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of Engineers
Waterways Experiment
Station

Final Report: RCRA Facility Investigation, Phase III Groundwater Release Characterization, SWMU 10/15 Rockeye Facility, Naval Surface Warfare Center Crane, Indiana

Volume I: Main Text, Figures, Tables, and Plates

by *William L. Murphy, Roy Wade, WES*
Mark Barnhill, Indiana Geological Survey

WES

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Final report

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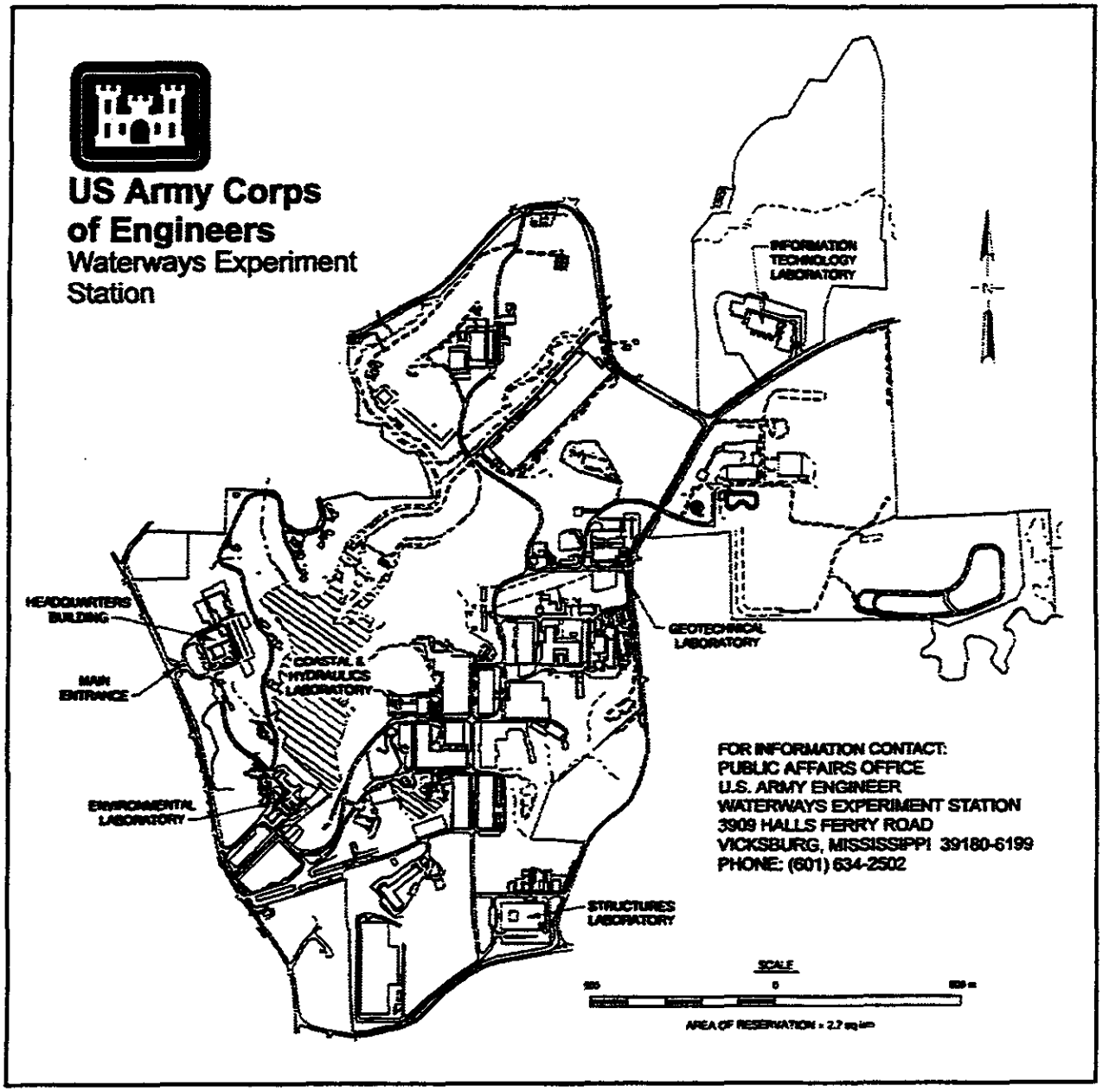

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Preface

This investigation was begun in July 1988 by the U.S. Army 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 was performed under authority provided by several NAVCOMPT documents, funding made available through the Navy's Installation Restoration Program, Defense Environmental Restoration Account (DERA).

Most of the geologic field work, including mapping and subsurface exploration by core logging, was performed by Mr. Richard W. Hunt, geologist, of the Engineering Geology Branch (EGB), Geotechnical Laboratory (GL), WES. Mr. William L. Murphy of 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 Mr. Eric Kvale of the Indiana Geological Survey, Indiana University, Bloomington, IN. Mr. Mark Barnhill, Indiana Geological Survey, provided additional interpretation of core samples, identification of stratigraphic units, and interpretation of facies relationships, and coauthored the report. Groundwater quality sampling and data validation were performed by Mr. Roy Wade, 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 Mr. Murphy, Mr. Wade and Mr. Barnhill. Mr. Thomas Brent of Naval Surface Warfare Center Crane (NSWCC), Indiana, Environmental Protection Department, provided logistical and technical assistance. Mr. James Hunsicker was Manager, Environmental Protection Department, Crane. Messrs. Jeffrey Ciocco, Byron Brant, and Bill Schrock, formerly of Northern Division, and Ms. Adrienne Townsel-Wilson of 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. Dr. Robert W. Whalin was Technical Director of WES.

This report is submitted in accordance with the RFI Phase III Release Characterization Work Plan for Groundwater, Rockeye. The report complies with USEPA portion of the RCRA Permit for Corrective Action.

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During the publication of this report, Dr. Robert W. Whalin was Technical Director of WES. COL Robin R. Cababa, EN, was Commander.

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Executive Summary

This report documents the Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI), Phase III Release Characterization for Groundwater, Solid Waste Management Unit (SWMU) 10/15 Rockeye Facility, at the NSWCC. The investigation was conducted in the period July, 1988 to September,1993. Data from earlier investigations was incorporated.

The purpose of the RFI 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 Rockeye Facility. The RFI fulfills Corrective Action requirements for the SWMU 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 Rockeye Facility, have the potential, primarily from past operations, for releasing contaminants to the groundwater.

The Rockeye Facility occupies approximately 40 acres atop a ridge in the northeastern portion of the NSWCC adjacent to Crane Highway 45. The facility has been used in the loading and filling of projectiles and Rockeye bombs and has generated wastewater from washdown and melt and pour operations. Past operations have discharged explosives-contaminated wastes to the ground surface and into drainageways flowing away from the facility.

Monitoring of the groundwater for chemical constituents began in November, 1981 with the installation of monitoring wells at the sites. Twenty-four wells were installed between 1981 and 1983 for a confirmation study, and an additional 83 wells were installed beginning in 1988. Subsurface geological information extracted from logs of the core and other boring samples was used to develop the hydrogeology of the site. Monitoring wells consisted of PVC slotted screens set at depths varying from 23 to 288 ft. Wells were sampled by NSWCC contractor for selected contaminants prior to 1989 and by WES beginning in 1989 for most Appendix IX constituents and explosives.

Several aquifers or water-bearing zones were monitored in the Rockeye study area. The Beech Creek limestone, a Mississippian formation dipping gently to the southwest and which occurs consistently beneath much of NSWCC, and other Mississippian aquifers were monitored by five wells. All other monitoring wells screened sandstones and coals of Pennsylvanian age underlying the Rockeye Facility and the surrounding ridge tops.

Groundwater flow in the lower of the Pennsylvanian aquifers is radially away from a groundwater high in the southeast corner of the facility. The middle and upper aquifers merge in the northern half of the facility. Flow in the middle and upper aquifers is primarily to the northeast, with components of flow radially away from highs in the southwest and southeast corners. Surface flow away from the operations area is to the northeast and southeast. The upper and middle aquifers are intercepted by the surface drainageways below the ridge to the northeast and southeast.

Operations at Rockeye have contaminated the shallow aquifer beneath the facility and the surface drainageway to the northeast. Contaminants were primarily the explosives compounds RDX, HMX and TNT. Detected levels of explosives in the groundwater were below 1.0 mg/l. Metals were present in the groundwater but, with the possible exception of barium, are interpreted to be natural constituents of the rock. The concentrations of some metals were exacerbated by unusually low pH produced in the Pennsylvanian depositional environment. Some metals were detected at levels above MCLs for drinking water.

Potential receptors of groundwater originating at the Rockeye Facility include Sulphur, Turkey and First Creeks to the northeast, southwest and west, respectively, and Lake Greenwood, which is fed by First Creek. Aquifers exposed in the valley of Sulphur Creek and its western tributary downslope of Rockeye are potential receptors of contaminants. No explosives were detected beyond wells located about 3,500 ft downslope of the facility to the northeast.

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
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

Conversion Factors, Non-SI to SI Units of Measurement

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

Multiply	By	To Obtain
acres	4,046.873	square meters
feet	0.3048	meters
feet per mile	0.1893935	meters per kilometer
inches	2.34	centimeters
miles (U.S. statute)	1.609347	kilometers

1 Introduction

Purpose

This report documents field and laboratory work conducted for the Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI), Phase III Release Characterization for Groundwater, of the Solid Waste Management Unit (SWMU) Rockeye Facility, SWMU 10/15, Naval Surface Warfare Center, Crane Division, Crane, Indiana (NSWCC).

The purpose of the RFI was to determine the presence or absence, nature, and the rate and extent of migration and the concentrations, of hazardous wastes or hazardous constituents released into the groundwater. The Phase III RFI determined the extent of the release to groundwater and the horizontal and vertical distribution of contaminants.

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. The NSWCC provides material, technical, and logistic support to the Navy for equipment, weapons systems, and expendable and non-expendable ordnance items. The facility was opened in 1941 as the U.S. Naval Ammunition Depot, Burns City, Indiana and renamed The U.S. Naval Ammunition Depot Crane, Burns City, Indiana in 1943. Its mission was to serve as an inland munition production and storage center for all types of ammunition, including pyrotechnics and illuminating projectiles. As the complexity of weapons increased, the facility became more involved in the technical aspects of weaponry through the development of test methods, procedures, and equipment, while the facility's basic mission remained the same. The facility name was changed to the Naval Weapons Support Center Crane in 1975 and again changed to the Naval Surface Warfare Center, Crane Division in 1991. The Department of Defense (DOD) appointed the U.S. Army as the Single Manager for Conventional Ammunition in 1977. The Army has assumed ordnance production, storage, and related

responsibilities under this single service management directive. All environmental activities on the installation, including permitting activities, remain 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 installation. 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 disposal 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. The IRP consists of four major steps; (1) Preliminary Assessment (formerly IAS), (2) Site Inspection (formerly Confirmation Study), (3) Remedial Investigation/Feasibility Study (RI/FS), and (4) Remedial Design/Remedial Action (RD/RA).

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 Rockeye Facility as requiring further investigation because of the potential to introduce explosive contaminants created by past wastewater discharges to both surface and groundwater.

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 Rockeye Facility 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 Rockeye 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 two

groundwater monitoring wells in November, 1981 at the Rockeye Facility (Locations on Plate 1, Wells "10-01" and "10-02") and provided a report in April, 1982 (Dunbar 1982). The report was not published, but the text of the report pertaining to the Rockeye Facility, the accompanying well logs and the well installation diagrams are included as Appendix A of this report. An additional 24 groundwater monitoring wells (Locations on Plate 1, Wells "10-03" through "10-22") were installed by the WES from July to September, 1983. Results of the 1983 work were reported by Dunbar (Dunbar 1984), also as an unpublished report. Pertinent portions of Dunbar's 1984 report are included in this report as Appendix B. A RFI Phase II Soils Investigation at the Rockeye Facility was conducted by the U.S. Army Corps of Engineers in September and October of 1990. A report of the results was prepared by the WES and currently exists in draft form (USAEWES 1991).

The Hazardous and Solid Waste Amendments (HSWA) of RCRA established corrective actions programs (CAP), Section 3004, at TSD facilities. The provision required the NSWCC to address past releases of hazardous waste or hazardous constituents at 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 all of the IAS-identified hazardous waste sites as SWMUs, and was submitted to the USEPA in January 1985. The next step of the CAP, a RCRA Facility Assessment (RFA), was conducted by A. T. Kearney, an USEPA contractor. The contractor conducted a file search of the facility and a site visitation and prepared a report in 1987 which characterized possible releases from 100 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 the RFI Phase III Groundwater Investigation at the Rockeye Facility in July, 1988 by the drilling of two borings and the drilling and installation of eighty-three (83) additional groundwater monitoring wells (Locations on Plate 2, "10C23" through "10C61"). Cluster wells are located at well sites 10C23 through 10C53 and at 10C55 (See Plate 2). These cluster well sites have from two to four wells at each location. Continuous-core sampling at the deep well boring at each cluster provided subsurface data for a hydrologic assessment of the area. Well sampling and analysis for water quality began in 1983. From 1983 through 1989, water quality was analyzed mainly for explosives and some general water quality parameters. Water quality analysis on samples retrieved in March, 1991, June, 1991, and January, 1992 included most Appendix IX compounds and explosives.

