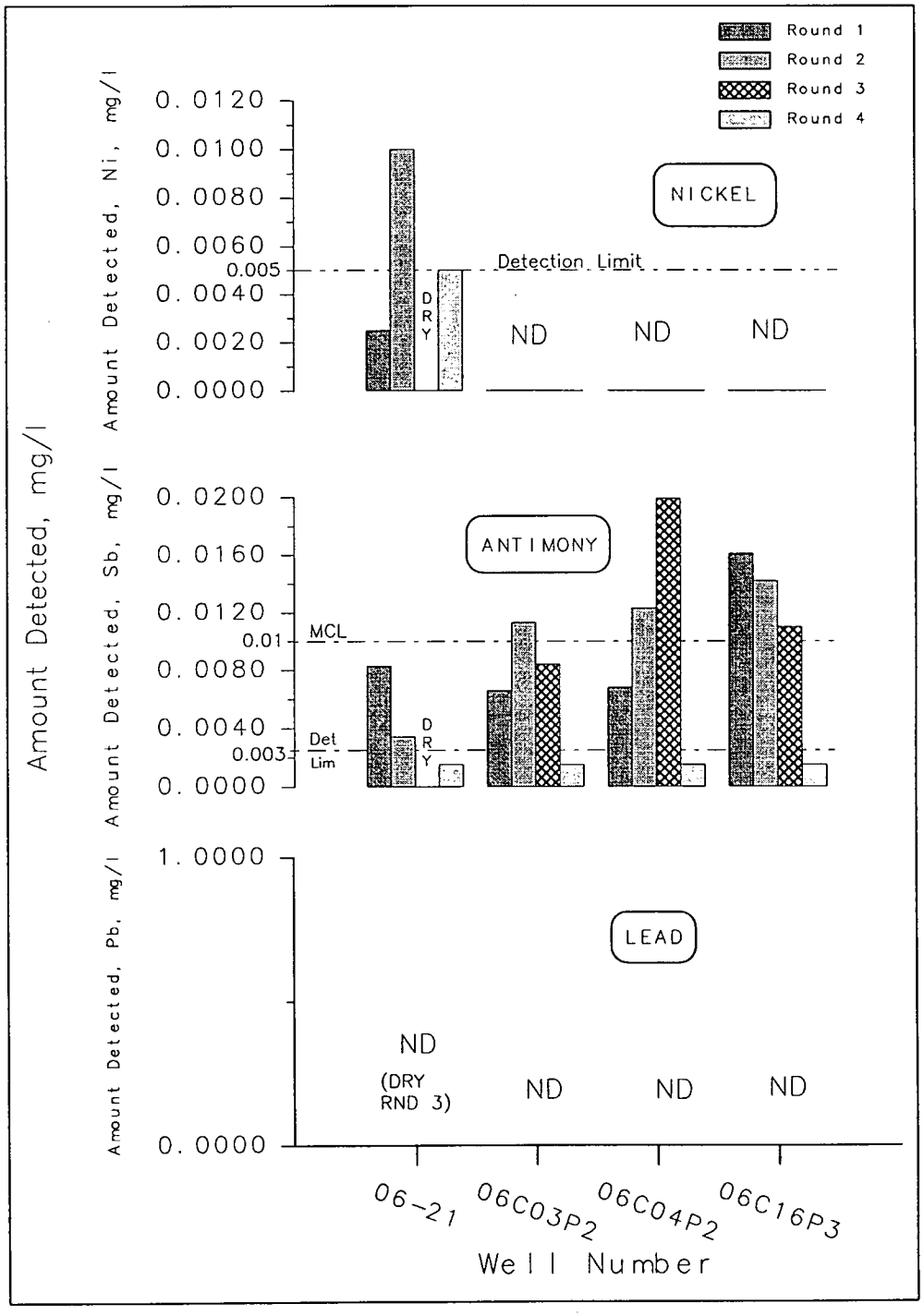


Figure 76. Levels of nickel, antimony, and lead in Golconda/Haney wells

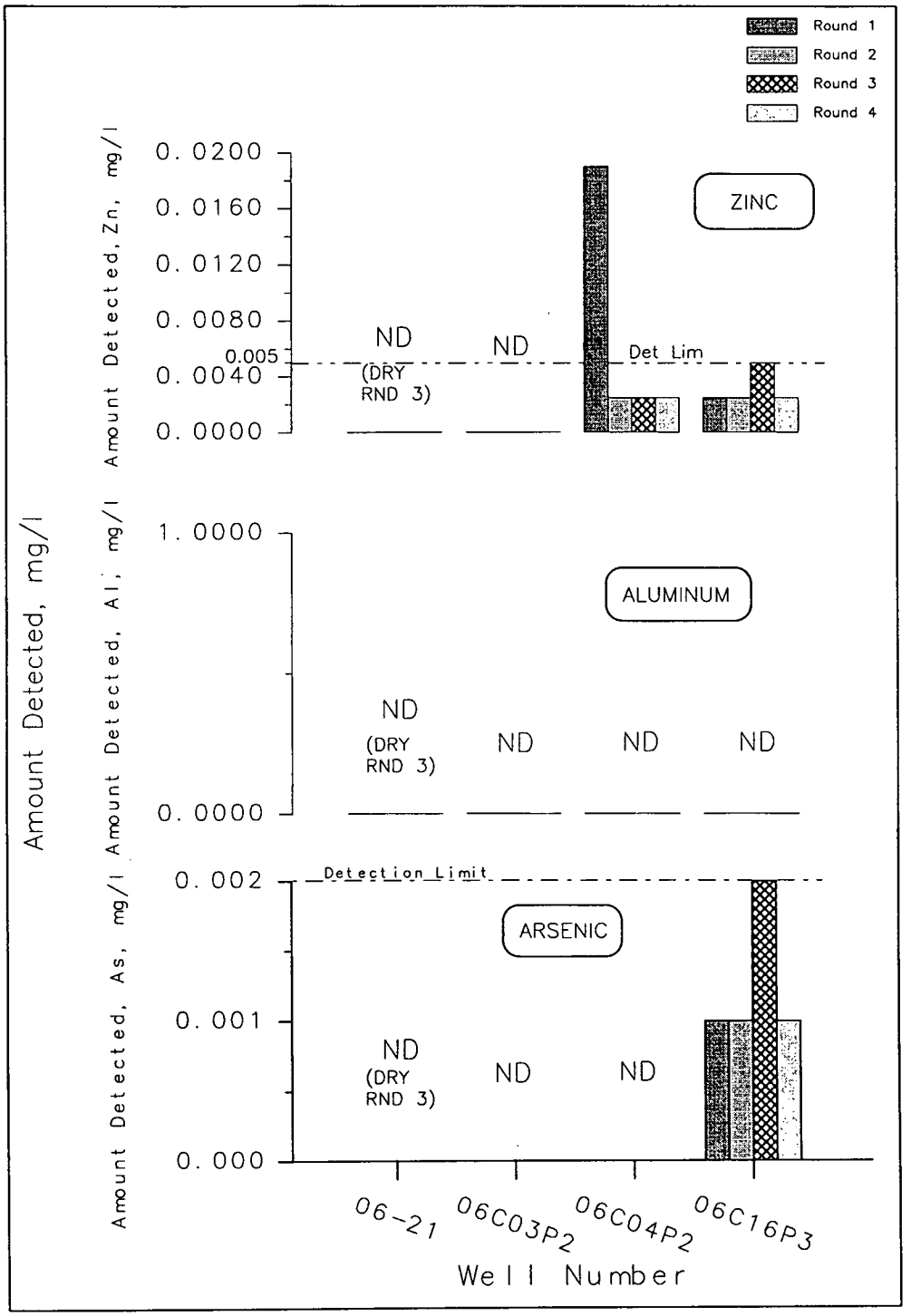


Figure 77. Levels of zinc, aluminum, and arsenic in Golconda/Haney wells

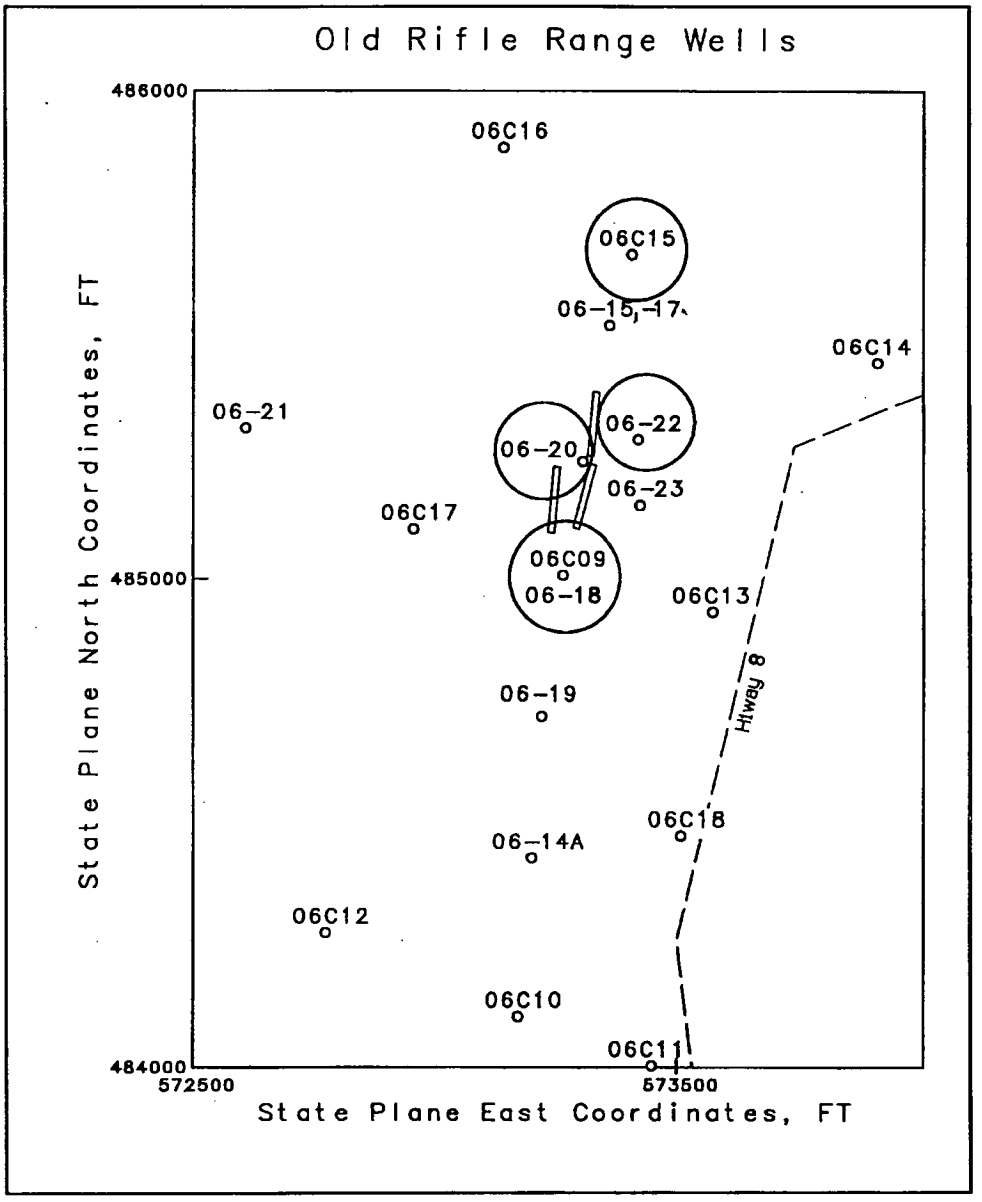


Figure 78. Wells with explosives, Old Rifle Range

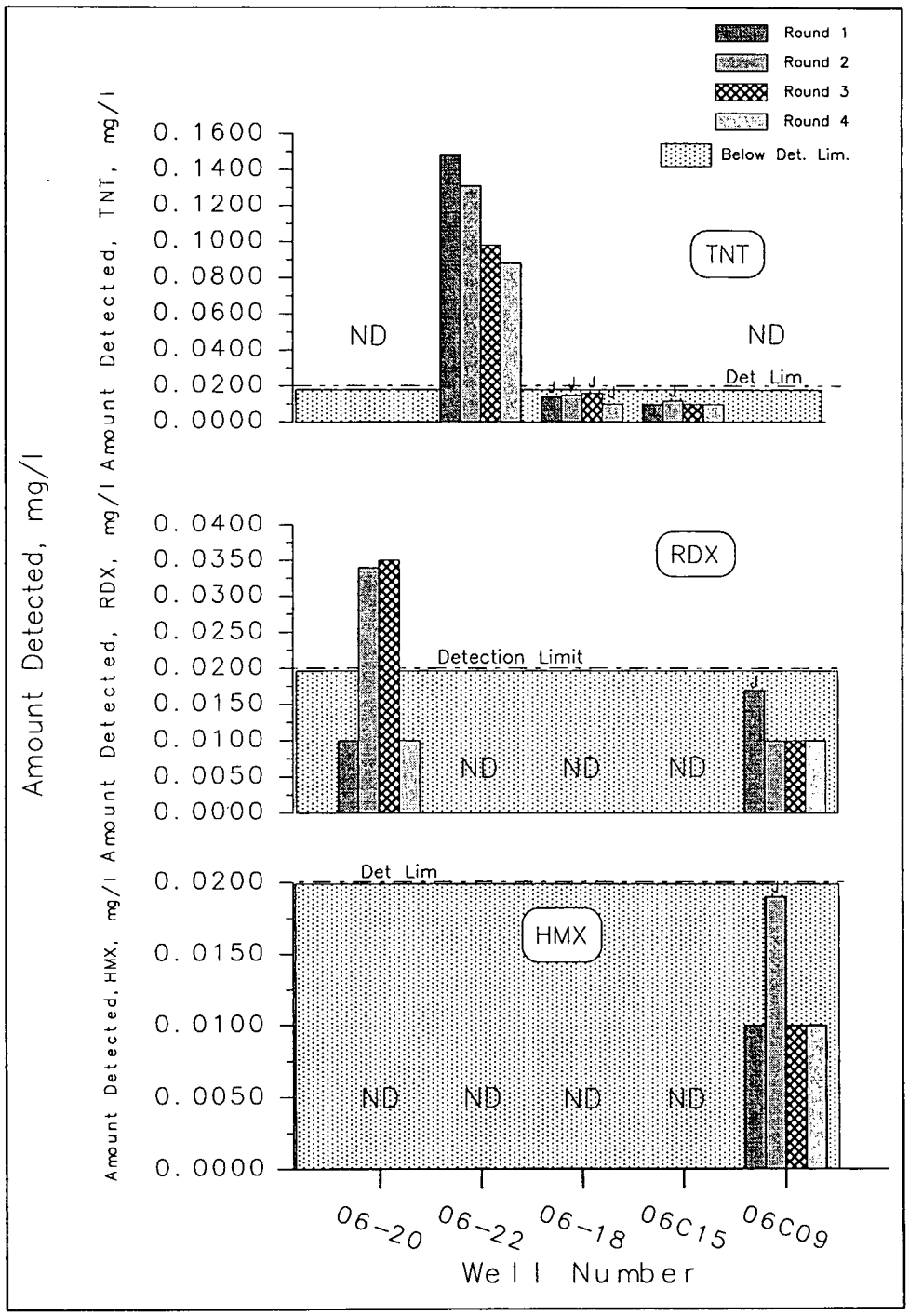