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 Hazardous and Solid Waste Corrective Action Requirements and Compliance Schedules (RCRA Section 3004). 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 established a compliance schedule under which the RFI Phase II Soil and Phase III Groundwater work plans/reports for the Rockeye Facility would be submitted to the EPA.

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.

Scope

The information and discussion in this report pertains to the facility known as the Rockeye Facility (SWMU 10/15), of the NSWCC. 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 as needed. Laboratory chemical analysis methods discussed in this report generally followed the United States Environmental Protection Agency (USEPA) protocol for RCRA Facility Investigations and are applicable to other RCRA facility investigations with modification for site-specific requirements.

Operational History and Description of the Rockeye Facility

Rockeye is a 40-acre tract located in the north central portion of the NSWCC in the SE 1/4 of Section 5, T5N, R3W (see Figure 2). The area is located on Highway 45, approximately two miles south of North Gate #1. It is situated on a flattened ridge crest which separates the headwater drainages of Sulphur Creek, First Creek, and Turkey Creek (see Plate 1). Drainage to the north and east flows into Sulphur Creek, drainage to the south flows into Turkey Creek, and drainage to the west flows into First Creek and thence into Lake Greenwood. Figure 3A is a high-altitude color infrared aerial photograph (reproduced in monochrome) showing the Rockeye Facility and surrounding area. The photograph was taken in May of 1988. Figure 3B is an oblique aerial view of the facility taken in April of 1981, looking north-northwest.

The Rockeye Facility began operation in the mid-1950's as a press loading operation for 3-inch projectiles using Composition A-3 explosive (RDX and wax). In 1967-68, the Rockeye Facility was converted to a case-filling operation in order to produce the MK20 series anti-tank Rockeye cluster bomb. The explosive material in Rockeye bombs is Octol Compound B (RDX, HMX, TNT, and wax) high explosive. As part of the loading operation, the system generates a large volume of wastewater, primarily from bomblet and tray

washdown and from melt and pour operations in Buildings 2731 and 2734 (Plate 2). The wastewater was collected in four sumps which were periodically pumped. After pumping, the remaining residue was sent to the Ammunition Burning Grounds for disposal. Prior to 1978, explosive-contaminated waters were discharged, from full sumps, directly into local surface drainage pathways. Red-colored "pink water" from washdown operations was observed in drainageway surface waters in 1977, prior to installation of a treatment facility. On the north side of the facility, the waters were released to a headwater branch of Sulphur Creek. On the south side, the waters were released to a headwater branch of Turkey Creek (See Plate 2, Surface Drainage "North" and "South"). Discharges with TNT concentrations as high as 50 ppm have been detected at these discharge points. In the Spring of 1978, an activated carbon water treatment facility, located in building 3044 (See Plate 2), was brought into operation to purify the wastewater for recycled usage. In addition to a water treatment system, a scrubber system to remove contaminated particles in the steam-fed tray wash area was designed and installed. In the tray wash area, explosive contaminated trays are steam cleaned. Before the scrubber was installed, emissions were discharged directly to the atmosphere. With the installation of the pollution abatement equipment, the release of explosive contaminated waters has declined.

Groundwater contamination (explosives) was detected at the Rockeye Facility through groundwater quality monitoring during the 1983 groundwater sampling program (HMTC 1985). Subsequent monitoring has revealed various levels of groundwater contamination in the area.

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 CMS. The discussion in Part II of this report 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 USEPA to be indicators for protection of human health and the environment. The USEPA 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 level [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 USEPA 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 USEPA believes it should

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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 USEPA's intention that the action level "trigger" approach serve to identify the need for initiating a CMS early in the process. Such studies should typically not be delayed until the completion of the remedial investigation. In many instances, it will be appropriate to conduct the facility RFI and CMS simultaneously.

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 USEPA 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 USEPA has promulgated health-based standards appropriate for action levels for specific media. Where these standards are available, the USEPA intends to use them as action levels. The most obvious of these are MCLs. The USEPA 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 USEPA intends to broadly define the type of groundwater contamination situations that may require a CMS, However, the intention is to "trigger" such studies only in situations where actual groundwater cleanup is a reasonable remedial approach. The USEPA 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. Therefore, the wording of the proposed rule will also allow the USEPA 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 the USEPA for protection of environmental media (Table 2). Where an MCL is available for a particular constituent found in groundwater not currently being used for a drinking water supply, and unlikely to be used as a drinking water supply in the future, the MCL will still ordinarily be used as an action level. However, cleanup to the MCL might not be required. In cases where groundwater is contaminated at a level above the action level, further study is necessary to make sure that sources of releases are controlled.

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

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3 Investigation Methods and Rationale

Exploratory Drilling and Well Installation Methods

Monitoring wells installed 1988 and 1989

The locations of the 31 monitoring well clusters and the 6 single monitoring wells (total of 83 monitoring wells) installed as a part of the RFI Phase III Release Characterization for Groundwater for the Rockeye Facility are shown on Plates 1 and 2. The well numbers are designated by "10" followed by "C" to distinguish them from the confirmation wells installed prior to 1988. The deepest well (deepest intake screen placement) of a cluster is designated with a "C" followed by the cluster number (for example "10C25"). Progressively shallower wells of each cluster are designated by a "10C" followed by the well number "P2" or "P3" or "P4." The higher digit after the "P" is the uppermost (shallow) well of each cluster (for example "10C41P3"). Because of the proximity of wells in a cluster, only the deep well is shown on the location maps.

Seventeen of the clusters consist of paired wells, one deep and one shallow well. Thirteen are three-well clusters, one is a four-well cluster, and there are six single wells. The first and deepest well at each drill site or cluster site was logged by a geologist on-site by the examination of continuous rock cores retrieved with a rotary wireline core barrel. The overburden soil was logged by the 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, resp.) coordinates, in feet, were reported in Indiana State Plane Coordinates, North American Datum (NAD) 1927, which allowed plotting the 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 hundredths of a foot NGVD (National Geodetic Vertical Datum). Table 3 lists available well data for all Rockeye Facility wells, including the pre-1988 wells. Table 4 lists the survey data for all Rockeye Facility wells.

Monitoring well locations were selected to provide sufficient areal coverage to characterize the subsurface hydrogeology at and around the site and were

completed at a sufficient depth to determine the vertical extent of potential contamination. Wells at the site were placed at a sufficient density to provide an adequate amount of data for the needs of a Phase III groundwater characterization of the site (See Plate 2). Four monitoring wells and two borings without wells (10C58 and 10C59) were placed at locations east of the Rockeye Facility, along or adjacent to headwater tributaries of Sulphur Creek, the primary surface water recipient of runoff from the Rockeye operations area (See Plate 1).

The general stratigraphy and hydrologic characteristics of the geologic formations at the site were known from pre-1988 investigations. The positions of water-bearing strata (aquifers) at the Rockeye Facility were further defined by continuously logging the first deep well at each cluster and other individual deep monitoring wells. Decisions on the positioning of well screens for monitoring purposes were based on data retrieved during the drilling of the first well boring and refined with consideration of the data retrieved from subsequent borings.

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, and at other individual monitoring wells/borings, soil overburden was penetrated and sampled to refusal depth (top of rock) using a 10-in. flight auger. Rock was then drilled and sampled using an HQ wireline core barrel. If the depth to auger refusal was less than 10.5 ft (the depth needed to insert the HQ barrel), a roller-rock bit was used to advance the boring to the required 10.5-ft depth as the geologist logged the subsurface materials encountered. The HQ wireline core barrel retrieves a 2-1/2 in. diameter core and produces a 3-25/32 in. diameter borehole. Subsequent well borings of a monitoring well 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 C.

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 wells. Drilling was conducted with clean water obtained from the water treatment plant at NSWCC. No other drilling fluids or additives were introduced into the borings. 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 from lower zones to prevent potential cross-contamination of the separate aquifers. When this occurred, PVC casing was grouted a distance of 2 to 5 ft into a relatively impervious bed that

underlay each aquifer and the grout allowed to set overnight. When drilling into a lower aquifer, the procedure used to "seal off" the higher aquifer was to set a 6 in. or 4 in. diam PVC casing through an 8 in. PVC casing (used to seal off surface soils) into the relatively impervious bed just beneath the upper aquifer zone. The casing isolated the upper aquifer from any lower aquifers encountered. If more than one additional aquifer was encountered beneath the upper aquifer, a 4 in. diam PVC casing was set through the 6 in. diam casing into the relatively impervious bed just beneath the middle aquifer zone. The lower aquifer was then screened within the open borehole, isolated from the other two aquifers by the 6 in. and 4 in. diam casings. Each casing was grouted up through the higher, previously set casing. 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.

Figure 4 illustrates the typical procedures used for progressive casing and sealing of deep borings that penetrated more than two aquifers. Monitoring well cluster 10C37 is used to illustrate this procedure. After coring to a depth of 36 ft and penetrating the uppermost water-producing zone, the boring was reamed out. 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. diam PVC casing was then set in the hole to 36 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 grout within the casing.

After the 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. diam, 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 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.

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. The bottoms of the well screens were terminated with a threaded PVC plug. The top of each well has a vented PVC cap. The riser pipe is protected at the surface by 3 in. diameter steel pipes fitted with locking caps and grouted 3-1/2 ft inside the 4-in., 6-in. and 8-in. diam PVC surface casings. Well installations for the cluster 10C37 illustrate the installation procedures for the Rockeye Facility (see Figure 4).

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. 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-installation diagrams are included at the back of each well log in Appendix C.

Well development

The procedure for developing the wells consisted of bailing well water, alternated 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 process was 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. diameter, 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 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 the Rockeye study area wells were recorded during July 1989, March 1991, June 1991, January 1992, and May 1992. All the acquired water level data for these wells is presented in Table 5. Water level measurements were used to construct groundwater surface contour maps, which are discussed later in this report.

Monitoring Well Sampling and Analysis for Groundwater Contamination

Selection of background wells

Background wells for the statistical analysis of metals were selected by studying the contour maps of mean levels of metals in wells in the upper and lower aquifers and the tabulated mean levels of metals for each well (presented in a later section). Well clusters 10C42/10C42P2, 10C43/10C43P2, and 10C52/10-03 were selected as background wells. All of the background wells were located south of the Rockeye facility, outside the boundary fence (see Plate 2). the wells also are generally in areas of groundwater highs, i.e., upgradient, as shown on the water level contour maps in a later section. The six wells selected had low mean levels of metals, relative to other wells. Well cluster 10C37/10C37P2, located off-site to the southwest, was considered, but the upper well of the cluster was relatively high in several metals, including barium, beryllium, copper, lead, manganese and zinc, and the cluster was dismissed from consideration as background.

Selection of groundwater contamination parameters

An extensive list of contamination parameters was developed for the RFI work at the Rockeye Facility 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 (Federal Register 1990). The parameter list was amended to include explosives compounds. Five rounds of sampling were originally scheduled. 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, nitrogen compounds, cyanide/sulfide and explosives.

A list of the modified Appendix IX groundwater quality parameters monitored at Rockeye and detection limits is provided in Table 6.

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. The possibility of external sources of contamination to the samples was eliminated through the use of good sampling techniques.

The following sections describe the field sampling procedures followed for groundwater sampling at Rockeye.

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 its pre-drilling condition.

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 Rockeye wells.

The water level and the well depth of each well were taken using an M-Scope brand water level indicator incremented in hundredths of a foot (see Appendix D 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 water 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 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.

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 D). The equations used for calculating purged volumes of water in a 2-in. diameter well are as follows:

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

where

A = volume of water in well, cu ft

B = volume of water in well, gals

d = diam. 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, which was lowered into the well with a spool of Teflon coated cable, or by immersing a 2-in. submersible pump with flow adjustment. The pump 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 analytical results to be qualified as suspect if equipment rinsate 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 metal 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 D).

The appropriate preservative was added to the collected sample and the container cap was securely fastened. Samples were labeled by facility (SWMU), 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 decontamination, 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 7a. 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 5 and 6, 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 volatile 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 ten samples per matrix.[1] All the duplicates were sent to the primary laboratory responsible for analysis. Samples used as field duplicates were split by the laboratory and used as the laboratory duplicate or matrix spike. Thus, for the duplicate sample, there were analyses of the normal sample, the field duplicate, and the laboratory matrix spike/ duplicate.