Figure 79. Levels of explosives, Old Rifle Range wells

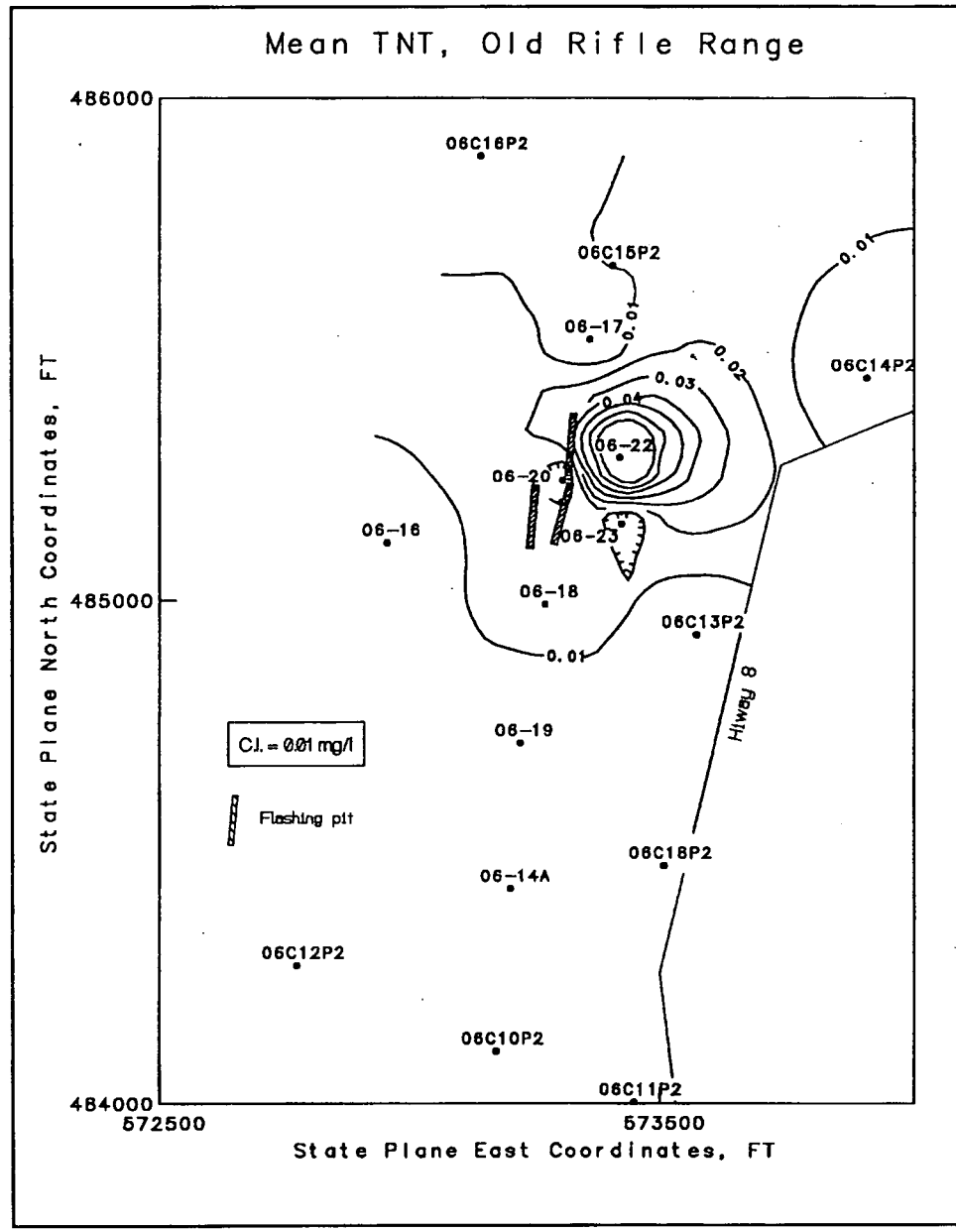


Figure 80. Mean values of TNT (four rounds), Old Rifle Range

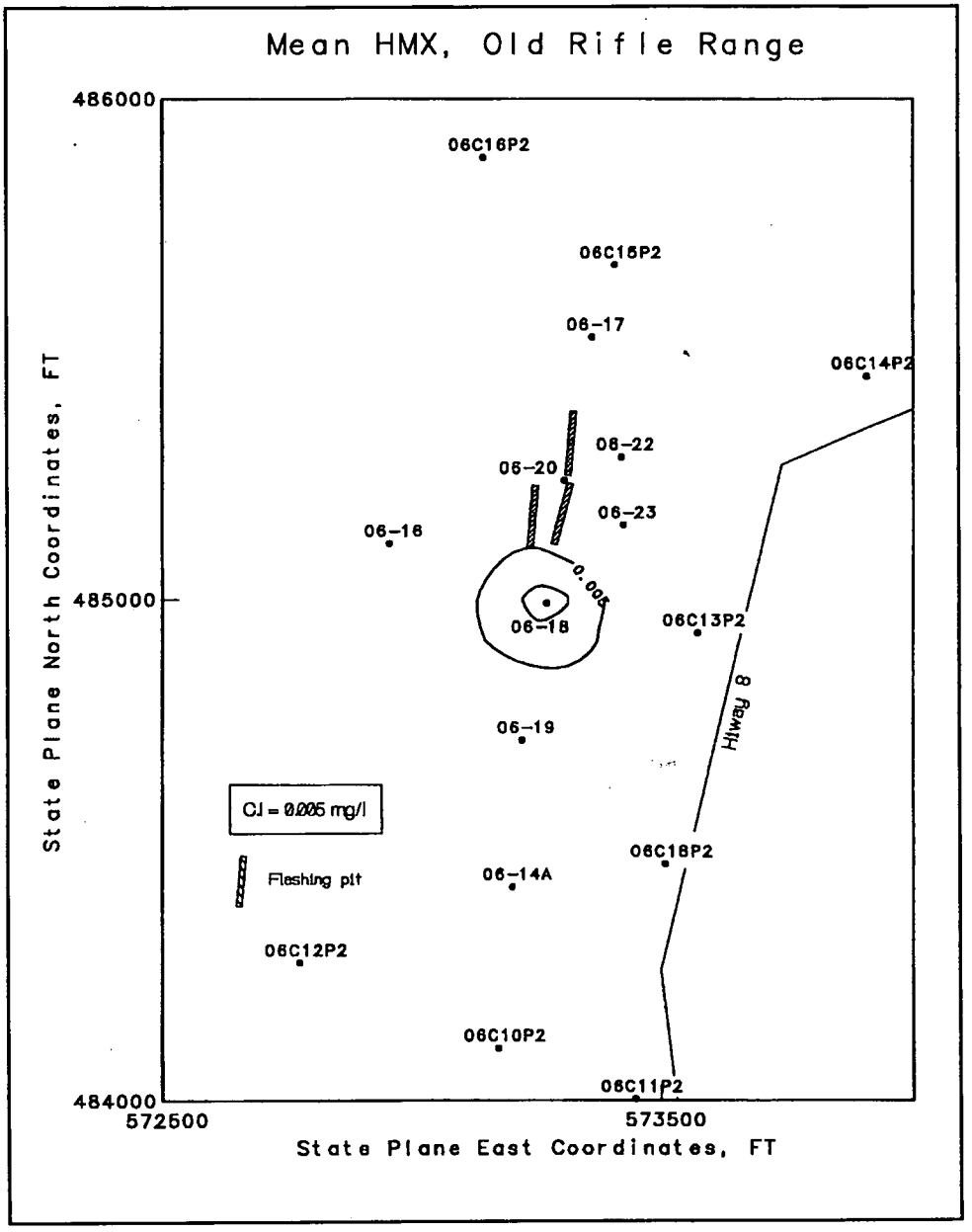


Figure 81. Mean values of HMX (four rounds), Old Rifle Range

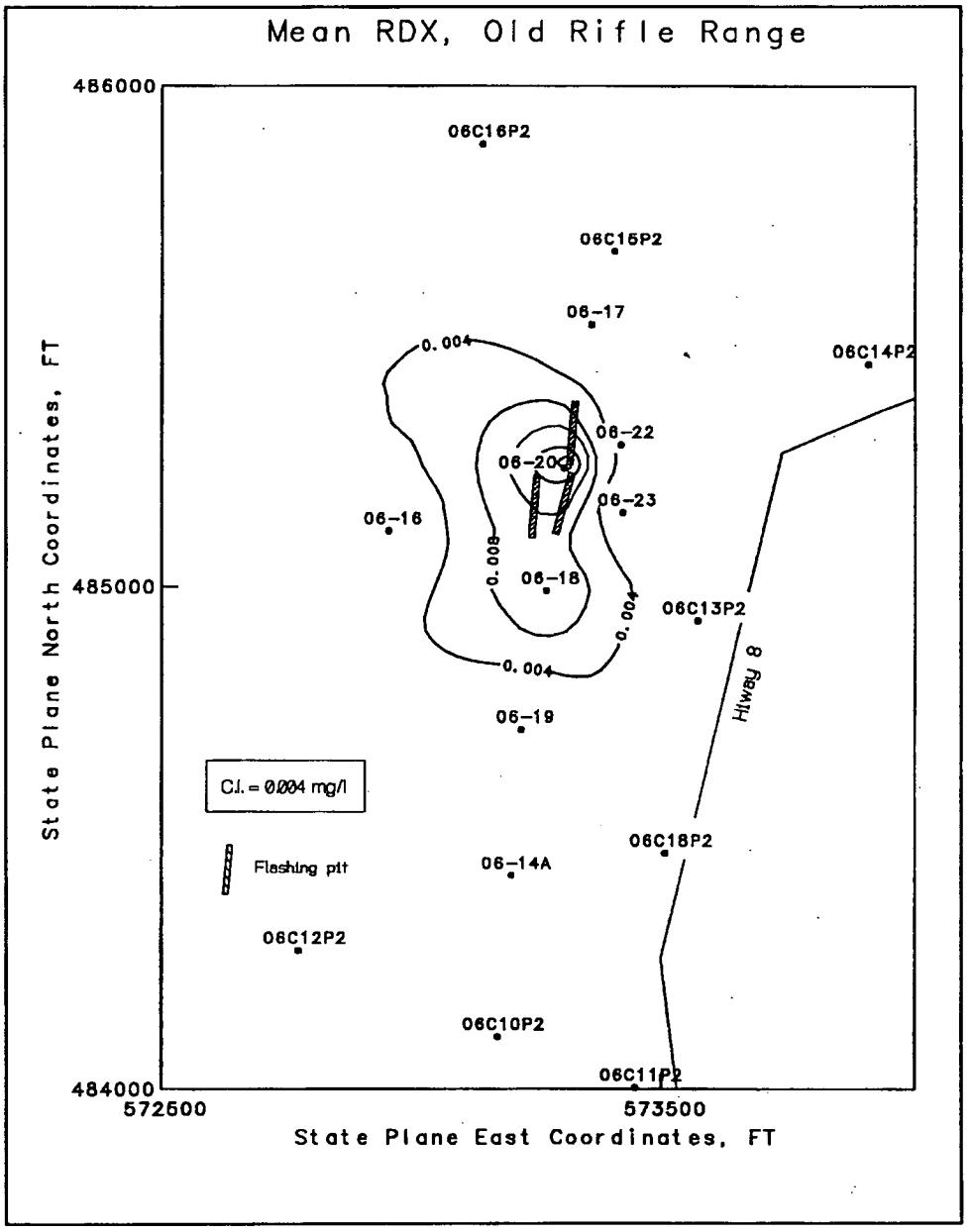


Figure 82. Mean values of RDX (four rounds), Old Rifle Range