Blind samples were collected simultaneously with the water sample at a frequency of one blind sample per ten 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 7b lists well numbers from which blind samples were collected for the four sampling rounds. Well numbers assigned to blind samples were fictitious (e.g., Blind Sample well number 10C28P4 of Round 1, Table 7b, 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.).

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

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4 Hydrogeology of the Rockeye Facility

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 83 RFI and the 24 confirmation borings and wells emplaced in the Rockeye study area. The lithology, stratigraphy and geologic structure of the study area were defined from the extensive and continuous rock core recovered in the deep well of each RFI well cluster and from core recovered 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. An additional geologic interpretation of the Pennsylvanian section at Rockeye was provided by the Indiana Geological Survey (the Survey) through detailed analysis of the core recovered in the RFI boring program. The system of closely spaced boreholes and extensive coring at the Rockeye Facility provided a large database for detailed subsurface analysis of the stratigraphy, sedimentology, and characteristics of potential reservoir rocks (aquifers) beneath the site. The Survey has extensive knowledge of and experience in the Pennsylvanian section of Indiana and provided invaluable assistance in the interpretation of the Rockeye Facility and surrounding area. The Survey also conducted aquifer tests and geophysical surveying of Rockeye wells and described the relationship between the hydrogeologic properties and the sedimentary facies present.

The confirmation work performed in 1981 through 1984 emplaced relatively shallow borings and wells around and downslope of the Rockeye Facility. Confirmation borings were less than 50 ft deep and were emplaced outside of the boundary fence surrounding the operations area of Rockeye. The RFI expanded on the earlier effort by emplacing borings and wells on a rough grid pattern in and around the operations area, including twelve well clusters inside the Rockeye boundary fence. RFI borings were as deep as 288 ft, but most often 100 ft or less in depth. The purpose of the gridded, relatively dense pattern of well clusters was to adequately sample the laterally and vertically variable, stratigraphically complex Pennsylvanian sequences beneath the Rockeye Facility. The approximately 400 ft spacing between wells was

considered minimal to sufficiently characterize the subsurface. Two borings were extended into the Mississippian units beneath the site to permit determination of structural trends across NSWCC by correlating identifiable and persistent geologic units (like the Beech Creek limestone) from site to site. Well clusters commonly consisted of three wells per cluster screened in uppermost, middle, and lower groundwater zones. With the exception of deep well 10C40, the deepest zone screened was a sandstone underlain by a laterally persistent and uniformly thick shale. The shale was shown by the two deep borings at Rockeye to be approximately 10 ft thick and was adopted as the base of investigations for groundwater characterization of the site. The lateral and vertical variability in lithology and stratigraphy of the Pennsylvanian units at Rockeye made delineating aquifers difficult. Nevertheless, each well screen emplacement was assigned to a lower, middle or upper aquifer, primarily on the basis of the piezometric level within each well. Each aquifer, in turn, was correlated as much as possible to stratigraphic units defined by the Survey in their core analysis.

Probable flow paths of groundwater beneath the Rockeye facility were interpreted from contour maps of piezometric levels in each well recorded during groundwater sampling events. Average flow gradients were also calculated from the piezometric contour maps.

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 7. 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 escarpment. 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 mean sea level (M.S.L.) to greater than 850 ft M.S.L. Relief on the upland varies from about 100 ft to 350 ft, with higher elevations and greater relief generally occurring 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 8. 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

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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 9. The Rockeye facility is located on the drainage divide between Basins III and IV, at the headwaters of Sulphur, First, and Turkey Creeks.

Groundwater in the unglaciated southwest portion of Indiana is, in general, contained in joint openings of limestone and sandstone aquifers. In the area of the Crawford Upland (Figure 7), 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. Because the regional dip of the strata is to the southwest, the regional flow pattern of groundwater in each aquifer is also to the southwest.

Regional geologic structure

The state of Indiana and the 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 10. 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 accumulation of the sedimentary rock ranges 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/mile.

Recent mapping of the base of the Beech Creek limestone in Martin County by the Survey (1980, revised 1991) produced a structural contour map of the area. Figure 11 is a rendition of the northern half of the Survey's map, which includes the NSWCC. The structure contours represent the elevation of the base of the Beech Creek limestone. The Rockeye site is located at the northernmost cluster of borings northeast of Greenwood Lake. Local structural

anomalies exist within the NSWCC, but the Rockeye area is characterized by only a regular, west-southwest dip of approximately 35 ft/mile.

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 etal. 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 six miles SSW of the Rockeye Facility. The 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 and environments of deposition

The surface rocks underlying the NSWCC were deposited in the Lower Pennsylvanian and Upper Mississippian geologic time periods. A generalized stratigraphic column at the NSWCC is presented in Figure 12. 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. 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, coastal plains, 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 NSWCC. 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 study area for the Rockeye facility groundwater investigation is approximately as depicted on Plate 1. Primary surface drainage is along the ephemeral stream draining to the northeast and east into the northwest tributary of Sulphur Creek. The facility sits astride a major north-south drainage divide

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defined approximately by Highway 161 (see Plate 1 and Figure 9). Drainage east of the divide is to Sulphur Creek and thence south, passing off the reservation boundary approximately four miles downstream. Drainage west of the divide is into the headwaters of Turkey Creek to the southwest or to First Creek to the west, through Lake Greenwood. Turkey Creek flows through the middle of the NSWCC and leaves the Center approximately ten miles south of the Rockeye facility.

Ground surface elevations in the area range from 570 ft NGVD in the valley of Sulphur Creek in the southeast corner of Plate 1 to approximately 860 ft NGVD along the divide immediately south of the facility. The topography surrounding the facility is rugged and the terrain heavily vegetated. The Rockeye site was modified by the process of cut-and-fill in the early fifties to prepare the site for construction. Plates 3 and 4 display the original and post-construction topography, respectively, of the facility site. Profiles of the original and modified (present) surfaces are also shown on geologic cross sections accompanying this report. Slopes surrounding the facility are as steep as about 45 percent on the east, with local maximum relief of about 200 ft from the facility to the position of monitoring wells 10-01 and 10-02 along Highway 165 northeast of the facility. Present elevations within the Rockeye facility range from about 810 ft to 827 ft NGVD (elevations as high as 842 ft exist on the man-made berms surrounding some of the buildings).

Geologic units exposed in the study area

The surface exposures (with soil overburden disregarded) of mappable geologic units at the NSWCC was provided in a map constructed by Erik Kvale of the Survey (Kvale 1992). The map was constructed from field reconnaissance of outcrops within NSWCC, which included the Rockeye study area. That portion of the geologic map encompassing the study area is reproduced as Figure 13, showing only group contacts. The Pennsylvanian aged Raccoon Creek (probably Mansfield Formation), represented by the symbol ℘, occupies all of the study area above approximately 680 ft elevation, including all of the ridge on which the Rockeye facility is situated. Several Mississippian-aged units are exposed in the tributary and main valleys of Sulphur Creek to the east and in the headwaters of First and Turkey Creeks to the west of the facility. Mapped units appearing on the map of Figure 13 include, from youngest to oldest, the Quaternary and recent alluvium of Sulphur Creek (stippled pattern), the Mississippian formations of the Stephensport Group, consisting of the Glen Dean Limestone, the Hardinsburg Shale, the Golconda/Haney Limestone, the Indian Springs Shale Member, the Big Clifty Sandstone, and the Beech Creek Limestone (Stephensport Group of Figure 13), and the Elwren Shale, the Reelsville Limestone, and the upper part of the Sample Formation (West Baden Group of Figure 13). Plate 5 illustrates the subsurface geology of the Rockeye study area interpreted from well borings as a vertical cross section extending east-southeast from boring 10C40, located immediately northwest of Rockeye, down the northeast drainage way to the tributary of Sulphur Creek to boring 10C59 (inset map of Plate 5). Boring 10C59 penetrated the Beaver Bend Limestone, the deepest and oldest unit encountered. The cross section illustrates the westward component of dip of the Mississippian units and shows the

approximate positions of the interception of the unit contacts with the ground surface. Note that there is a 10:1 (vertical:horizontal) enhancement in the profile. The Pennsylvanian section occupies all of the upper elevation above boring 10C58. Selected Pennsylvanian units depicted in the profile, sandstones "A" and "B" and the "basal shale," are elaborated in the discussion below.

The majority of borings emplaced for the Rockeye study penetrated only Pennsylvanian aged rock units. Only seven of the 107 borings encountered Mississippian units. Most of the discussion in the following sections concerns Pennsylvanian units encountered from the ground surface to the "basal shale" of Plate 5.

Geology of the Rockeye Facility

Investigative methods for the Pennsylvanian sequence. The geologic units and potential qroundwater aquifers beneath Rockeye were sampled extensively by the more than 2,800 ft of diamond drill core recovered in the boring program. The geology at the Rockeye site was recognized early in the program as very complex both stratigraphically and sedimentologically. Lithologic units tend to be thin and laterally discontinuous. The dense coring pattern at the site, however, provided a detailed picture of the rock units beneath the site. The Survey, which has extensive experience in interpretation and analysis of the Pennsylvanian sequences in southwest Indiana, studied the core at the site and in the laboratory. The Survey provided a much needed interpretation of not only the sedimentology, lithology and stratigraphy of the rock units, but also the size, shape and groundwater parameters of potential aquifer bodies. An understanding of the depositional system and facies[1] of each depositional environment allowed a more accurate prediction to be made of the geometry and extent of reservoirs (aquifers) and confining units (aquicludes) beneath Rockeye. Rock core from the Rockeye Facility were also correlated to Pennsylvanian core recovered at other sites within NSWCC to provide a regional setting for the Pennsylvanian sequence. The Survey produced a report in June of 1992 on the sedimentology of the Pennsylvanian rocks within the NSWCC (Barnhill 1992). Much of the discussion in this report concerning sedimentology, stratigraphy and description of core is excerpted from the Survey's report. The Survey published a report of the hydrogeologic properties in February of 1996 (Fisher 1996).

The relatively dense grid pattern of well clusters at Rockeye is evident in Plate 2. Borings were placed on approximately 400-ft centers to obtain the subsurface data needed for hydrogeologic interpretations. Table 8 lists the total depths and amount of Pennsylvanian core recovered in the 35 Rockeye well borings investigated by the Survey.

Reservoir (aquifer) characterization of the Pennsylvanian core included detailed facies descriptions, which were used to generate vertical columnar

[1] A "facies" as used here is a distinct rock unit corresponding to a certain depositional environment or mode of origin.

profiles and geologic cross sections. Representative core samples from potential aquifer facies were analyzed for reservoir quality at Reservoir, Inc., Houston, Texas. Porosity and permeability measurements were made of each of the major sandstone facies. The Survey collaborated with the U.S. Geological Survey in Denver, Colorado to obtain scanning electron microscopy of core samples to determine the amount and location of clay minerals within the pore network, and thin section petrography to determine the degree of primary and secondary porosity within potential reservoir bodies. The Survey analysis was combined with observations and analysis by WES geologists to produce a detailed, three-dimensional interpretation of the geology and groundwater hydrology at the Rockeye Facility. Field slug tests of Rockeye wells provided additional hydrogeologic data.

Facies identified in the Pennsylvanian sediments at NSWCC and Rockeye. The Survey identified ten depositional/lithologic facies in the core recovered at NSWCC. All of the facies were represented in the Rockeye core. Figure 14 shows the relative percent of occurrence of the ten facies described in the core obtained at NSWCC. The description and interpretation of the depositional environments associated with each facies are presented below, beginning with the fine-grained facies. A dark gray shale is the dominant facies. Figures 15 through 17 are photographs of samples of the facies described below.

Dark gray shale facies (Figure 15). Dark gray shale comprises approximately 40 percent of the total Pennsylvanian section described at NSWCC. It is a structureless, waxy, platy, sometimes silty, micaceous, sparsely fossiliferous shale often containing fine plant fragments along parting planes. The shale has been interpreted as an estuarine-fill up to 60 ft thick, deposited near the mouth of a tide-dominated estuary; as a regional marker bed up to 35 ft thick representing a transgressive marine unit deposited during a rise in sea level; and as a thin, discontinuous unit capping fining-upward, estuarine or tidal channel sandstones.

Lenticular shale facies (Figure 15). The lenticular shale facies comprises only about 8 percent of the described core at NSWCC and consists of dark gray, silty, micaceous, carbonaceous shale in beds about 2 cm thick and thin (less than one centimeter) lenses of very fine grained quartz-rich sandstone. Lenticular bedding is a common feature in tidally influenced environments, reflecting the systematically fluctuating flow conditions of tidal flat settings.

Rooted mudstone, siltstone and sandstone facies (Figure 15). Rooted facies comprise about 15 percent of the described core. Rooting is present primarily in sandstones but also in siltstones and mudstones. Rooted sandstones are typically light gray, clayey, silty, and very fine grained. Rooting has disrupted primary bedding features making them difficult to observe. Many of the rooted mudstones and siltstones appear to be underclays; that is, they directly underlie the coals and terminate upward into either a coal or a subaerial exposure surface. Rooting is indicative of a shallow water depositional setting typical of intertidal to supratidal (above high tide) environments.

Wavy-bedded sandstone facies and flaser-bedded sandstone facies (Figure 16). These two facies are similar in appearance and depositional setting. Wavy-bedded sandstone accounts for about 15 percent and flaser-bedded sandstone about 2 percent of the described core at NSWCC. Wavy-bedded and flaser-bedded facies consist of light gray, well-sorted, subangular to subrounded, quartz-rich very fine grained sandstone interlaminated with gray, carbonaceous shale. The two facies are often interbedded. The shale drapes in wavy-bedded units extend over the troughs and crests of the sand ripples. In flaser-bedded units, currents have removed shale from the crests, leaving it only in the troughs. These facies are interpreted to be the product of intertidal to shallow subtidal sandflat deposition.

Ripple-bedded sandstone facies (Figure 16). The ripple-bedded sandstone facies comprises about 8 percent of the described core at NSWCC. It consists of very fine to fine, well sorted, micaceous, quartz-rich sandstone. Ripple-bedded sandstone is commonly associated with the flaser-bedded and cross-bedded facies. At the Rockeye site, ripple-bedded sandstone is associated with fining upward, tidally influenced, fluvial point bars.

Massive-bedded and cross-bedded sandstone facies (Figure 17). Massive- and cross-bedded sandstones occur interbedded with each other and comprise about 7 percent of the described core. The facies consist of light gray to tan, very fine to fine, well sorted, micaceous, quartz-rich sand. At Rockeye, the massive- and cross-bedded sandstones form the active channel-fill portion of tidally influenced, fluvial point bars similar to the ripple-bedded environment.

Rhythmically bedded siltstone facies (Figure 17). Rhythmically bedded siltstone comprises only about 1 percent of the described core. It consists of thin couplets of light gray siltstone and medium to dark gray, silty mudstone that form well developed neap-spring-neap (14 day) tidal cycles (rhythmites). Rhythmites are compelling evidence of tidal influence.

Disturbed-bedded sandstone and shale facies (Figure 17). The disturbed-bedded facies comprises about 1-1/2 percent of the described core. The contorted bedding, load-casted ripples and microfaulting associated with the facies were formed contemporaneously with deposition, typically along channel margins where steep dips resulted in gravity-flow deposition and the development of disrupted bedding.

Coal facies (Figure 17). Coals are common in Pennsylvanian rocks and comprise about 2 percent of the described core at NSWCC. The coals, of bituminous rank, range in thickness from a few inches to 5 ft and are generally only correlatable over short distances. Most of the coals show well-developed cleating (jointing), and pyrite often lines the cleats. Coals are produced in peat-forming, low-energy environments.

Reservoir characterization of potential aquifers from laboratory data. The massive- and cross-bedded sandstone, the ripple-bedded sandstone, the flaser- and wavy-bedded sandstone, and the rooted sandstone were considered

potential reservoir facies. Laboratory-determined porosity and permeability (to gas) measurements were made on representative samples of these facies. Porosities were uniformly high, ranging from 12.6 percent to 30.2 percent and averaging 21 percent. Permeabilities to gas were high but showed much more variation than porosities. The massive and cross-bedded sandstone showed the highest permeability, followed by ripple-bedded sandstone, wavy- and flaser-bedded sandstone, and finally rooted sandstone. On a relative permeability scale with the permeability of the massive and cross-bedded facies equal to 100, ripple-bedded sandstone was 26, wavy- and flaser-bedded were 12, and rooted sandstone was 6.

The massive and cross-bedded sandstone facies is clearly the best reservoir, or aquifer, facies on the basis of the laboratory tests. Photomicrographs of thin sections of the sandstone revealed the clean, quartz-rich, clay-free nature of the facies. The facies exhibits a well developed effective primary intergranular porosity. The ripple-bedded sandstone is also considered to be a good reservoir rock, but is characterized in thin section as having local zones of poor reservoir quality. Quartz overgrowths and clays coat quartz grains in the ripple-bedded sandstone, reducing permeabilities.

The massive, cross-bedded and ripple-bedded sandstone facies dominated the three channel sandstones, "A", "B" and "C," mapped in the subsurface at the Rockeye Facility as potentially excellent aquifers by the Survey. Geologic units identified by the WES geologist during coring operations correlated to variable extent with the channel sandstones (note that sands "B" and "C" appear on the study area profile of Plate 5, above). Further discussion of aquifers and their characteristics at Rockeye are discussed later in this report in the section on groundwater hydrology. The survey calculated equivalent hydraulic conductivities for the laboratory-measured gas permeabilities. Their data are presented in Table 9. Individual test results are show are shown at the appropriate boring depths on the geologic cross sections presented as Plates 7 through 15, below.

Aquifer characterization from field tests. The Survey conducted 145 slug tests in 76 Rockeye wells in January through July of 1995 (Fisher 1996). A four- or six-foot long slug of 1-in. O.D. PVC tubing was rapidly lowered into the well to displace the water. Downhole pressure transducers and an automated data logger recorded the timed recovery of the water level. The storativity (S), transmissivity (T), and bulk hydraulic conductivity (K_b) were calculated using the curve fitting method of Cooper, etal. (1967). Slug test data for Rockeye wells are presented in Table 10.

Subsurface geology at Rockeye. Virtually all of the Pennsylvanian facies described above were observed in rock underlying the Rockeye site. The Survey constructed eight vertical geologic profiles, or cross sections, using the core data obtained from the well borings in and around the Rockeye facility. Geologic units displayed in the cross sections were delineated and described in terms of the facies discussed earlier. A supplemental cross section was subsequently added by WES to provide additional subsurface information in a critical portion of the Rockeye facility. Geologic units displayed in the

supplemental cross section were delineated and described in standard lithologic terms derived from the original field coring logs.

Plate 6 shows the locations of the nine geologic cross sections. The cross sections are presented in Plates 7 through 15 (cross sections AA through II). The cross sections were produced by projecting the boring logs and topographic contours into cross section lines oriented parallel to either the east-west coordinate or the north-south coordinate. Figure 18 shows how borings and contours were projected into the cross section line. The cross sections are thus compressed in length on Plates 7-15. Sections AA through EE are aligned from west-northwest to east-southeast; sections FF through II are aligned from south-southwest to north-northeast. There is approximately a 5 to 1 vertical enhancement in the cross sections. The subsurface geology is best discussed by referring to the geologic cross sections.

Several features are shown on the geologic cross sections. For example, in Section BB of Plate 8, the solid line at the top of the profile represents the present ground surface derived from the map of Plate 4 and the dashed line the preconstruction surface from Plate 3. The cross-hatched areas at the surface represent topographic lows filled to prepare the construction surface. A dashed ground-surface line appearing above a solid line indicates an area of cut (soil removal) during site construction. The vertically oriented rectangles adjacent to the well logs show the positions of well screens within the borings. The short-and-long dashed lines represent the piezometric surfaces, designated UPPER, MIDDLE, and LOWER, mapped from water levels in the well screens. The circles at the ends of some of the piezometric surface lines show approximately where the particular aquifer terminates, or ceases to be measured in adjacent well screens. The symbols P_1, P_2, etc. designate the lowermost, next higher, and so on, of well screens and piezometric levels (▽) within the wells. The basal shale that defined the bottom depth of most of the borings is shown by a horizontal-line pattern. The channel sandstones defined by the Survey are labeled "A," "B," or "C" and are shown by a stipple pattern. The width of the facies within the vertical well logs reflects the grain size of the facies, from medium grained (M) to very fine grained (Vf) to clay or shale size (Cl).

The pod-like geometry and extent of the channel sandstones is evident in isochore (drilled thickness) maps constructed for sandstones "A," "B," and "C," Figures 19, 20, and 21, respectively. Fining upward grain size trends combined, with the pod-like shapes, suggest that these sandstone bodies are point bar deposits formed by the lateral accretion of meandering channels. The presence of wavy bedding, lenticular bedding and herringbone cross-stratification capping some units suggests that these channels were tidally influenced (Barnhill 1992, p.60). In plan view, sandstone "A" occupies the eastern two-thirds, sandstone "B" the north-central two-thirds, and sandstone "C" the southeast corner of the Rockeye site (see Figures 19, 20, and 21).

Cross sections BB and CC (Plates 8 and 9) illustrate the geometry and stratigraphic relationships of the three channel sandstones, "A," "B," and "C." Channel sandstones grade laterally into lenticular-bedded shale and

wavy-bedded, flaser-bedded or ripple-bedded sandstones interpreted to be the product of intertidal mudflat and sandflat deposition. For example, in cross section BB, sandstone "A" grades laterally from cross-bedded sandstone of the active channel fill to flaser-bedded sandstone typical of the intertidal sandflat environment between wells 10C34 and 10C35. Similarly, sandstone "B" grades laterally from the massive and cross-bedded sandstone in well 10C34 to the ripple-bedded, wavy-bedded and lenticular-bedded facies of wells 10C35 and 10C39. Fluids in the cross-bedded channel sandstones would be expected to migrate laterally into the tidal flat facies (the wavy-bedded and flaser-bedded sandstones) because the latter have locally good reservoir characteristics.

Fining upward point bar sequences often are capped by rooted horizons followed by a coal (see, for example, sandstone "A" in cross section CC (Plate 9)). Coal forming environments associated with the point bar deposits are interpreted to be supratidal (above high tide level) backswamp marshes. Coals associated with the channel deposits of Rockeye show well-developed cleating and are therefore likely conduits for fluid flow. However, most coals are overlain by impermeable dark gray shale and pinch-out over short lateral distances (usually within 1,000 ft), and would not have conducted fluids over long distances except where coals grade laterally into other reservoir facies.

One to 15 ft of the dark gray and/or lenticular shale facies separates individual channel sandstone bodies in most core. Dark gray shale separates sandstone "A" from sandstones "B" and "C" in cross section CC. The dark gray shale facies separating sandstone packages in the Rockeye area is thin and discontinuous (in a regional sense), and is interpreted to be a bay-fill shale resulting from abandonment of the active channel and resulting local subsidence.

The depositional environments present during deposition of the Pennsylvanian sediments at Rockeye consist predominantly of tidally influenced, thin and laterally discontinuous deposits of a prograding,[1] tide-influenced deltaic sequence. Environments include tidally influenced point bar deposits, intertidal mudflats, sandflats, and mixed mud and sand flats, supratidal backswamp peat-forming marshes or raised mounds, supratidal marshes and swamps, distributary channel fill deposits, and bay-fill environments. The depositional environments that produced the facies described at the Rockeye site during deposition of channel sandstones "A" and "B" are reconstructed in Figure 22. The upper diagram of Figure 23 depicts the depositional environments present during maximum lateral accretion of sandstone "A." To the west of the active channel, on the cutbank side, were deposits of the intertidal mudflat, mixed sand and mudflat and sandflat environments. Immediately south of the intertidal flats, a supratidal marsh was present and is indicated on the block diagram by vegetation symbols. The accreting bank was dominated by well-sorted sands of the point bar. Behind the point bar (to the right) was the coal-forming peat swamp indicated by the heavy vegetation.

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[1] "prograding" is descriptive of a shoreline building outward, toward the sea, as in a prograding delta.

The bottom diagram of Figure 23 shows the facies distribution during deposition of sandstone "B," which occurred sometime after the deposition of sandstone "A." The cutbank side of sandstone "B's" channel was dominated by intertidal sandflat, mixed flat and mudflat deposition. Cross-bedded and massive-bedded sandstone formed by lateral accretion to the north of the active channel. The supratidal marsh and peat-forming environments present during deposition of sandstone "A" were no longer active during this time.

The "basal shale" referred to earlier was encountered in most of the borings located atop the ridge on which Rockeye is situated. The shale, part of the dark gray shale facies, was 2 to 12 ft thick beneath Rockeye, easily recognized in the core, and was a convenient "marker" unit. The shale was a reasonably persistent aquiclude, providing a logical base of investigation for groundwater monitoring. The shale was described in the core logs as a black to gray, hard, conspicuously slickensided shale that became slippery when wet. Where a boring did not completely penetrate the shale, the position of the base of the shale was extrapolated from adjacent borings.

Borings 10C23 and 10C40 penetrated the Pennsylvanian-Mississippian unconformity and bottomed in the Beech Creek limestone. Cross section FF (Plate 12) includes the logs for those two borings. Well 10C40 was screened in the Beech Creek (screen P1 of 10C40, Plate 11). The top of the Mississippian is about 260 ft deep at 10C23, or 150 ft below the base of the "basal shale," and about 200 ft deep at 10C40, or 97 ft below the base of the "basal shale."