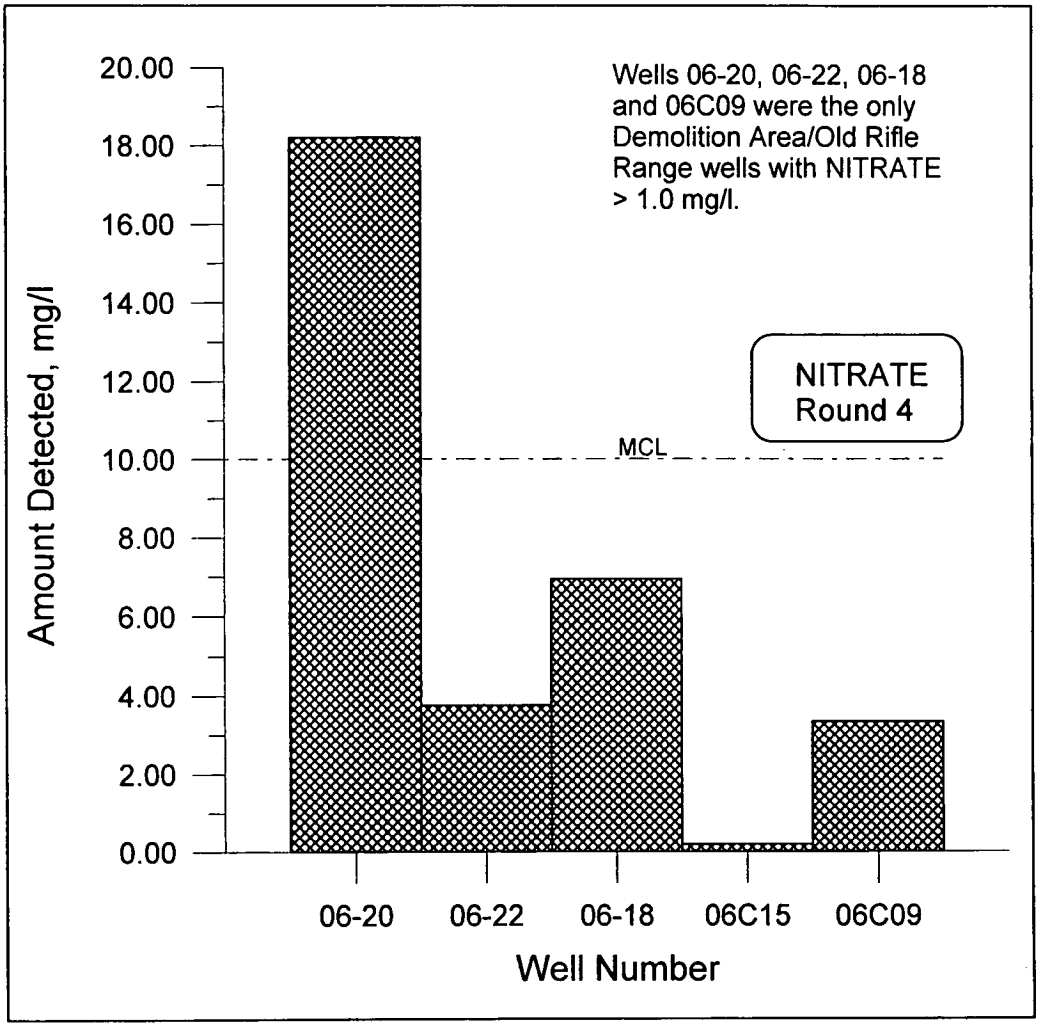


Figure 83. Levels of nitrates in Old Rifle Range wells (fourth round only)

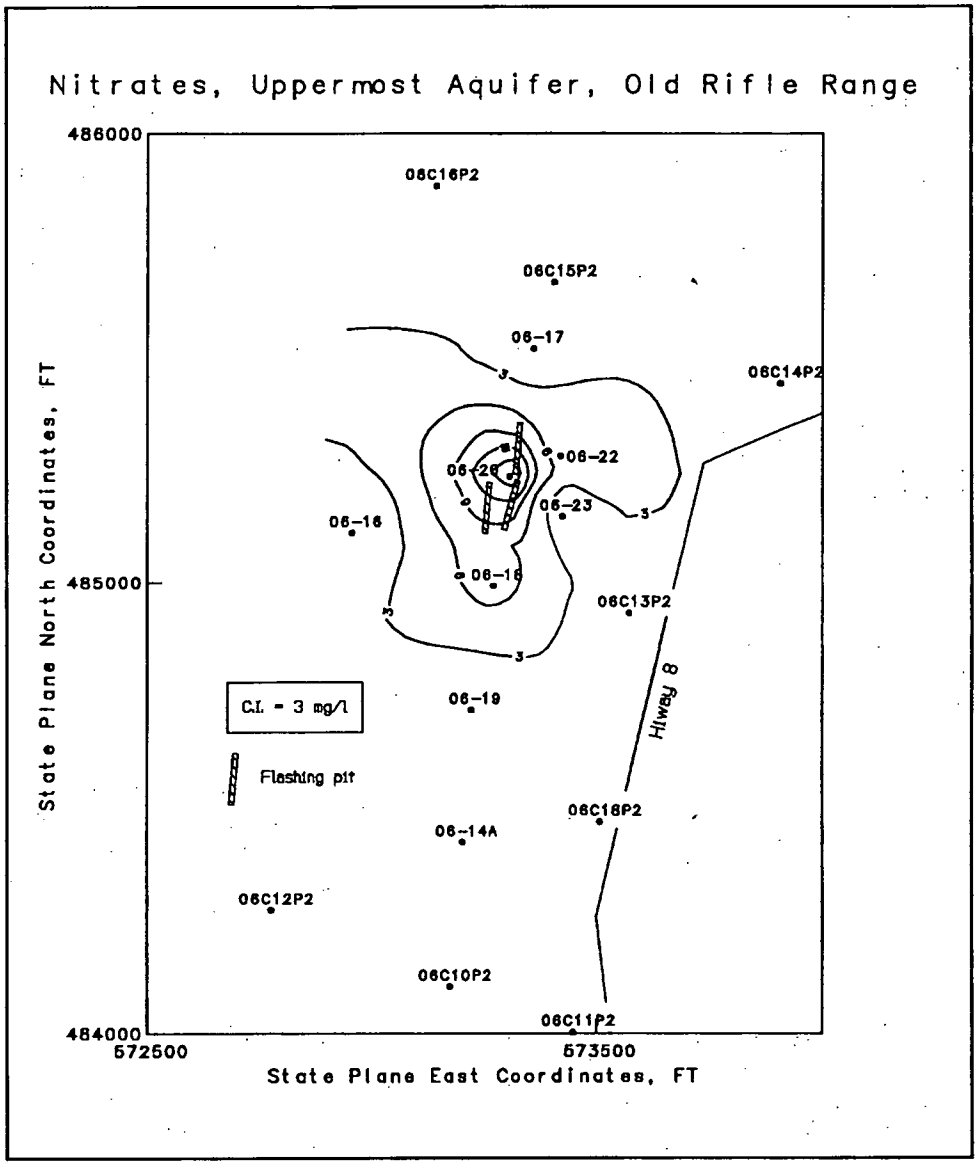


Figure 84. Levels of nitrates of at least 3 mg/l, Old Rifle Range (fourth round only)

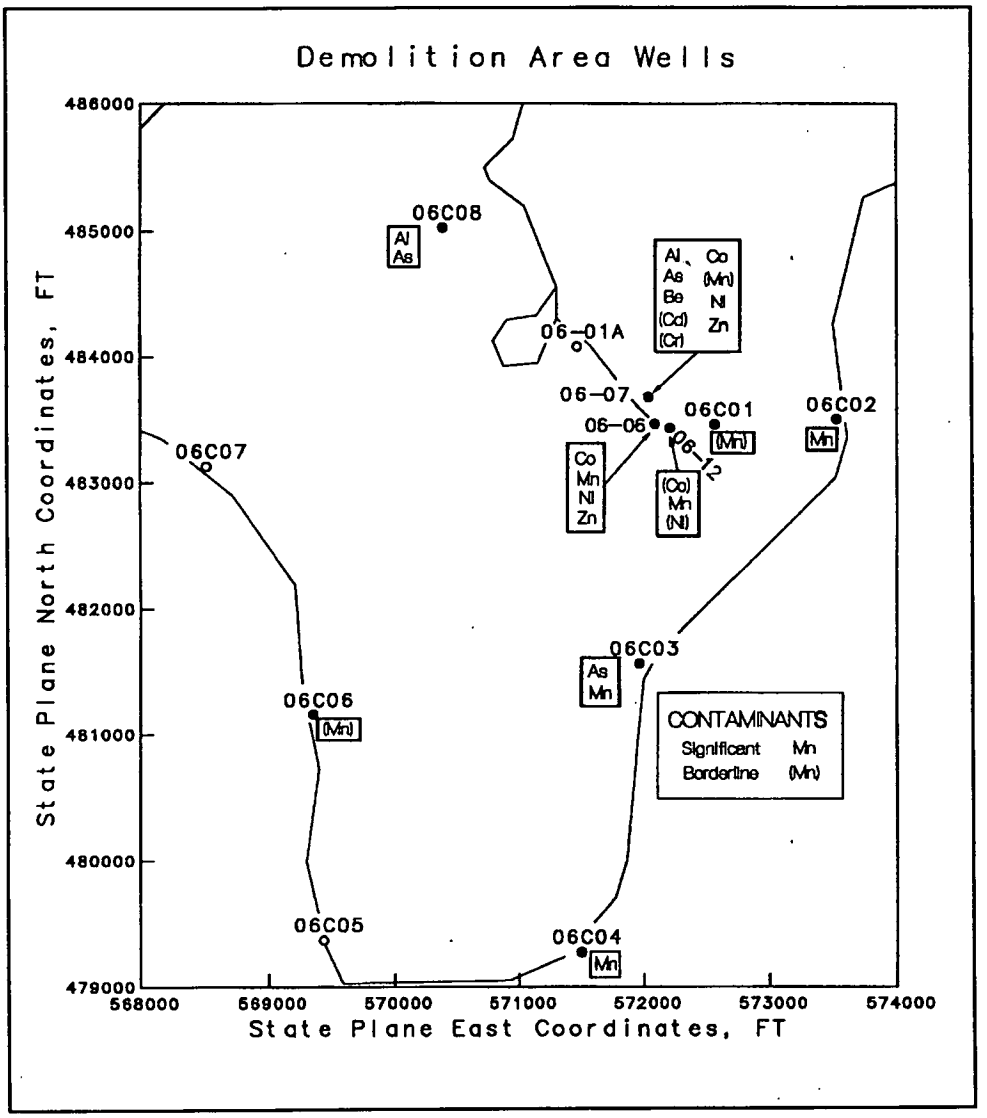


Figure 85. Statistically significant and borderline significant contaminants in Demolition Area wells