Groundwater hydrology of the Rockeye Facility

Aquifers monitored for the Rockeye investigation. Three discrete aquifers were delineated and monitored at and immediately adjacent to the Rockeye facility. These were designated the upper, middle and lower aquifers, all within the Pennsylvanian aged rock. Wells also screened four other, deeper geologic units within the Mississippian aged rock southeast and topographically below the Rockeye facility. The Mississippian aged units screened were the Sample(?) Formation, the Beech Creek Limestone, the Big Clifty Sandstone, and the Golconda/Haney Limestone. The Mississippian units are described below in ascending order (oldest units first).

Sample(?) Formation. Well 10C61, located off Highway 165 near the west tributary to Sulphur Creek (see Plates 1 and 5) screened the Sample(?) Formation (Plates 1 and 5). The well screen for 10C61 was set at a depth of 17 to 27 ft below ground in a gray, massive, fine grained, shaly sandstone tentatively assigned to the Sample Formation, which lies immediately below the Elwren Shale. The Sample(?) Formation sand comprises the uppermost aquifer in this portion of the study area. Groundwater presumably flows toward the permanent stream, Sulphur Creek. The static water level was 593.0 ft NGVD (5.3 ft below ground) on 11 March 1991.

Beech Creek Limestone. Well 10C40, located immediately to the northwest of the Rockeye facility, west of Highway 45, screened the Beech Creek limestone at a depth of 275 to 285 ft below ground (see Plate F for the graphic well log). The Beech Creek is a gray, hard and dense, crystalline, fossiliferous limestone with occasional joints. The geometry of groundwater flow within the Beech Creek beneath Rockeye cannot be determined from this one well. The static water level was 581.5 ft NGVD (248 ft below ground) in 10C40 on 11 March 1991.

Big Clifty Sandstone. Confirmation wells 10-01 and 10-02, located off Highway 161 where the northeast drainage from Rockeye intersects the road (Plates 1 and 5) screened the lower portion of the Big Clifty sandstone at depths of 16 to 24 ft and 11 to 19 ft below ground, respectively. The Big Clifty consists of a red-brown, fine-grained, friable sandstone. The Big Clifty comprises the uppermost aquifer at this location. The static water levels for 10-01 and 10-02 were 602.8 and 601.7 ft NGVD (19 and 20.7 ft below ground), respectively, on 28 June 1991 (both wells were dry on 11 March of that year). Groundwater flow is presumably toward the permanent stream, Sulphur Creek.

Golconda/Haney Limestone. Well 10C60, located southeast and downslope of Rockeye, approximately half-way between the facility boundary and Highway 161 (Plates 1 and 5), screened the Golconda/Haney Limestone at a depth of 25 to 35 ft below ground. The Golconda/Haney, designated the Haney in recent literature, is a hard, dark gray, fossiliferous limestone to limey shale in well boring 10C60. The limestone comprises the uppermost aquifer at this location. The static water level in 10C60 was 643 ft NGVD (9 ft below ground) on 11 March 1991.

Lower aquifer. The lower aquifer beneath Rockeye consists of saturated, primarily massive, cross-bedded and wavy-bedded sandstones and occasional cleated coals of the Pennsylvanian sequence. The lower aquifer is present in all of the geologic cross sections of Plates 8 through 13. The aquifer is above the basal shale described earlier, from about elevation 725 ft to about 770 ft NGVD. During drilling of each well, the geologist sited the well screens at a depth most likely to produce water at the well site. The high lateral variability in lithology and aquifer properties characteristic of the many Pennsylvanian facies made selection of correlatable aquifers from well to well very difficult. Screens within the lower aquifer, primarily the P_1 screens, were not always placed at the same elevation in different wells. The piezometric surface representing the groundwater within the lower aquifer, however, was relatively consistent in elevation across the site (see, for example, section DD, Plate 10 and FF, Plate 12). The sandstones dominating the lower aquifer were all classified as good reservoir rock in the Survey's laboratory analysis. Additional short screens installed in lower aquifer coals in some of the wells produced piezometric levels very near those of deeper screens in the same cluster, indicating that there is effective hydraulic connection in the entire vertical sequence comprising the lower aquifer. For example, section DD, Plate 10, well 10C24, depicts a coal screened as P_2 with a piezometric level very near the level of the P_1 screen in the sandstone some 25 ft deeper. Similar agreement is shown in wells 10C37 and 10C25 in section DD. The position and extent of the lower

aquifer was determined more by the position of the piezometric surface than by the positions of well screens and corresponding lithologic units.

The channel sandstone "A" described in this report occupies a portion of the lower aquifer as shown on geologic sections AA, BB, CC, DD, GG, HH, and II. Many of the well screens placed in the lower aquifer intercepted Sandstone "A," especially in the eastern two-thirds of the site, confirming the importance of the sandstone as a reservoir unit. Other lower aquifer screens, for example to the west (see section BB), were in a portion of the aquifer not occupied by the channel sandstone, but produced equivalent piezometric levels. The consistency of piezometric levels across stratigraphic facies boundaries is another indication that the units are effectively hydraulically connected.

Well screens set at elevations above about 770 ft NGVD, an interval dominated by the dark gray shale facies in many borings, generally produced piezometric levels several feet higher than those of the lower aquifer. The shaly interval, exemplified in wells 10C48, 10C33, 10C29, 10C32, 10C28, 10C45 and many others, is apparently persistent enough across the site to hydraulically separate the upper and middle aquifers from the lower.

The lower aquifer piezometric surface probably intercepts the ground surface in the deep drainage gully south of the facility, shown in section EE, Plate 11, near well 10C44. Similarly, the piezometric surface projects to the ground in the northeast drainage, downslope of the facility, as shown on section HH, Plate 14. The piezometric surface of the lower aquifer on 11 March 1991 is shown by elevation contours in Figure 23.

Only one of the wells set in the lower aquifer was "dry" on the four monitoring dates between March of 1991 and May of 1992. Table 5 names the wells assigned to the lower aquifer (Lower Pennsylvanian in the table) and provides elevations of the piezometric surface on several monitoring dates.

Values of bulk hydraulic conductivities (K_b) determined from slug tests (Fisher 1996) in lower aquifer screens were predominantly in the 10^{-3} to 10^{-4} cm/sec range (see Table 10 and Plates 7-15).

Middle aquifer. The middle aquifer at Rockeye was represented by water-producing sandstones lying roughly between elevations 770 and 790 ft NGVD. The middle aquifer was limited in lateral extent, confined primarily to the north-central portion of the site. The middle aquifer, as defined by the piezometric surface in monitoring wells (primarily the P_2 screens), corresponds very well to the reservoir sandstone "B" described by the Survey. Some wells placed at the general elevation of the middle aquifer proved to be dry (did not produce water) when monitored. The dry wells fall outside the mapped limits of sandstone "B," as depicted on cross sections AA, wells 10C40 and 10C51; and BB, well 10C50. Other wells placed at the general elevation of the middle aquifer but outside of the mapped limits of sandstone "B" produced piezometric levels equivalent to the upper aquifer, and thus were not hydraulically equivalent to the middle aquifer. The latter phenomenon was exhibited by

cross sections BB, well 10C39; section CC, wells 10C36, 10C30, and 10C32; section GG, wells 10C45 and 10C25; and section II, well 10C32.

The piezometric elevation contours for 11 March 1991 and the dashed line of Figure 24 illustrate the limited extent of the middle aquifer and its high degree of correlation with sandstone "B" (see also Figure 20). Sandstone "B" thins near its boundaries to the west, east and south. Some wells placed within sandstone "B," but near its boundary, were dry, indicating that the water-producing capability of the sand is less near its limit because of thinning of the sand or through facies change. Well screen P_2 of well 10C31, sections CC and GG, was dry in the southern limit of sandstone "B." An open circle on the dashed line representing the piezometric surface on the cross sections represents the terminus of the middle aquifer (section GG, Plate 13). The terminus is an arbitrary point between producing and dry wells at which the aquifer ceases to produce groundwater. In the case of the middle aquifer and sandstone "B," the terminus coincides closely with the physical limits of sandstone "B." Note that where sandstone "B" was not present there was no middle aquifer encountered. For example, in section FF (Plate 12) on the west side of Rockeye, only upper and lower aquifer piezometric surfaces are present although screens were available at middle aquifer elevations. A similar situation exists in sections DD and EE to the south. The elevation of the middle aquifer piezometric surface lies between about 778 and 787 ft NGVD. The middle aquifer is projected to intersect the ground surface on the slopes surrounding Rockeye, as illustrated by section HH (Plate 14).

The Survey (Fisher 1996) conducted slug tests in a few middle aquifer screens but produced questionable results. There was poor correlation of field curves with the theoretical curves. A total of five tests were conducted in wells 10C47P2 and 10C29P2, which are screened in sandstone "B" of the middle aquifer (see Plates 7 and 8 and Table 10), with questionable K_h values. Laboratory values of hydraulic conductivity for two core samples from sandstone "B" were about 10^{-4} and 10^{-5} cm/sec. Hydraulic conductivity determined from slug tests of the screened interval would be expected to be somewhat higher because laboratory tests fail to account for the influence of open discontinuities present in the in situ rock mass. Hydraulic conductivities of sandstone "B," middle aquifer, are therefore probably similar to that of the lower aquifer.

Upper aquifer. The upper aquifer at Rockeye is represented by sandstones and siltstones at depths usually 20 to 25 ft below ground surface. The upper aquifer piezometric surface is irregular in elevation because it generally parallels the ground (topographic) surface. The piezometric surface is consistent across the ridge top on which Rockeye is situated except where intercepted by topographic incision and where the upper aquifer drains to the middle aquifer. Sections AA and EE, located near the northern and southern edges of the ridge top, respectively, show the upper piezometric surface "daylighted" by erosional gullies on the ridge slopes.

The drop in elevation of the upper piezometric surface near well 10C26 (section DD, Plate 10) may indicate that the gully fill represented by the diagonal lines between 10C25 and 10C26 provides an avenue of easier flow

and thus channel water to the south. Section II (Plate 15) also suggests flow through the fill.

The upper piezometric surface for 11 March 1991 is contoured in Figure 25. Elevations range from about 780 to 814 ft NGVD. The conspicuous "hole" or gap in the contours in the northeast portion of the site represents an important characteristic of the shallow groundwater at Rockeye. The upper aquifer apparently is able to drain vertically into the middle aquifer, the channel sandstone "B," in that part of the site. The section below on groundwater flow discusses the merging of the two aquifers.

The channel sandstone "C" recognized by the Survey occupies a portion of the subsurface that forms the upper aquifer (see especially sections CC, DD and HH). Sandstone "C" coincides with the positions of several upper aquifer well screens. However, most of the upper aquifer groundwater at Rockeye is tapped by wells screened in rock outside the limits of sandstone "C." The presence of sandstone "C" has no apparent influence on groundwater production and flow at Rockeye.

Values of K_b determined from slug tests (Fisher 1996) in the upper aquifer, which included sandstone "C," were predominantly in the 10^{-4} to 10^{-5} cm/sec range, or somewhat lower than those of the lower and middle aquifers.

Groundwater flow at Rockeye. The direction and rate of groundwater flow through the monitored aquifers beneath Rockeye were determined from maps of contoured piezometric levels measured in each aquifer's assigned wells. The groundwater measurements for 11 March 1991 (Table 5) were used to prepare the maps. Many of the earlier (confirmation) wells installed in 1981-83 were at depths that made it difficult to assign aquifers for the wells. Data from those wells were not used to construct the piezometric maps. There was sufficient coverage available in the newer RFI wells to portray the piezometric surfaces for the three assigned aquifers. Data from some confirmation wells supplemented the maps. Groundwater quality (chemical) monitoring data from all wells were included in the mapping of contaminants, presented later in this report. Groundwater flow is discussed first for the lower aquifer. The middle and upper aquifers are discussed as a unit because their flow merges to the northeast.

Lower aquifer. Figure 23 presented the piezometric surface for wells of the lower aquifer at a 2-ft elevation contour interval. The surface is one of irregular, radial drainage centered about a high in the southeast corner of the facility. The high is elongated as a ridge to the northwest, following the general trend of the drainage divide defined by the topography on Plate 1. Flow in the lower aquifer across the Rockeye facility is to the northwest and north on a gradient of about 0.006 or about 31 ft/mile (Figure 23). The gradient increases to about 0.012 or 62 ft/mile on the southern, southeastern, and northern flanks of the facility, obviously influenced by the high relief of the terrain.