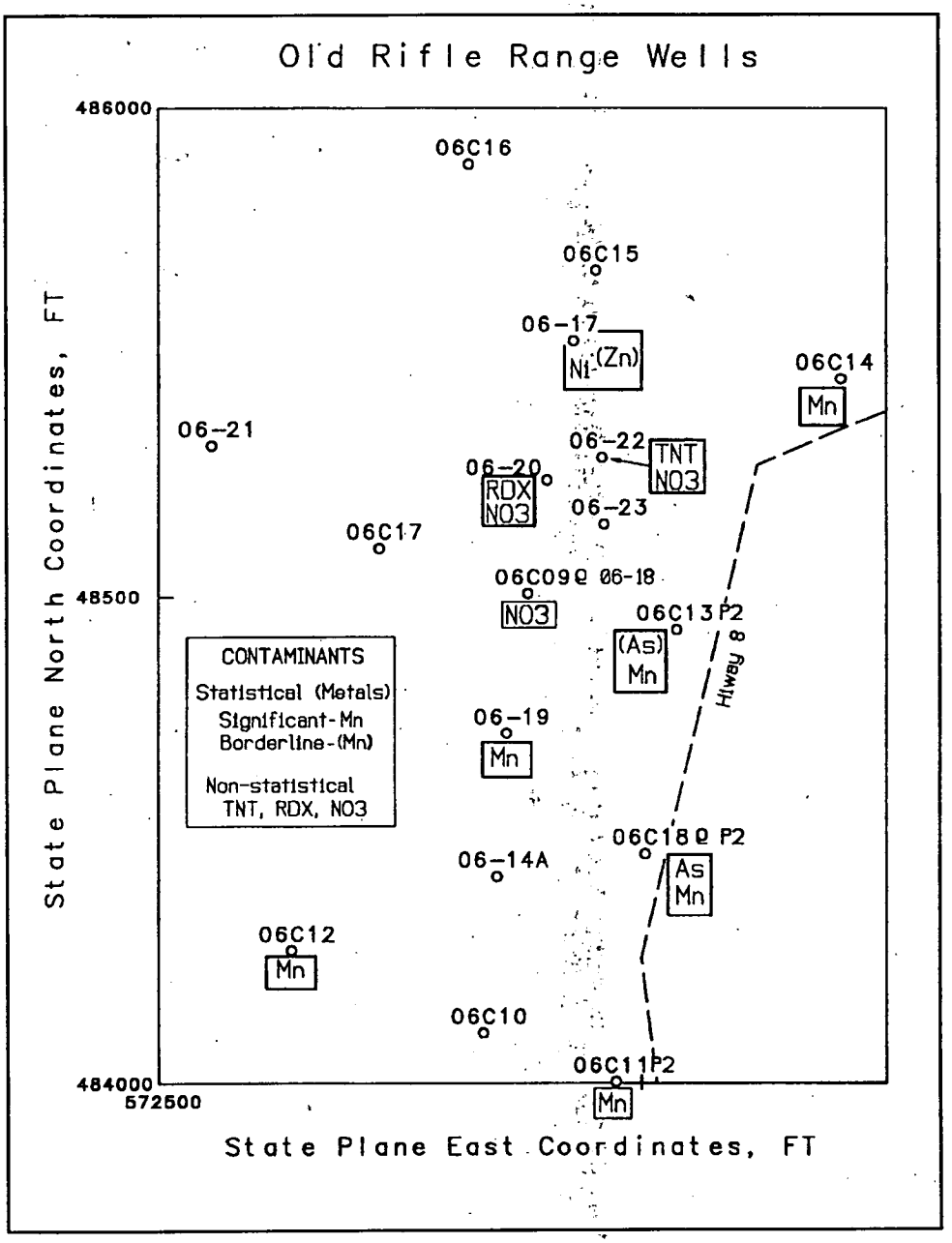
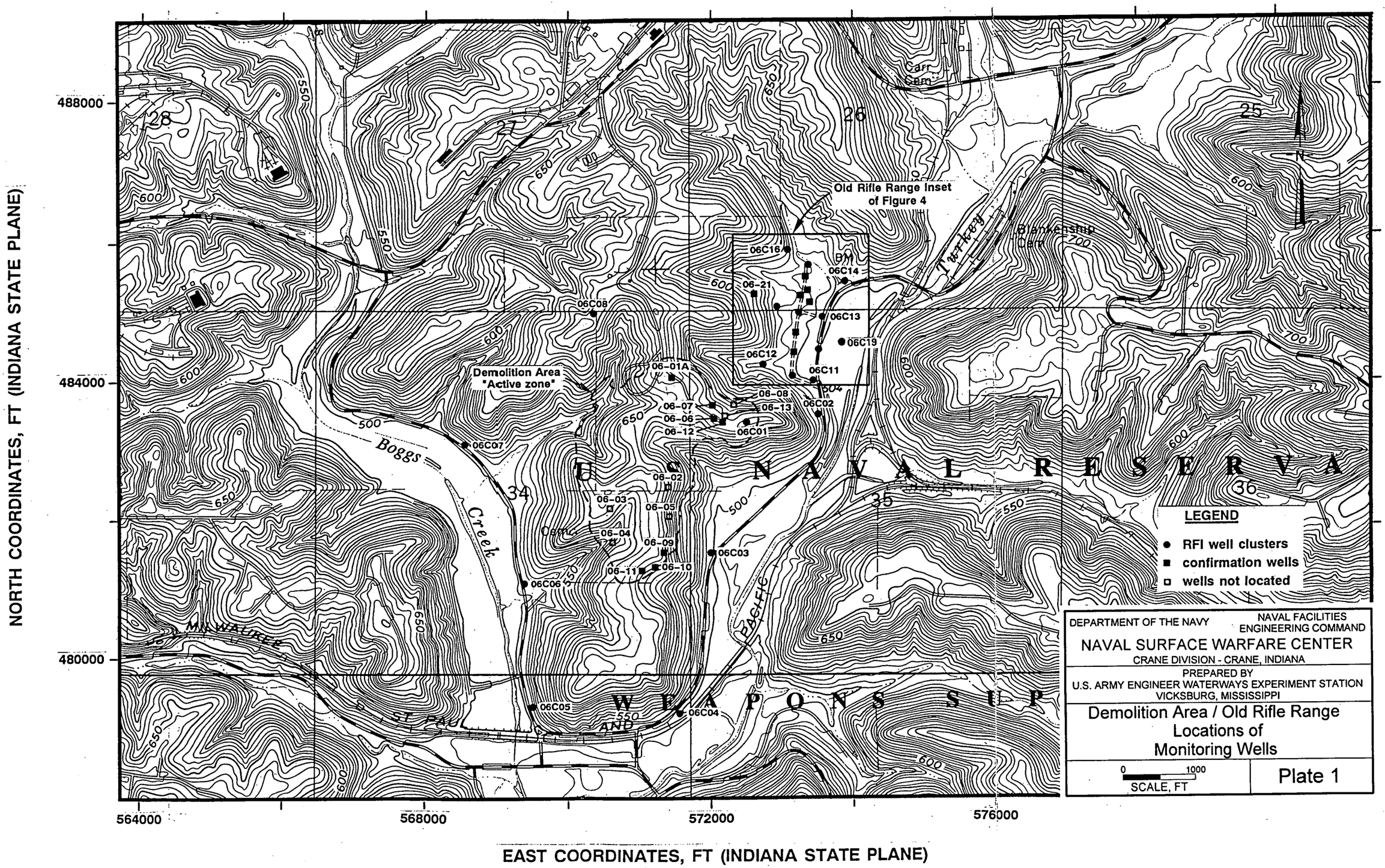


Figure 86. Statistically significant, borderline significant, and non-statistical contaminants in Old Rifle Range wells (explosives shown only for wells with amounts > detection limits)


NORTH COORDINATES, FT (INDIANA STATE PLANE)
488000
484000
480000
564000
568000
572000
576000
EAST COORDINATES, FT (INDIANA STATE PLANE)
Old Rifle Range Inset of Figure 4
Demolition Area "Active zone"
Carr Cem
Blankenship Cem
Turkey
Boggs
Creek
Cemetery
U.S. NAVAL RESERVA
WEAPONS SUP
MILWAUKEE
ST PAUL
AND
PACIFIC
06C16
06C14
06-21
06C13
06C19
06C12
06C11
06C08
06-01A
06-08
06-13
06C02
06-07
06-06
06-12
06C01
06C07
06-02
06-03
06-05
06-04
06-09
06-11
06-10
06C03
06C06
06C05
06C04
25
26
27
28
34
35
36
LEGEND
RFI well clusters
confirmation wells
wells not located
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NAVAL FACILITIES ENGINEERING COMMAND
NAVAL SURFACE WARFARE CENTER
CRANE DIVISION - CRANE, INDIANA
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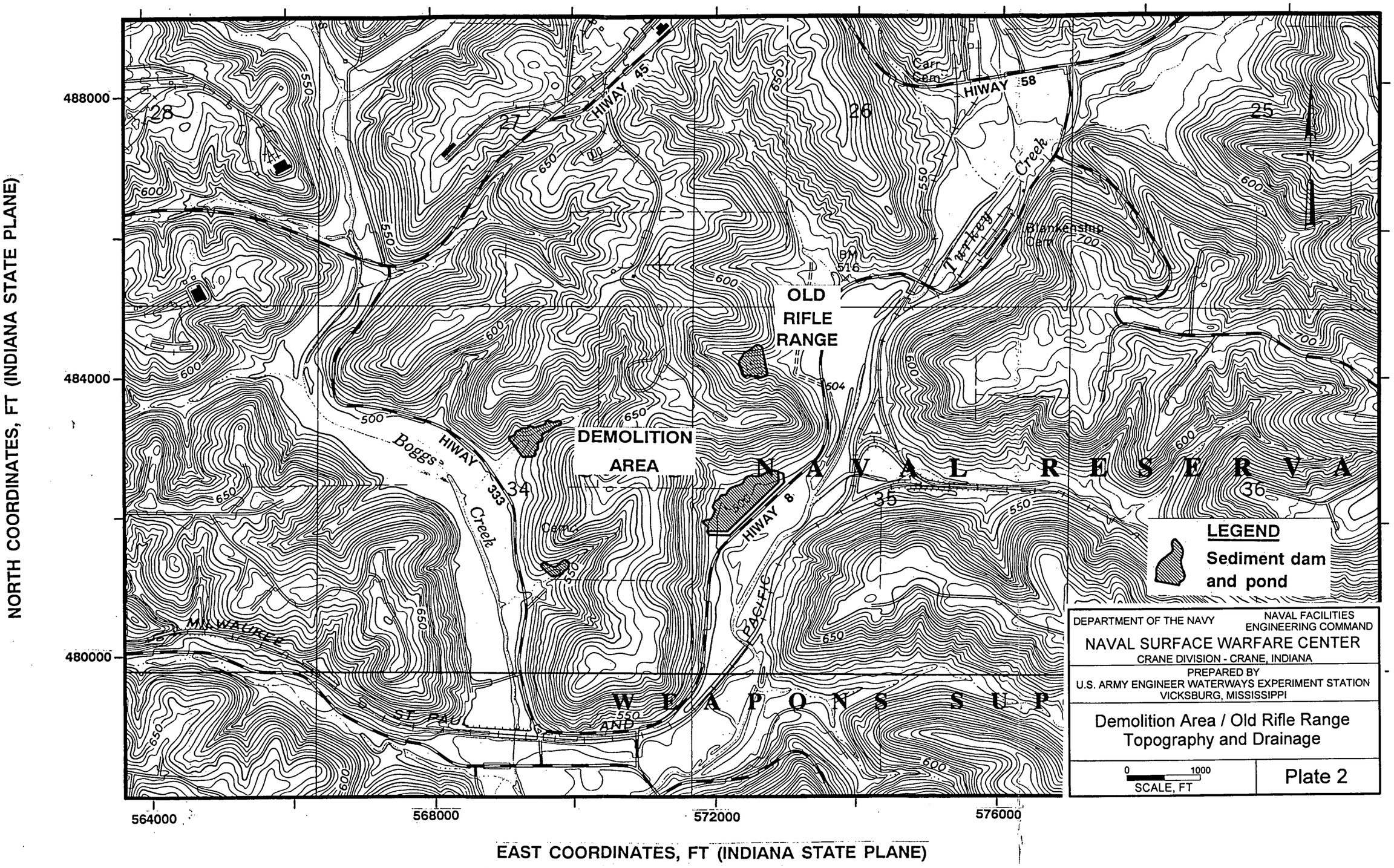
VICKSBURG, MISSISSIPPI
Demolition Area / Old Rifle Range
Locations of
Monitoring Wells
0
1000
SCALE, FT
Plate 1