There was 10 to 20 ft of piezometric (head) differential between the middle and lower aquifers, and 30 to 50 ft between the upper and lower aquifers (for example, see cross sections AA and DD). Flow in the lower aquifer appears to be independent of that in the middle and upper aquifers as shown by the difference in configuration of the piezometric surfaces and as predicted by the head differences.

The top of the lower aquifer is deep (about 50 ft) beneath the Rockeye facility but is projected to intercept the ground surface in gullies draining the site to the northeast and south. The erosional gully on the south side, shown in cross section EE, Plate 11, is as deep as the piezometric surface of the lower aquifer in the cross section but probably does not drain the aquifer until the actual aquifer sandstone is breached some six to ten feet deeper, or downslope of Section EE. Similarly, the erosional drainage gully on the northeast slope, shown in section HH, Plate 14, breaches the lower aquifer sandstone at about elevation 765 to 770 ft. No springs or seeps that would indicate drainage of the aquifer were mapped in either the south or northeast drainage gully and it is probable that near-surface residual clay soils prevent groundwater from contacting the free surface in the gully banks.

Middle and upper aquifers. The middle and upper aquifers at Rockeye are portrayed by the piezometric elevation contours on Figures 24 through 27. Figure 24 shows the middle aquifer as a discreet unit and the dashed outline of the geologic unit, sandstone "B," which was described earlier as containing the middle aquifer. Figure 25 shows the upper aquifer as a discreet unit. Figure 26 presents the two aquifers superimposed, the middle aquifer shown by dashed lines. In the previous section, the two aquifers were shown to be hydraulically connected, i.e., to merge, in the northeast portion of the site. The flow in the upper aquifer across Rockeye is primarily to the northeast, ultimately discharging to the middle aquifer and thence downslope to the northeast. Because the two aquifers ultimately act as one with respect to groundwater flow and potential contaminant migration, data from wells of both aquifers were combined and plotted as a unit (i.e., all piezometric elevations were considered to be within the same aquifer) in Figure 27.

Groundwater flow is discussed with reference to the combined upper and middle aquifer regime, renamed the uppermost aquifer for purposes of discussion. The piezometric surface of the uppermost aquifer is characterized by two highs at the southwest and southeast corners of the site with groundwater divides running west-northwest to east-southeast along the southern half of the site, and roughly north-south along the western side (Figure 27). Groundwater flow across the northern two-thirds of the site, which includes the main operations buildings 2731 and 2734 near well clusters 10C30, -31 and -32 (see Plate 2), is primarily toward the northeast drainage way. Another component of flow is to the south drainage way near well clusters 10C25, -26 and -44. The gradient of flow is about 0.024 or 127 ft/mile across the center of Rockeye. The gradient steepens slightly to 0.029 or 155 ft/mile in the northeast drainageway where the upper and middle aquifers merge. The heavy dashed lines clipping the contours on the periphery (Figure 27) represent the intercepts of the ground surface with the piezometric level of the aquifers.

The west-east cross-section BB (Plate 8) exhibits the phenomenon of the merging of the upper and middle aquifers, where the highest piezometric surface in well cluster 10C33 is that of the middle aquifer, but is the upper aquifer in adjacent well clusters. Upper aquifer water from the east and west merges with that of the middle aquifer near well 10C33P2. The steepening of the gradient between wells 10C34P3, 10C33P2, and 10C29P2 in Figure 27 further illustrates the merging of flow. South-north section II similarly shows the merging of the upper piezometric surface of well 10C32 with the middle surface of well 10C33. South-north Section HH shows a similar merging between wells 10C29 and 10C49. Contaminants attributed to operations at Rockeye, particularly the introduction of explosives compounds to the ground surface near buildings 2731 and 2734, were discharged previously within the catchment of the now-filled drainage gully that drained the central part of the Rockeye site prior to site construction (Plates 2 and 3). Contaminants infiltrating the ground surface to the upper aquifer would be carried to the northeast, into the window connecting the upper and middle aquifers, and thence to the northeast and downslope. Groundwater monitoring and analysis confirmed that contaminants followed that flow path. A similar contaminant transport mechanism existed to the south of the operations buildings. Contaminants in wells to the south, however, were detected only early in the monitoring program (1981-83) and have not been detected in recent monitoring. The predominant and most important flow in the uppermost aquifer is to the northeast drainage way.

Potential groundwater receptors. Potential receptors of contaminated groundwater originating at Rockeye include the shallow aquifers of the Pennsylvanian system (the lower, middle, and upper aquifers described above), the Golconda/Haney Limestone aquifer, the Big Clifty Sandstone/Beech Creek Limestone aquifer, and deeper aquifers exposed in the stream valley of Sulphur Creek downslope to the northeast and east of Rockeye. There is also potential flow of groundwater to the south into Turkey Creek and to the northwest into First Creek, which debouches into Lake Greenwood. Vertical infiltration of groundwater of the Pennsylvanian aquifer to deeper aquifers is unlikely because of the thick sequence of Pennsylvanian shales above the Mississippian aquifers (see deep boring logs of section FF, Plate 12). Migration of groundwater laterally is likely because the Pennsylvanian aquifers are breached by the gullies and slopes surrounding Rockeye. Monitoring wells in the northeast drainage way had detectable levels of explosives compounds, the "indicator compounds" for Rockeye-attributed contamination, as far downslope as wells 10-01 and 10-02, at Highway 165 (see Plate 1). Big Sulphur Creek runs south and southeast from the intersection of its tributary with the northeast drainage way and passes the NSWCC boundary approximately 5 miles from that point. However, explosives were not detected in well 10C61, which is located about 2,500 ft downstream of wells 10-01 and 10-02 near Sulphur Creek.

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 conducted under the following protocol:

a. CLP data were reviewed according to the criteria in the latest versions of the following USEPA CLP documents: "Laboratory Data Validation: Functional Guidelines for Evaluating Organic Analyses," February 1988; "Laboratory Data Validation: Functional Guidelines for Evaluating Inorganic 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 E.

Organic Analytes

Holding times

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 and non-aromatic volatiles must be analyzed within 14 days. Pesticides/PCBs, explosives, herbicides, and BNA samples must be extracted within 7 days and the extract must be analyzed within 40 days (see Table 7a for holding times). If holding times were exceeded, all positive results were flagged as estimated (J). If holding times were grossly exceeded, professional judgement was used to determine the reliability of the data and the effects of additional storage on the sample results. The non-detect 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-hour 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 minutes on the standard chromatogram and that there was adequate resolution between peaks. If the retention time was less than 12 minutes, 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 Target Compound List (TCL) compounds must be greater than or equal to 0.05. All percent relative standard deviations (percent 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 percent RSD must be less than or equal to 10 percent for each 72-hour period for initial calibration and percent difference less than 15 percent for continuing calibration.

All Target Compound List (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 percent 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 percent 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 concentration of any of the five compounds detected in the sample was greater than 10 times the blank concentration, which was also detected in any associated blank, the result was reported as submitted. If concentration of other TCL organic and pesticide compounds detected in the sample was greater than 5 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 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 judgement 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 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 compound identification

TCL compound analysis for volatiles and semivolatiles was performed by GC/MS, which resulted in a low incidence of misidentification. A misidentification 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 pesticides 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 mg/uL (nanogram 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 National Bureau of Standards (NBS, now the National Institute of Standards and Technology, or NIST) 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 is 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 was 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 times

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 7a shows the holding time for each analyte. If holding times were exceeded, all positive results were flagged as estimated (J) for results > IDL and as estimated (UJ) for results < IDL. If holding times were grossly exceeded, professional judgement 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 less than 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 inductively coupled plasma (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 requirement for cyanide analysis are a blank and at least three standards to establish an analytical curve. The mid-range 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 less than IDL as estimated (UJ). The results were also as estimated (J) for midrange cyanide standards that were not distilled.

For the initial and continuing calibration verification (ICV, CCV), analysis results for metals (other than mercury), mercury, and cyanide must fall within the control limits of 90-110, 80-120, and 85-115 percent R, respectively. Positive results were qualified as unusable (R) if ICV or CCV percent Recovery (R) was less than 75 percent, 70 percent, and 65 percent for metals (except mercury), cyanide, and mercury, respectively. If the ICV or CCV percent 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 results 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 ±20 percent for Relative Percent Difference (RPD) which should be used for sample values greater than five times CRDL. The control limit of ± 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 fall 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 judgement 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 4 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 AA raw data verified that the Furnace Atomic Absorption Scheme described in the July 1987 Statement Of Work of the Functional Guidelines was followed. The raw data were also checked to verify that duplicate injections agreed within ±20 percent 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 percent 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). Tabulations of qualified (validated) data for Rounds 1 through 4 are presented in Appendix E (Volume 3 of this report). Qualified non-detected analyte data are indicated by a "U."

First round data

Samples collected from wells 10-14B, 10C30P2, 10C35P2, 10C37, and 10C45P2 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 nondetectables.

Acetone, methylene chloride, and bis(2-ethylhexyl)phthalate were found in concentrations less than the detection limits in several wells and/or associated

blanks from the Rockeye Facility. The data were qualified as BJ for an estimate found in the blank and the sample.

Samples collected from wells 10-19, 10C30, 10C32, 10C32P2, 10C32P3, 10C38, 10C39, 10C40P2, 10C40P4, 10C53, 10C55P2, 10C56P2, and 10C57 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 surrogate recovery for wells 10C31P3, 10C33, 10C33P2, 10C34, 10C34P2, 10C34P3, 10C39, and 10C40P2 were outside the QC limits for terphenyl-d14 since the acid was not recovered. The acid surrogates were not detected when the pH was adjusted. The surrogate solution was remade checking for problems, yielding a slightly high terphenyl-d14 recovery with the other surrogates within QC limits. The data were acceptable.

Chemical analysis for several well samples resulted in values less than the CRDL but greater than the IDL and/or post-digestion spike for the Furnace AA analysis outside the control limits, while sample absorbance was less than 50 percent of spike absorbance. The samples were rerun, yielding the same results. The data were qualified as B for detectables and UB for nondetectables, with values less than the CRDL but greater than the IDL as W for detectables and UW for nondetectables, with post-digestion spike for the Furnace AA analysis outside the control limits, while sample absorbance was less than 50 percent of spike absorbance.

The first round chemical results at Rockeye indicated that volatile organics, pesticides/PCBs, BNAs, cyanide, and herbicides were not present in verifiable amounts. Explosives, metals and sulfides were detected at the Rockeye Facility.

Second round data

Samples collected from wells 10-20, 10-21, 10C54, and 10C55P2 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 nondetectables.

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

Samples collected from wells 10-04, 10-16, 10-19, 10C24P2, 10C30, 10C37P3, 10C43P3, 10C44, 10C45P2, 10C46, 10C48P2, 10C49, 10C51, 10C55, and 10C55P2 for BNAs had low chrysene d12 and/or perylene-d12 internal standard areas. An attempt to clean-up the extract was made but was not possible. However, the extract for other QC samples was verified. The surrogate recovery for wells 10-16, 10-17, 10C24P2, 10C39, and 10C46 and equipment rinsate R6D were 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 matrix spike and matrix spike duplicate BNA samples for wells 10-05 and 10-07 had high recovery of 1,4-dichlorobenzene, 1,2,4-trichlorobenzene, and acenaphthene. 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.

Wells 10-05, 10-07, 10-18, 10C24P2, 10C26P3, 10C40P4, 10C43P2, and 10C60 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.

Chemical analysis for several well samples resulted in values less than the CRDL but greater than the IDL and/or post-digestion spike for the Furnace AA analysis outside the control limits, while sample absorbance was less than 50 percent of spike absorbance. The samples were rerun, yielding the same results. The data were qualified as B for detectables and UB for nondetectables, with values less than the CRDL but greater than the IDL as W for detectables and UW for nondetectables, with post-digestion spike for the Furnace AA analysis outside the control limits, while sample absorbance was less than 50 percent of spike absorbance.

The second round chemical results at Rockeye indicated that volatile organics, pesticides/PCBs, BNAs, cyanide, and herbicides were not present in verifiable amounts. Explosives, metals and sulfides were detected at the Rockeye Facility.

Third round data

Samples collected from wells 10-03, 10-14B, 10C26, 10C26P2, 10C26P3, 10C27, 10C28, 10C30, 10C34, 10C36, 10C36P2, 10C36P3, 10C37, 10C37P2, 10C37P3, 10C38, 10C39, 10C40P2, 10C40P4, 10C41, 10C41P3, 10C45, 10C45P2, 10C46, 10C46P2, 10C46P3, 10C47, 10C47P2, 10C48, 10C55, and 10C55P2 and equipment rinsates R4F and R6F for BNAs had low perylene d12 internal standard areas. The sample was monitored for any problems, yielding none. The associated data were qualified as an estimate, J for detectables and UJ for nondetectables.