NORTH COORDINATES, FT (INDIANA STATE PLANE)
488000
484000
480000
564000
568000
572000
576000
EAST COORDINATES, FT (INDIANA STATE PLANE)
OLD
RIFLE
RANGE
DEMOLITION
AREA
N A V A L R E S E R V A
W E A P O N S S U P
HIWAY 45
HIWAY 58
HIWAY 333
HIWAY 8
Boggs Creek
Turkey Creek
Blankenship Cem
Cem
MILWAUKEE
ST PAUL
AND
PACIFIC
BM 516
504
25
26
27
28
34
35
36
N
LEGEND
Sediment dam and pond
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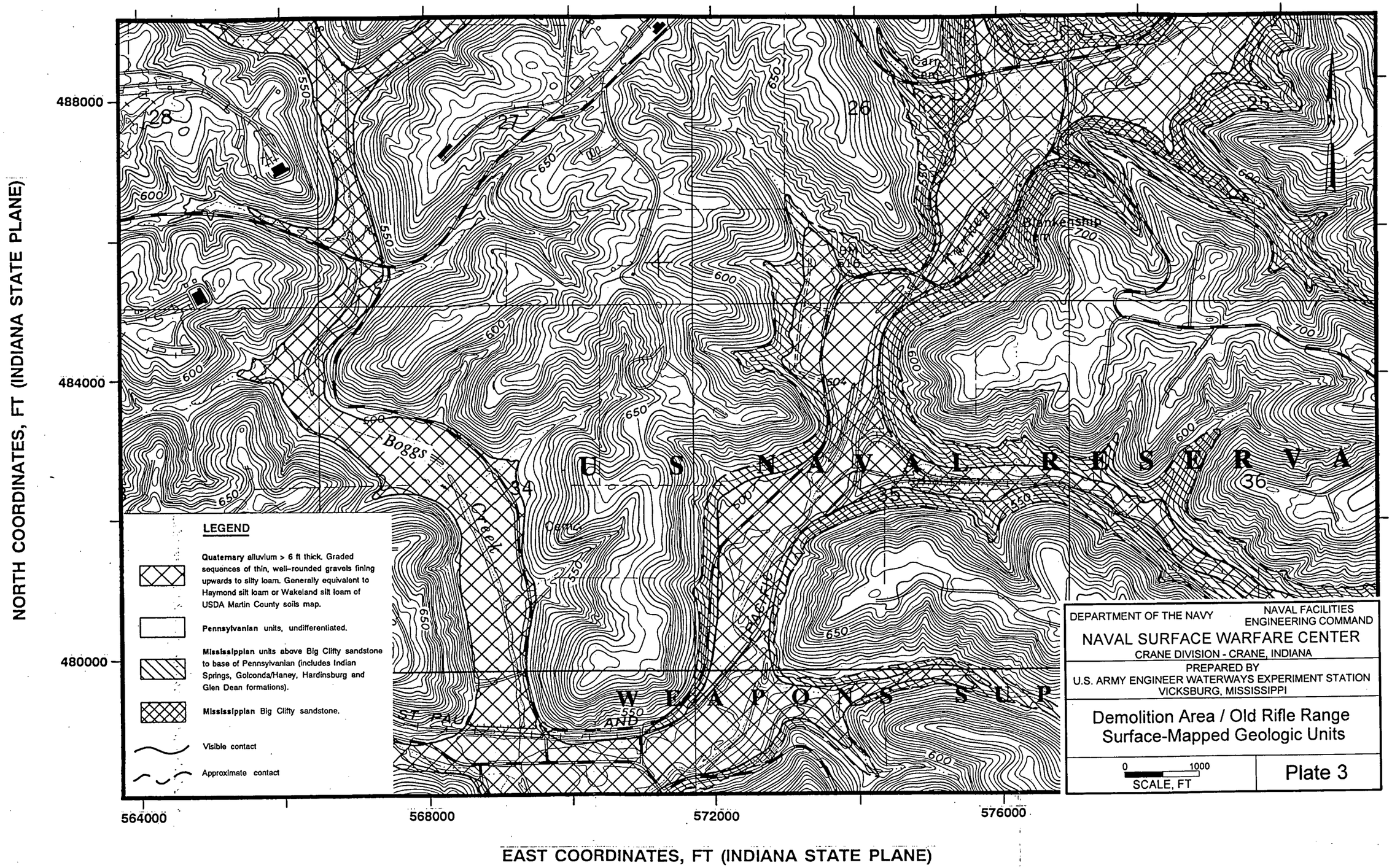
NAVAL SURFACE WARFARE CENTER
CRANE DIVISION - CRANE, INDIANA
PREPARED BY
U.S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION
VICKSBURG, MISSISSIPPI
Demolition Area / Old Rifle Range
Topography and Drainage
0 1000
SCALE, FT
Plate 2



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VICKSBURG, MISSISSIPPI

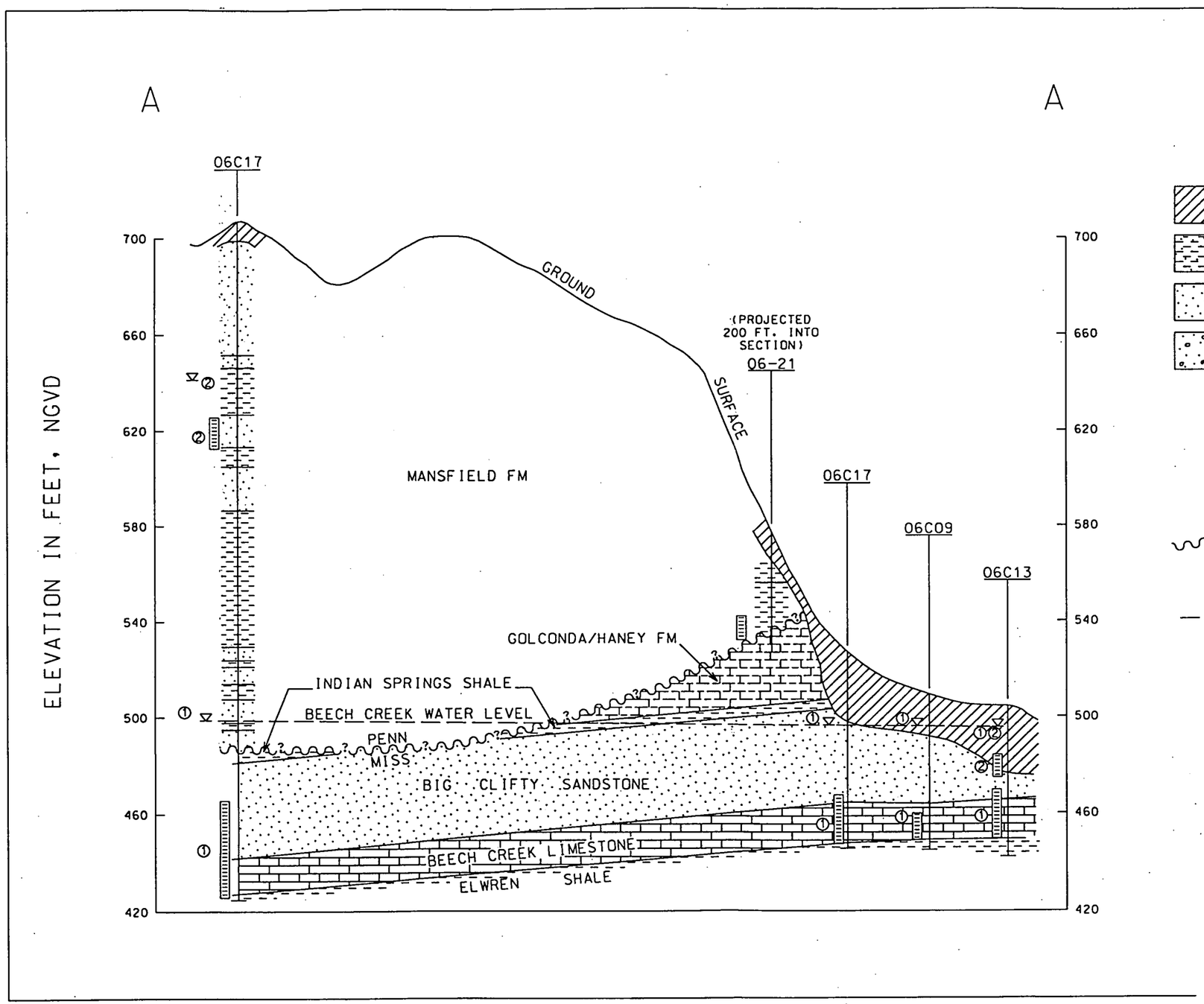
Demolition Area / Old Rifle Range

Surface-Mapped Geologic Units

0 1000

SCALE, FT

Plate 3



LEGEND

- SOIL OVERBURDEN
- SHALEY SANDSTONE
- SANDSTONE
- CONGLOMERATE
- SHALE
- COAL
- LIMESTONE & SHALE
- LIMESTONE
- ① WATER LEVEL FOR CORRESPONDING WELL SCREEN (MAY-JUNE 1991)
- ② WELL SCREEN NUMBER AND LOCATION
- MISS-PENN CONTACT
- 06C04 WELL CLUSTER NUMBER
- WATER TABLE/ PIEZOMETRIC SURFACE

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VICKSBURG, MISSISSIPPI

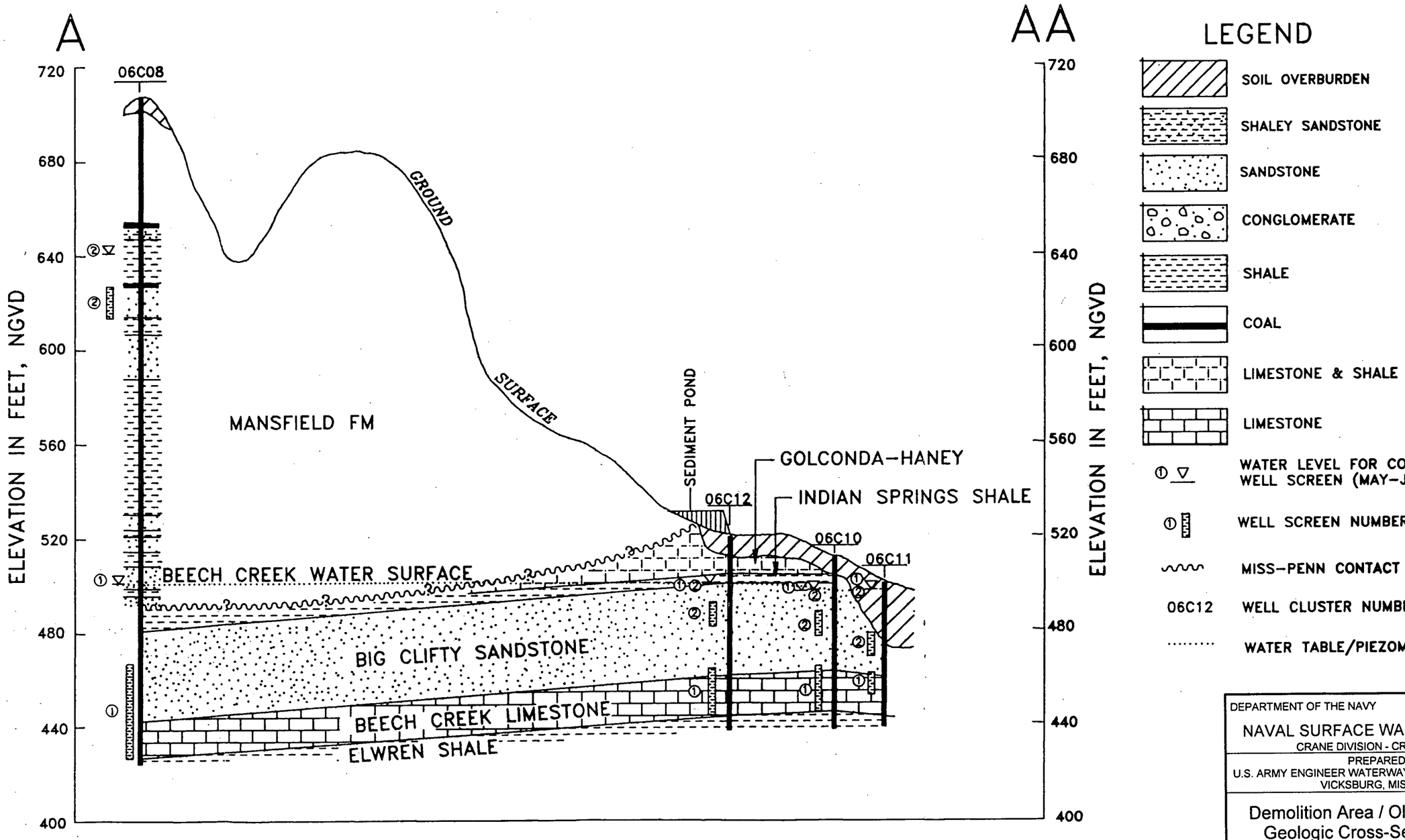
Demolition Area / Old Rifle Range

Geologic Cross-Section A-A

0 400

SCALE, FT

Plate 4



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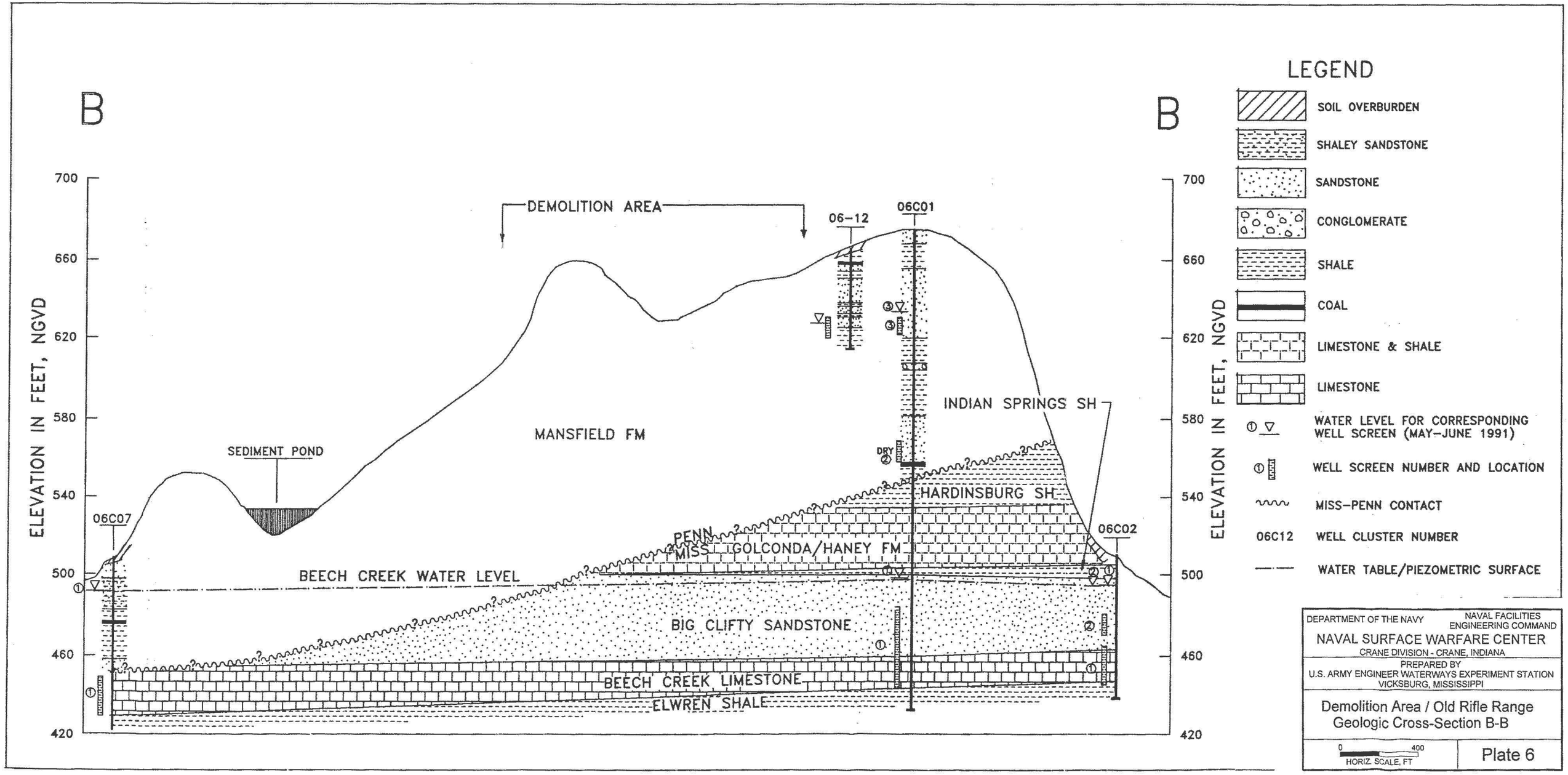
VICKSBURG, MISSISSIPPI

Demolition Area / Old Rifle Range
Geologic Cross-Section A - AA

0 400
HORIZ. SCALE, FT

Plate 5


B
B
ELEVATION IN FEET, NGVD
700
660
620
580
540
500
460
420
DEMOLITION AREA
06-12
06C01
06C07
06C02
SEDIMENT POND
MANSFIELD FM
INDIAN SPRINGS SH
HARDINSBURG SH
PENN
MISS
GOLCONDA/HANEY FM
BEECH CREEK WATER LEVEL
BIG CLIFTY SANDSTONE
BEECH CREEK LIMESTONE
ELWREN SHALE
DRY
LEGEND
SOIL OVERBURDEN
SHALEY SANDSTONE
SANDSTONE
CONGLOMERATE
SHALE
COAL
LIMESTONE & SHALE
LIMESTONE
WATER LEVEL FOR CORRESPONDING WELL SCREEN (MAY-JUNE 1991)
WELL SCREEN NUMBER AND LOCATION
MISS-PENN CONTACT
06C12 WELL CLUSTER NUMBER
WATER TABLE/PIEZOMETRIC SURFACE
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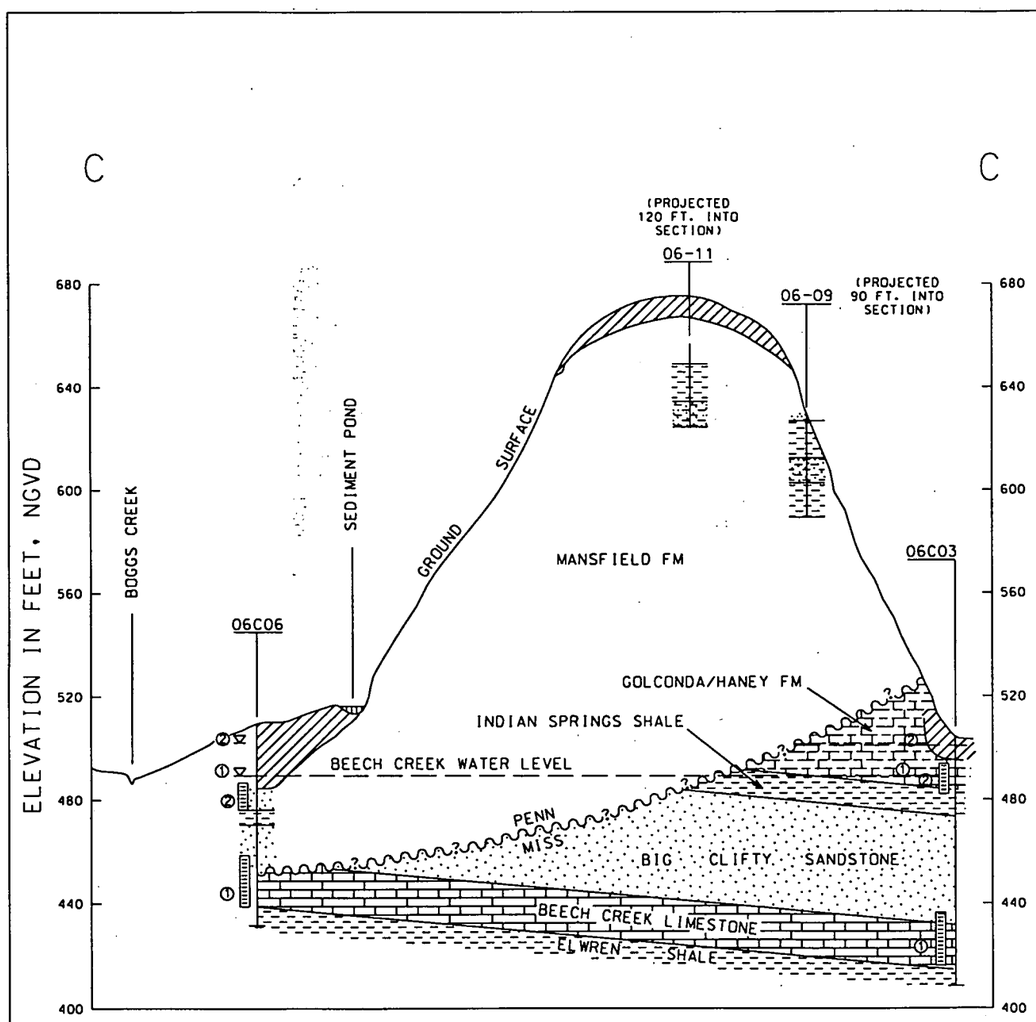
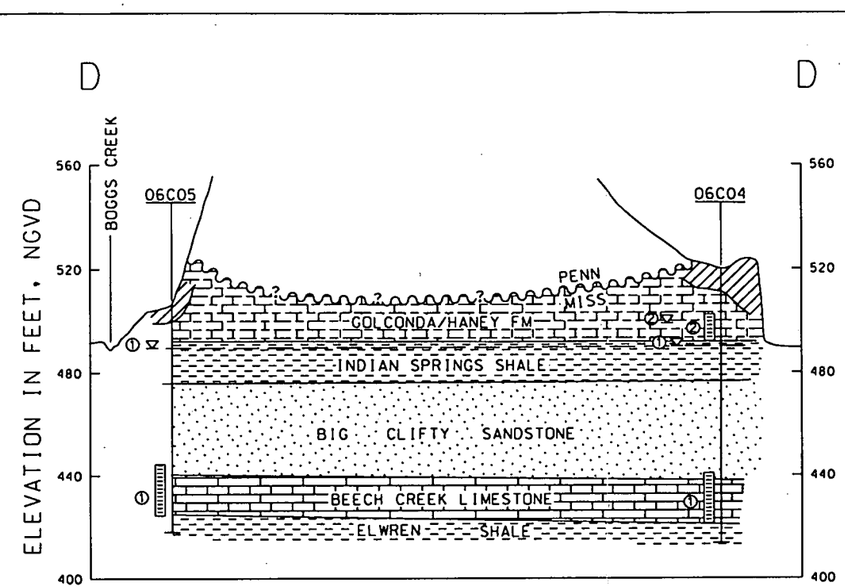
U.S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION
VICKSBURG, MISSISSIPPI
Demolition Area / Old Rifle Range
Geologic Cross-Section B-B
0
400
HORIZ. SCALE, FT
Plate 6