The surrogate recovery for wells 10-01, 10-02, 10-05, 10-20, and 10C60 was 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.

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

The sulfide holding times were exceeded by 2 to 3 days for Rockeye wells 10C26, 10C26P2, 10C26P3, 10C38, 10C41P3, 10C42, 10C42P2, 10C43, 10C43P2, 10C43P3, 10C44, 10C44P2, 10C45, 10C45P2, and 10C52. The data were qualified as an estimate, J for detectables and UJ for nondetectables. The pesticide/PCBs holding times for wells at Rockeye were exceeded by 1 to 3 days for wells 10-03, 10-06, 10-09, 10-13, 10-14B, 10-15, 10C43P2, 10C43P3, 10C44P2, 10C52, and 10C55P2; 6 to 8 days for wells 10C28P2, 10C30P2, 10C31P3, 10C32, 10C32P2, 10C34, 10C34P2, 10C35P3, 10C39P2, 10C40P4, 10C60, and 10C61; and 14 to 26 days for wells 10-01, 10-02, 10-04, 10C23, 10C24, 10C24P3, 10C25, 10C25P2, 10C25P3, 10C27, 10C27P2, 10C28, 10C29, 10C29P2, 10C30, 10C31, 10C34P3, 10C35P2, 10C36, 10C36P2, 10C36P3, 10C37, 10C37P2, 10C37P3, 10C39, 10C40P2, 10C53, 10C53P2, and 10C54. The data were qualified as an estimate, J, for detectables and UJ for nondetectables with holding time less than 3 days. The data were qualified as unreliable, R, for nondetectables and an estimate, J, for detectables with holding time greater than 6 days.

The third round chemical results at the Rockeye Facility indicated that volatile organics, pesticides/PCBs, BNAs, cyanide, and herbicides were not present in verifiable amounts. Explosives, metals and sulfides were detected at the Rockeye Facility.

Fourth round data

The groundwater analytical data were reviewed and were 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 (see Part III). Explosives, metals, sulfides and nitrates and nitrites were detected at the Rockeye Facility.

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 (Appendix E).

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 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 three or 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 monitoring wells indicated no significant or verifiable amounts of organic analytes other than explosives. Sulfide and metals were detected at significant levels in a few wells at both sites in four sampling rounds. Nitrates and nitrites were detected in several Rockeye wells in the fourth round. Explosives were detected in certain wells at the Rockeye Facility in all four rounds.

6 Nature and Distribution of Groundwater Contamination

Detected Compounds

Appendix E is a printout of all compounds detected at any quantity in four rounds of sampling of monitoring wells in the Rockeye study area. The tabulation also shows the amounts detected. 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. Certain explosives compounds were detected consistently only in a narrowly distributed band of wells associated with a drainage way in the northeast quadrant of Rockeye. In addition to explosives, only inorganics (metals, cyanide/sulfide, nitrates, and nitrites) 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.

Statistical and Qualitative Data Evaluation

Selection of methods

Two methods were used to evaluate the presence and distribution of groundwater contaminants at Rockeye. Statistical analysis was performed only on metals because metals were detected in a large number of wells over four sampling events and were susceptible to statistical evaluation. Other contaminants were evaluated using maps of contoured mean concentrations.

Statistical analysis of metals concentrations reported for four rounds of sampling in Rockeye wells was conducted 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

(USEPA 1989). The actual analysis and reporting of results were performed on a personal computer using the Groundwater Information Tracking System/ Statistics (GRITS/STAT) software and manual developed for USEPA by Alliance Technologies Corporation (June 1992 version) and provided to the author by USEPA Region V (Chicago).

The USEPA recommends the one-way parametric ANOVA statistical analysis method 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 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 G is a reproduction of selected portions of the Guidance Manual explaining the method selection and analytical techniques for compliance monitoring data. Appendix G also provides a step-by-step example of statistical analysis of a hypothetical group of wells monitored for lead contamination. A typical computer-generated statistical analysis for monitoring wells for metals contamination at the Rockeye proceeded as follows:

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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. 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. Background wells were 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 list of wells with significant evidence of contamination with the selected metal was produced.

d. If either of the tests of original data failed, a parametric ANOVA 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 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. The non-parametric ANOVA test procedure is also 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. If 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(s) 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 Rockeye Pennsylvanian aquifers: the lower aquifer; the middle aquifer; and the upper aquifer.

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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.

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f. Examples of statistical analyses of Rockeye wells for three metals are presented in Appendix H.

Results of statistical analyses for metals

Statistical ANOVA tests were performed for three aquifers and 19 heavy metals. Table 13 presents the metals and the corresponding detection limits used in ANOVA calculations. ANOVA was not performed for metals that were not detected in a particular aquifer. Silver was not detected in any of the three aquifers. Selenium and thallium were not detected in the middle aquifer nor in the lower aquifer. Most of the statistical results, regarding which wells show evidence of the presence of metals at levels above background, i.e., are "statistically significant," agree with the metals occurrences implied from contour maps of mean levels of metals presented in a later section of this report (Figures 47 through 95). The ANOVA comparisons of background and detection well mean levels generally show statistical significance only for consistently elevated levels, i.e., levels detected consistently in several rounds of sampling. Anomalously high levels in one or two rounds that produce high standard deviations from mean levels often are not statistically significant. For that reason, some wells indicating high-level anomalies on the contour maps were not shown to be statistically significant in the ANOVA tests.

Uppermost aquifer. A total of 42 wells comprised the statistical population of detection wells in the uppermost aquifer (including wells not used in constructing the piezometric maps and wells of the middle aquifer). Three wells, 10C42P2, 10C43P3, and 10-03, served as background wells (refer to Plate 2 for well locations). Table 14 lists the wells used in statistical analysis and the rounds for which data were available. Evidence was shown for the presence of 13 of the 18 tested metals above background levels in one or more wells of the aquifer, as follows and in Table 15:

Aluminum: 10 wells, arsenic: 3 wells, barium: 2 wells, beryllium: 9 wells, cadmium: 4 wells, chromium: 2 wells, cobalt: 5 wells, copper: 5 wells, lead: 7 wells, manganese: 2 wells, nickel: 5 wells, selenium: 1 well, zinc: 5 wells. No wells had significant levels of antimony, mercury, thallium, tin, or vanadium.

Table 15, which indicates with an "X" statistically significant metals for each well, shows that wells 10-16, 10C25P3, 10C29P2, 10C30P2, 10C31P3, 10C39P2, 10C40P4, 10-04 and perhaps 10C46P3 had statistically significant levels of several metals in the uppermost aquifer. Seven of these nine wells recorded low (<4.5) mean pH levels (discussed in a later section).

Middle aquifer. A total of 7 wells comprised the statistical population of detection wells in the middle aquifer. Background wells were those used as background for the uppermost aquifer (10-03, 10C42P2 and 10C43P3). Table 16 lists the wells used in statistical analysis and the rounds for which data were available. Evidence was shown for the presence of 8 of the 16 tested metals above background levels in one or more wells of the aquifer, as follows and in Table 17:

Aluminum: 3 wells, arsenic: 1 well, beryllium: 2 wells, cobalt: 1 well, lead: 1 well, manganese, 1 well, nickel: 1 well, zinc: 1 well. No wells had significant levels of antimony, barium, cadmium, mercury, tin, or vanadium.

Table 17 shows that well 10C46P2 had statistically significant levels of several metals in the middle aquifer. Well 10C46P2 is the one middle aquifer well with anomalously low pH (discussed in a later section).

Lower aquifer. A total of 32 wells comprised the statistical population of detection wells in the lower aquifer. Background wells were 10C42, 10C43 and 10C52. Table 18 lists the wells used in statistical analysis and the rounds for which data were available. Evidence was shown for the presence of 9 of the 16 tested metals above background levels in one or more wells of the aquifer, as follows and in Table 19:

Aluminum: 9 wells, arsenic: 6 wells, barium: 2 wells, beryllium: 6 wells, cobalt: 14 wells, lead: 2 wells, manganese: 6 wells, nickel: 12 wells, zinc: 11 wells. No wells had significant levels of antimony, copper, mercury, tin, or vanadium.

Table 19 shows that wells 10C34, 10C35, 10C38, 10C46, 10C47, and 10C50, and to a lesser extent wells 10C41, 10C48 and 10C56, had statistically significant levels of several metals in the lower aquifer when compared to the lower aquifer background wells. Four of the nine significant metals showed a preference for wells with low pH.

Comparison of uppermost and lower aquifers. The mean values of the 4-round means for each well for each statistically significant metal in the upper and lower aquifers (42 and 32 wells, respectively) were calculated to compare general levels of metals in the two aquifers. The mean values are listed at the bottom of Tables 11 and 15 in the respective metals columns. Comparison of the means shows that, while the lower aquifer (Table 19) in some cases had a greater number of wells with statistically significant levels of metals than the uppermost, the uppermost aquifer had higher levels of the same metals, on average, and had more metals (13 metals) with statistically significant levels reported than the lower aquifer (with 9 metals).

Distribution of Potential Contaminants

The distribution of the potential contaminants at Rockeye was determined by constructing contour maps of mean levels of contaminants computed over the four rounds of sampling and, for metals, by analysis of the statistical test data discussed above. Inorganics (including metals) and explosives compounds were determined to be the only compounds with significant presence.

Explosives

The explosives compounds HMX, RDX, and TNT were measured at levels above detection level (DL) in certain wells regularly in the four rounds of groundwater sampling. Table 20 is a database printout showing Rockeye wells with detected amounts of explosives in each sampling event and the amount detected (AMTDET_A). Table 21 lists the mean amounts detected over four rounds for all wells at Rockeye. Ten wells had mean amounts of at least one explosive above the DL of 0.02 mg/l. All of the wells with amounts above DL were in the drainage way northeast and downslope of Rockeye. Referring to Plate 1, the wells with mean amounts of HMX, RDX, and TNT above DL were 10-07 and 10-08, 10-17 and 10-18, 10-21 (RDX only), 10C55 and 10C55P2, all atop the ridge, and 10C60, 10-01 and 10-02, downslope of Rockeye. Recall that means were calculated using a value of 1/2 the DL for rounds in which an analyte was not detected.

The compounds 2,4-DNT and TNB were measured at levels above DL only in well 10-17. Well 10C33, a lower aquifer well immediately southeast of the operations buildings near the preconstruction drainageway (Plate 2) had a level of TNT of 0.027 mg/l in the first round but none detected in the last three rounds. Three other wells, 10C34, 10C35 and 10C37 reported TNT at "J" level (below DL) in only one sampling round each. Wells 10C35 and 10C37 also reported a "J" level of RDX once. The other monitored explosives compounds DNB, Tetryl and 2,6-DNT were not detected.

Well 10-17 had the highest number of detects (Table 20). Well 10-17 also had the highest individual and mean detected levels of HMX, RDX and TNT (Table 21). The highest individual (single round) detected level of HMX was 0.518 mg/l, of RDX was 0.806 mg/l, and of TNT was 0.379 mg/l, all in the first round, March of 1991. Well 10-17 had the highest level of TNB at 0.034 mg/l. Well cluster 10C55/55P2, located approximately 80 ft upslope of 10-17 very near the axis of the drainageway, had the second highest mean values of the explosives.

Figures 28 through 35 are computer-generated contour maps of the four-round means of detected explosives in the combined upper and middle aquifers (the uppermost aquifer) and in the lower aquifer. Figures 36, 37 and 38 are maps showing the well numbers accompanying all of the contour maps for distribution of explosives and inorganics. Figure 36 is a map of the wells of the combined upper and middle (uppermost) aquifer. Figures 37 and 38 are maps of the wells of the lower and middle aquifers, respectively. The contour maps of Figures 28 through 35 illustrate the approximate distribution of the detected explosives at Rockeye. The downslope wells 10-01, 10-02 and 10C60 are not included on the maps. The explosives compounds occurred in wells of both the upper/middle (uppermost) and lower aquifers. The occurrence of explosives in the northeast quadrant and downslope within the drainageway is consistent with the direction of shallow groundwater flow and with early reconnaissance observations of pink water in the drainageway leading from the vicinity of the loading and washing buildings, 2731 and 2734 (see Part I and Plate 2). Explosives-contaminated surface water has apparently infiltrated through the drainage bed to the water table. Contamination in well 10C60,

approximately 600 ft downslope from the Rockeye boundary in the drainageway, and in wells 10-01 and 10-02 near Crane highway 165 (Plate 1) indicates that groundwater in the vicinity of those wells is subject to infiltration of explosives contaminated leachates, probably from the sediments within the drainageway. Wells 10-01 and 10-02 have been in service since November of 1981. Well 10C60 was installed in August of 1989. Explosives were not detected in well 10C61 approximately 2500 ft downstream of wells 10-01 and 10-02 in the tributary to Sulphur Creek (Plate 1).