00C341E00X





LEGEND

- SOIL OVERBURDEN
- SHALEY SANDSTONE
- SANDSTONE
- CONGLOMERATE
- SHALE
- COAL
- LIMESTONE & SHALE
- LIMESTONE

- WATER LEVEL FOR CORRESPONDING WELL SCREEN (MAY-JUNE 1991)
- WELL SCREEN NUMBER AND LOCATION
- MISS-PENN CONTACT
- 06C04 WELL CLUSTER NUMBER
- WATER TABLE/ PIEZOMETRIC SURFACE

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CRANE DIVISION - CRANE, INDIANA

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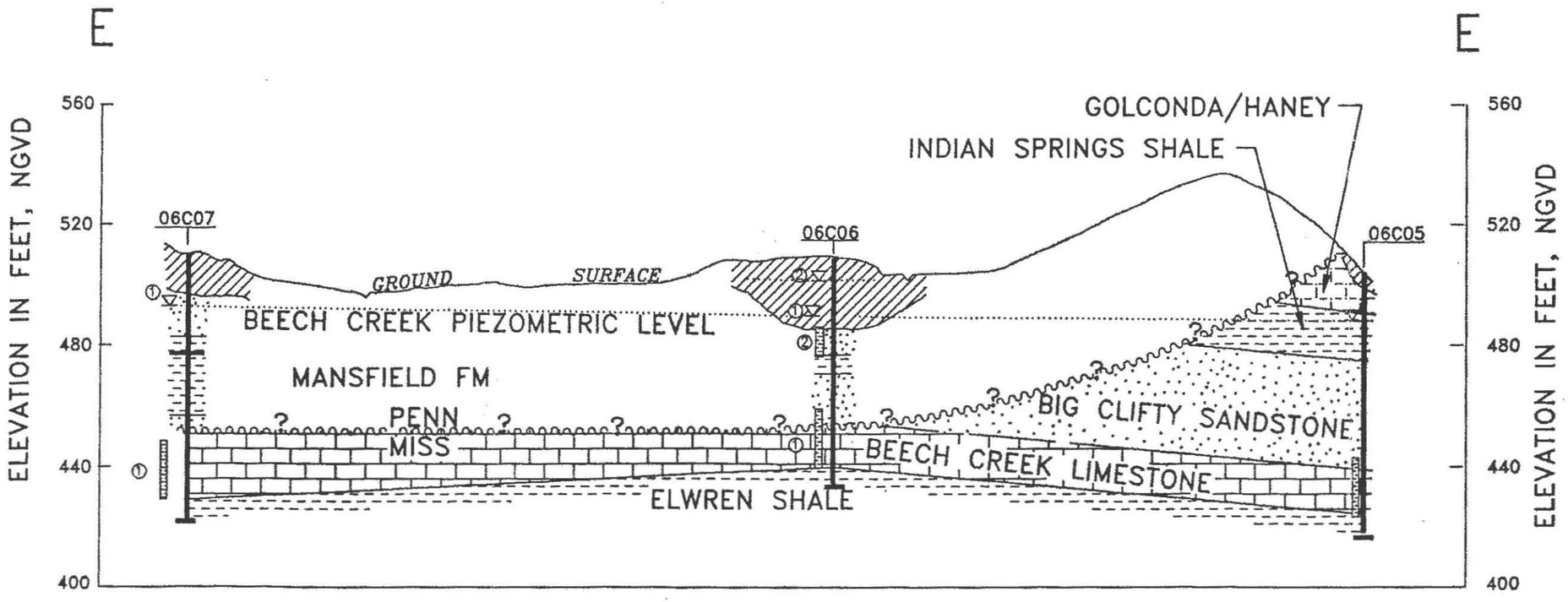
VICKSBURG, MISSISSIPPI

Demolition Area / Old Rifle Range
Geologic Cross-Sections
C-C and D-D

0 500
SCALE, FT

Plate 7



LEGEND

- SOIL OVERBURDEN
- SHALEY SANDSTONE
- SANDSTONE
- CONGLOMERATE
- SHALE
- COAL
- LIMESTONE & SHALE
- LIMESTONE
- ① ▽ WATER LEVEL FOR CORRESPONDING WELL SCREEN (MAY–JUNE 1991)
- ① WELL SCREEN NUMBER AND LOCATION
- MISS–PENN CONTACT
- 06C12 WELL CLUSTER NUMBER
- WATER TABLE/PIEZOMETRIC SURFACE

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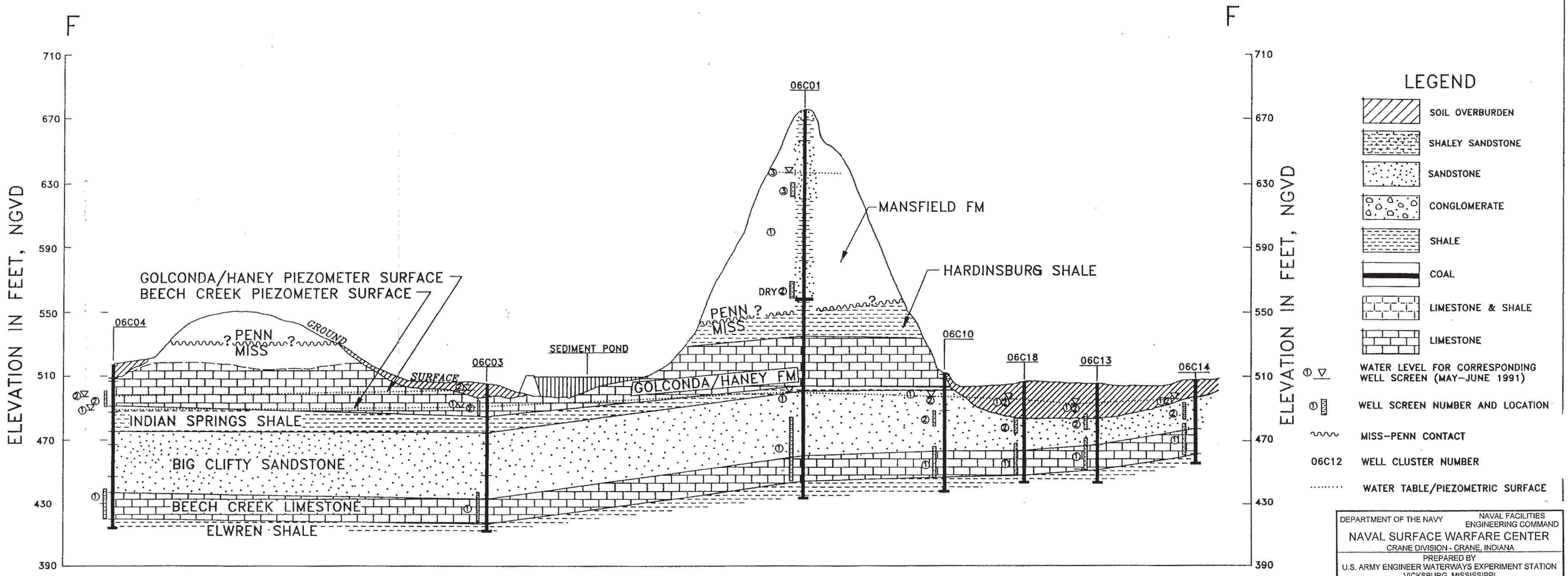
Demolition Area / Old Rifle Range
Geologic Cross-Section E-E

0 400
HORIZ. SCALE, FT

Plate 8



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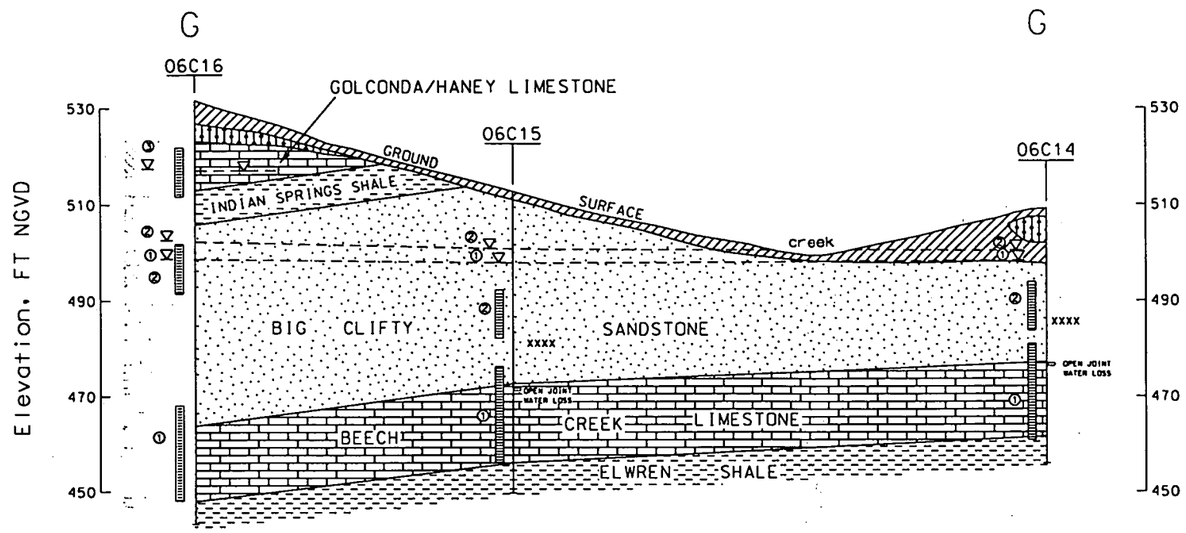
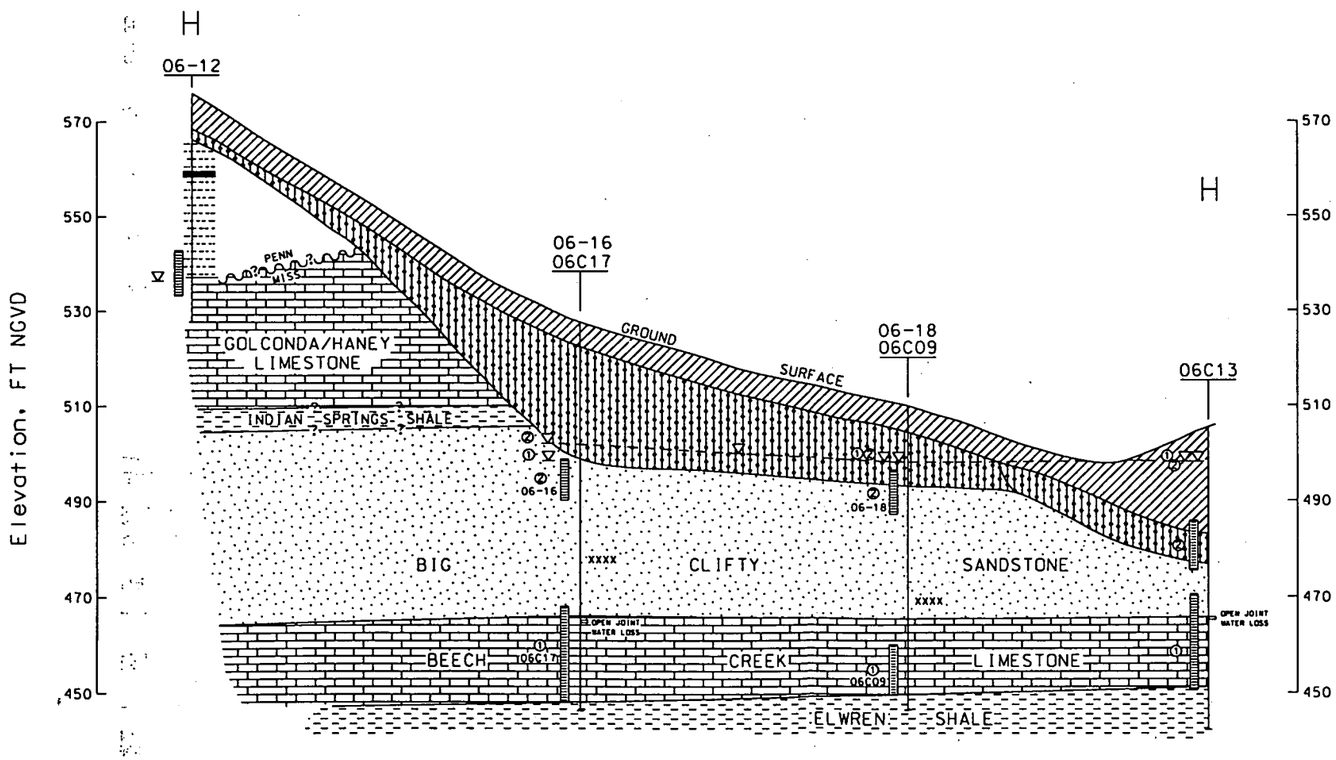
Demolition Area / Old Rifle Range
Geologic Cross-Section F-F

0 400
SCALE, FT

Plate 9

000341F01X





LEGEND

- CL (LEAN CLAY)
- GM (SILTY GRAVEL)
- SHALE
- SANDSTONE
- LIMESTONE
- COAL
- WATER LEVEL FOR CORRESPONDING WELL SCREEN
- WELL SCREEN NUMBER/POSITION
- 06C14 WELL CLUSTER NUMBER
- WATER TABLE/ PIEZO. SURFACE
- XXXX ZONE OF OXIDATION
- MISS-PENN CONTACT

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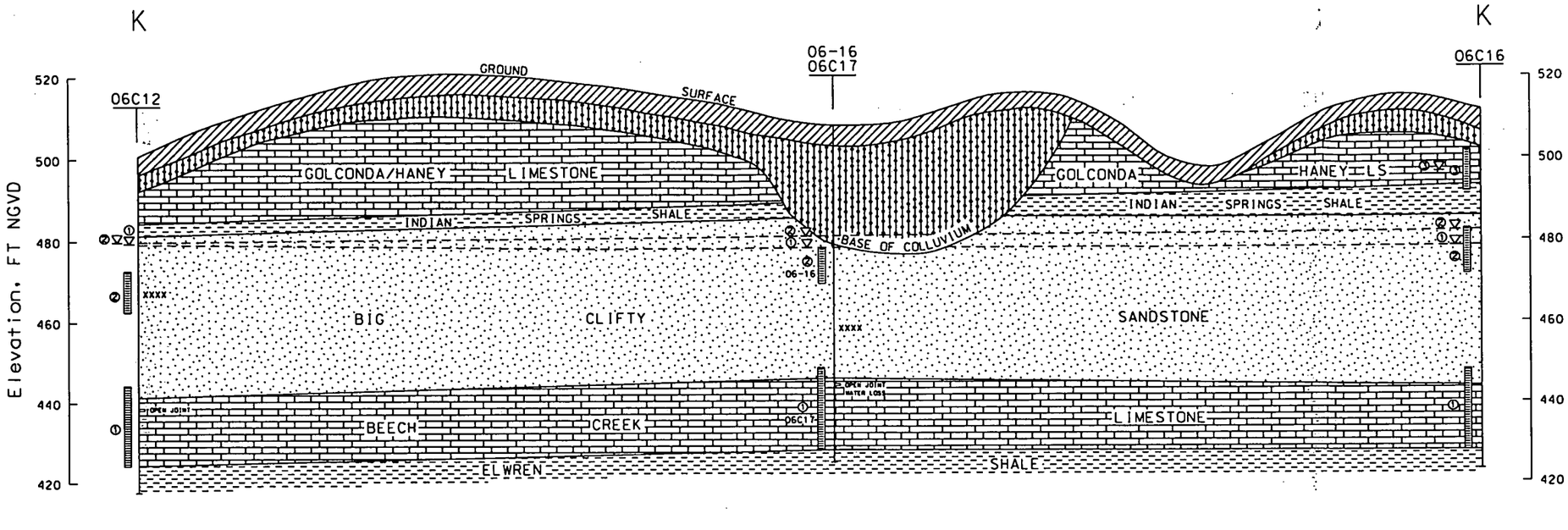
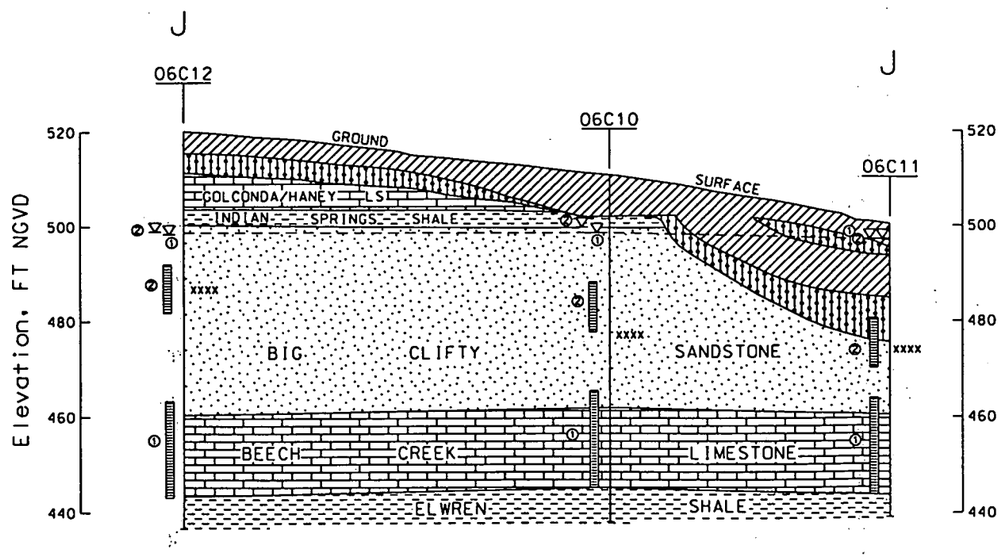
Old Rifle Range
Geologic Cross-Sections
G-G and H-H

0 100
HORIZ. SCALE, FT

Plate 10





LEGEND

- CL (LEAN CLAY)
- GM (SILTY GRAVEL)
- SHALE
- SANDSTONE
- LIMESTONE
- COAL
- WATER LEVEL FOR CORRESPONDING WELL SCREEN
- WELL SCREEN NUMBER/POSITION
- 06C14 WELL CLUSTER NUMBER
- WATER TABLE/ PIEZO. SURFACE
- xxxx ZONE OF OXIDATION
- MISS-PENN CONTACT

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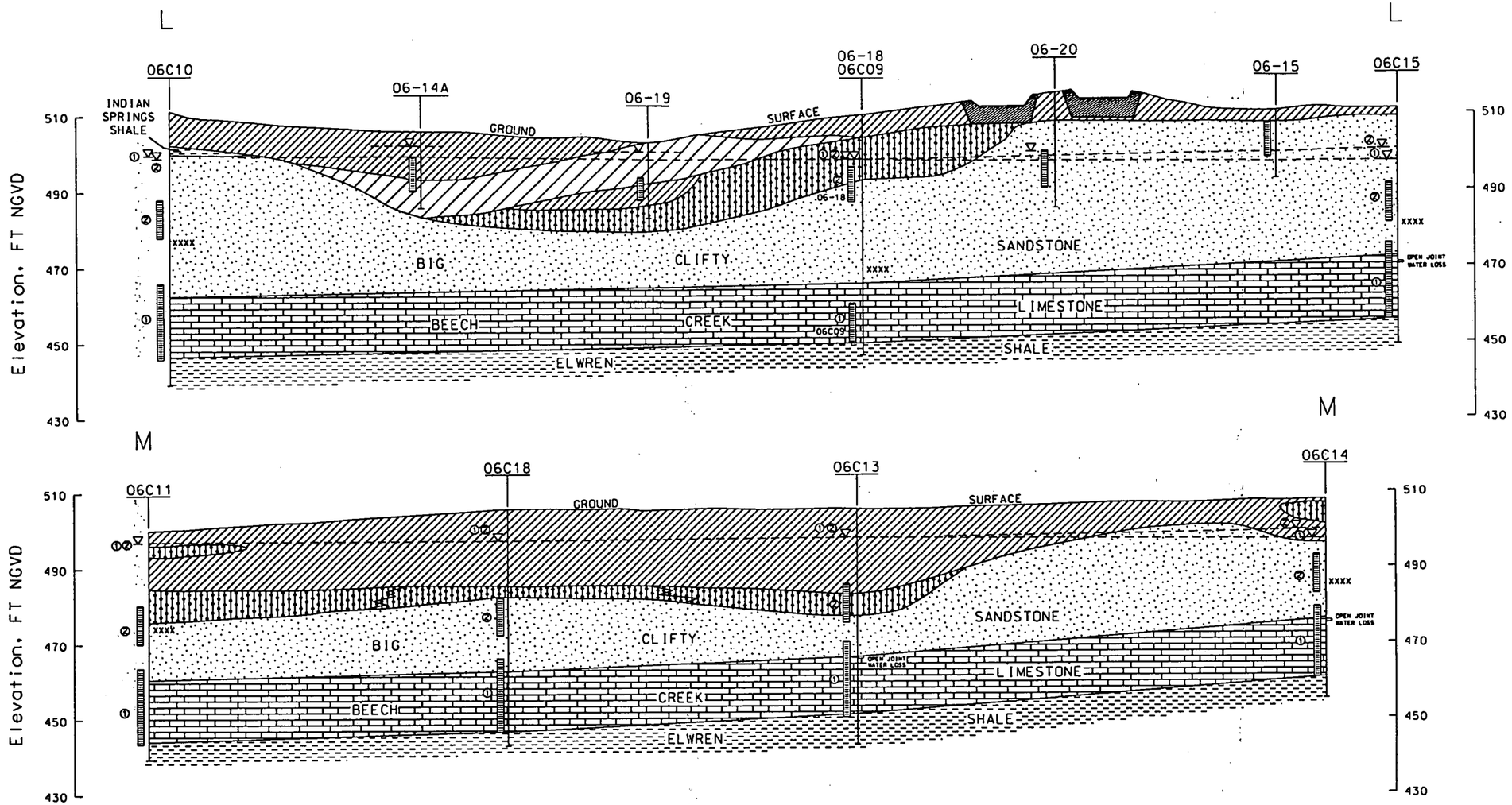
VICKSBURG, MISSISSIPPI

Old Rifle Range Geologic Cross-Sections J-J and K-K

0 — 100
HORIZ. SCALE, FT

Plate 11



LEGEND

- CL (LEAN CLAY)
- CH (PLASTIC CLAY)
- GM (SILTY GRAVEL)
- SM (SILTY SAND)
- SHALE
- SANDSTONE
- LIMESTONE
- COAL
- WATER LEVEL FOR CORRESPONDING WELL SCREEN
- WELL SCREEN NUMBER/POSITION
- 06C14 WELL CLUSTER NUMBER
- WATER TABLE/ PIEZO. SURFACE
- xxxx ZONE OF OXIDATION
- MISS-PENN CONTACT

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Old Rifle Range
Geologic Cross-Sections
L-L and M-M

0 — 100
HORIZ. SCALE, FT

Plate 12

REPORT DOCUMENTATION PAGE

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12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A Resource Conservation and Recovery Act Facility Investigation for groundwater was conducted at the Demolition Area and Old Rifle Range, Naval Surface Warfare Center Crane, Indiana. The Demolition Area renders waste munitions inoperative by detonation in trenches and pits. The Old Rifle Range is used for open burning of explosives. Monitoring wells and borings supplied subsurface geological information to develop the hydrogeology of the sites. Wells were sampled periodically for most Appendix IX constituents and explosives. Four aquifers or water-bearing zones were monitored at the Demolition Area and Old Rifle Range. Groundwater flow in the Big Clifty/Beech Creek aquifer is generally to the south and southwest but locally, in the vicinity of the Old Rifle Range, flows to the east toward Turkey Creek. Groundwater in the Golconda/Haney limestone is restricted to the eastern side of the Demolition Area. Flow in the Golconda/Haney is mainly to the south and southwest. Groundwater in the shallow aquifer atop the Demolition Area is confined in isolated perched zones. Inorganic compounds were detected in monitoring wells at the Demolition Area. Certain explosives compounds were found in addition to inorganics at the Old Rifle Range. Organics other than explosives were not present in significant or verifiable quantities in three rounds of sampling and analysis.

14. SUBJECT TERMS

Crane	Groundwater sampling	Navy
Explosives	Hazardous waste	RCRA
Geology	Hydrogeology	Wells
Groundwater	Military Explosives	
Groundwater contamination	Monitoring Wells	

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