The computer-generated contour maps are mathematical interpretations and extrapolations of contaminant distribution. They do not consider the effects of real physical features such as topography and drainage geometry. The contaminant boundaries are likely limited to the immediate vicinity of the present and pre-construction drainageway. Surface waters within the drainage have been observed to cease flow in dry seasons and to infiltrate the drainage bed upstream of wells 10-01 and 10-02. The highest detected values of HMX, RDX and TNT were in wells very close to the axis of the drainage (for example, well cluster 10C55/55P2 and 10-17).

An RFI for soils, Phase II, was conducted in the fall of 1990 (USAEWES 1992). The report of RFI concluded that the surface soils within Rockeye and in the drainageways are contaminated with explosives compounds. Explosives were found in the soils around the operations buildings and in the drainageways from the vicinity of the buildings. The report concluded that explosives in the soils of the wastewater sumps and in the discharge drainageways appear to be sources for explosives contamination of the groundwater.

Nitrogen compounds

Nitrogen as nitrates and nitrites was monitored in the fourth round of sampling. Nitrates commonly occur with explosives compounds as breakdown byproducts, and can serve as additional indicators of explosives contamination. For example, TNT reacts in the presence of oxygen (from ozone) and ultraviolet light to produce the following: $C_7H_5N_3O_6 + 18[O] \longrightarrow 7CO_2 + H_2O + 3NO_3^- + 3H^+$ (ICF Kaiser).

Table 22 lists amounts detected of nitrites and nitrates in Rockeye wells in the fourth round. The highest levels of nitrate detected in the upper/middle aquifer were 0.989 mg/l in 10C27P2 and 0.907 mg/l in 10C53P2. The highest level detected in the lower aquifer was 0.198 mg/l in well 10C23. Figures 39 and 40 show the distribution of nitrates in the upper/middle and lower aquifers, respectively. Except for the peak at well 10C55P2 of 0.832 mg/l there is no apparent relationship between the occurrence of explosives and the occurrence of nitrates. The MCL for nitrates is 10 mg/l, which is more than ten times the highest level detected at Rockeye.

The highest level of nitrite detected in the upper/middle aquifer was 0.082 mg/l in well 10C37P3. There were no levels of nitrites higher than 0.018 mg/l in the lower aquifer. The MCL for nitrite is 1 mg/l. Figures 41

and 42 show the distribution of nitrites in the upper/middle and lower aquifers, respectively. There is no apparent correlation between nitrite occurrence and explosives occurrence in the groundwater.

Metals

A suite of 24 metals was monitored in four rounds of sampling of Rockeye wells. Detection limits varied in some rounds for some metals because of limitations on laboratory analytical equipment. Aluminum DL varied from 0.01 to 0.03 (mg/l), barium from 0.01 to 0.02, beryllium from 0.001 to 0.002, cadmium from 0.0002 in rounds 1 and 2 to 0.004 in rounds 3 and 4, cobalt from 0.006 in rounds 1 and 2 to 0.01 and 0.02 in rounds 3 and 4, tin from 0.035 to 0.050, vanadium from 0.005 to 0.10, and zinc from 0.006 to 0.010. Data for 19 metals was analyzed statistically (see above) and with plots of mean concentration contours. Data for the metals calcium, magnesium, iron, potassium and sodium was not plotted because of the generally wide distribution of these secondary MCL metals in the subsurface.

The statistical analyses of metals, presented earlier, discussed the general occurrence of the 19 metals in the three Rockeye aquifers. This section presents contour maps of 4-round mean concentrations of the 19 metals. The field-measured parameter, pH, showed an apparent correspondence with anomalously high occurrences of metals. Contour maps of mean pH readings over four rounds were also prepared for each aquifer for visual comparison with the metals distribution maps.

Metals concentration contour maps of the upper aquifer incorporated data from more wells than were used in construction of the upper aquifer groundwater level contour maps. The groundwater maps were drawn to show the approximate limits of the three discrete aquifers (upper, middle and lower), whereas the metals concentrations and pH maps for the upper aquifer combined data from the upper aquifer wells and wells slightly downslope to the northeast that could be considered uppermost aquifer wells because of their proximity to the ground surface. Note that the uppermost aquifer maps for metals include those wells of the underlying middle aquifer that are hydraulically connected to the upper aquifer on the north and northeast side of Rockeye. Contour maps were also prepared for the discrete, areally limited middle aquifer.

Well location maps for the uppermost, lower and middle aquifers were presented earlier as Figures 36, 37 and 38, respectively. Contour maps of mean pH levels are presented as Figures 43, 44 and 45 (data for Figures 43, 44, and 45 are in Appendix D). The shaded areas in the pH plots indicate areas of anomalously low (acidic) pH (<4.8), with even lower values to the center of the areas. Contour maps of mean metals concentrations are presented as Figures 46 through 63 for the uppermost aquifer, Figures 64 through 78 for the middle aquifer, and Figures 79 through 94 for the lower aquifer.

The following sections discuss the occurrence and distribution of metals in each of the three aquifers. The discussions also address detected levels of metals that were above MCL.

Uppermost aquifer. Eighteen of the 19 analyzed metals were detected in the uppermost aquifer. Two metals, antimony and barium, showed a distribution similar to that of the explosives, i.e., with comparatively high levels in wells within the northeast drainage system (see Figures 47 and 49). All of the barium levels were well below its 2 mg/l MCL. The MCL for antimony, 0.01 mg/l, was exceeded in several wells within the northeast drainage area of Rockeye. However, antimony was determined by statistical analysis not to be statistically significant (above background levels) in the uppermost aquifer. Antimony has commonly been above the current MCL in wells at other SWMUs at NSWCC, including other background wells, and is possibly a natural constituent of the rock and soil that form the subsurface at NSWCC.

There were trends in the distribution of aluminum, beryllium, chromium, cobalt, lead, nickel, zinc, and possibly cadmium that paralleled the distribution of anomalously low pH (high acidity) indicated in Figure 43. A ridge of low pH (pH <4.8, as low as 3.5) is evident from well 10C25P3 to 10C30P2 to 10C39P2 and 10C40P4. Another low anomaly is at wells 10-16 and 10C29P2. Seven of the nine wells determined to have statistically significant levels of several metals in the uppermost aquifer recorded very low pH. The uppermost aquifer background wells 10C42P2, 10C43P3 and 10-03 did not record mean pH below 6.3.

Beryllium was present in several upper aquifer wells at mean levels above its MCL of 0.001 mg/l. The peak values, however, are within the low-pH trend discussed above (see Figure 50).

Cadmium was statistically significant in four wells and was at mean levels above its MCL of 0.005 mg/l in two of those four, 10C39P2 and 10C40P4. Both of these wells exhibited low pH.

Lead was above its MCL (at tap) of 0.015 in one of the statistically significant wells, 10C39P2. Peak lead values are within the low-pH trend.

Nickel was statistically significant in five wells, all within the low pH trend. Mean levels of nickel were above its MCL of 0.1 mg/l in all five wells (see Figure 58).

The occurrences of all of the statistically significant metals in the uppermost aquifer corresponded strongly to the presence of very low pH in the groundwater. The Pennsylvanian sandstones, shales and coals that comprise the aquifer materials beneath Rockeye represent depositional environments such as backwater, mudflat, marsh and coal swamp conducive to creating reducing conditions with subsequent formation of sulfide minerals. Pyrite (iron sulfide), limonite (ferrous iron oxides) and abundant carbonaceous material encountered in the borings for Rockeye wells were indicative of reducing conditions.

The acidic (low pH) condition of the groundwater in certain wells may be caused by the production of acids, for example sulfuric acid, as a result of oxidation of sulfide minerals. Davis and DeWiest (1966, p 76) report that very low (<4.0) values of pH can be associated with free acids in waters derived

from oxidizing sulfide minerals, usually pyrite. They provide (p 107) an equation for the formation of sulfuric acid by the oxidation of sulfide minerals:

$$FeS_2 + H_2O + 7O = FeSO_4 + H_2SO_4.$$

Hem (1985, p 111) states that oxidation of sulfide minerals in coal and metal mines causes low pH and strongly acid water. Hem (p 64) reports pH values ranging from 2.69 to 4.98 in runoff from an anthracite (hard coal) mine in Pennsylvania. The Soil Survey of Martin County, Indiana (USDA 1988) mapped the soils in the Rockeye vicinity as Zanesville and Wellston-Gilpin. The Soil Survey reported that both soils are strongly acidic. Zanesville has a reported range of pH of 4.0 to 5.5 and Wellston-Gilpin of 3.5 to 5.5.

The pH of water has a marked effect on the mobility of metallic elements, which are soluble as cations in acid groundwater (Davis and DeWiest 1985, p 88). Metals in the soil and rock would then be more readily extracted and placed in solution in the groundwater, which would account for the metals concentration peaks on the contour maps. The pattern of higher metals concentrations is not consistent with the location of potential contaminant producing operations at Rockeye, nor with the prevailing surface and groundwater flow pathways. For these reasons all of the metals anomalies except perhaps barium have a high probability of being natural, not man-made, phenomena.

Middle aquifer. Wells of the middle aquifer comprised much of the northern part of the uppermost aquifer discussed above. However, because the middle aquifer was portrayed as a discrete aquifer in the earlier section on groundwater flow, its metals distribution is presented here. Well 10C46P2 of the middle aquifer had statistically significant levels of aluminum, beryllium, cobalt, lead, nickel and zinc. The well also recorded a mean pH of below 4.2, as shown by the low-pH anomaly of Figure 44. Metals in the middle aquifer, like those of the uppermost aquifer, are probably natural phenomena. The MCL for antimony was exceeded in two wells in the northeast drainage way, but antimony was not a statistically significant contaminant in the middle aquifer. The MCL for beryllium, 0.001 mg/l, was exceeded in wells 10C46P2 (mean value of 0.0055 mg/l) and 10C47P2 (mean value of 0.0018 mg/l). The MCL for cadmium, 0.005 mg/l, was exceeded in well 10C34P2 (mean value of 0.0084 mg/l). The MCL for nickel, 0.1 mg/l, was exceeded in wells 10C34P2, 10C46P2 and 10C47P2 (mean values of 0.170, 0.359, and 0.145 mg/l, respectively).

Lower aquifer. Nine of the 32 wells comprising the lower aquifer at Rockeye were determined to have statistically significant levels of several metals. The metals distribution contour maps for the aquifer (Figures 79 through 94) show that many of the metals identified as statistically significant, including aluminum, arsenic, beryllium, cobalt, lead and nickel occurred at higher mean levels in that area of the aquifer characterized by anomalously low pH (Figure 45), especially wells 10C34 and 10C47. The MCL for antimony, 0.01 mg/l, was exceeded by several wells in the southwest quarter of the site (see Figure 80) but antimony was not a statistically significant contaminant. The MCL for beryllium, 0.001, was exceeded by many wells in much of the lower aquifer (at levels as high as 0.009 mg/l in two wells), and beryllium was

statistically significant in six wells (Figure 83). The MCL for cadmium, 0.005 mg/l, was exceeded in five wells (10C37, -39, -40P2, -47, and -48, with mean values as high as 0.008 mg/l (Figure 84) The MCL for nickel, 0.1, was exceeded in several wells (Figure 91).

With the exception of the six metals that occurred in areas of anomalously low pH, metals in the lower aquifer show an irregular and inconsistent distribution within the lower aquifer of Rockeye. Other metals showed no apparent preference for occurrence in particular areas within the aquifer, for example, areas that might be susceptible to infiltration from surface contaminant sources.

Other parameters

Cyanide and sulfides were monitored in all four rounds. Table 23 presents the means over four rounds for the two parameters for each well. The MCL for cyanide is 0.2 mg/l. The highest mean reported for cyanide in the nine wells in which it was detected was 0.008 mg/l. There is no MCL for sulfides. All but seven wells had detected amounts of sulfides. The highest mean reported for sulfides was 0.328 mg/l.

The field parameter pH was discussed earlier with respect to its effect on metals occurrence. A printout of all measurements taken in the field during sampling was presented earlier as Appendix D.

Summary of contaminant distribution

Explosives and nitrogen. The explosives HMX, RDX, and TNT occurred regularly in wells of the uppermost aquifer within the drainageway exiting the Rockeye Facility to the northeast. All detected levels of explosives were below 1.0 mg/l. The compounds 2,4-DNT and TNB occurred at detected levels only in one well. Other monitored explosives were not detected. Well 10-17 had the highest levels and the highest number of detected levels of HMX, RDX, and TNT. Explosives in the groundwater of the Rockeye site are concluded to be a result of past releases of wastewater from the operations buildings 2731 and 2734. The presence and distribution of explosives in the groundwater is consistent with the results of the Phase II RFI for soils conducted earlier. Explosives contamination in the groundwater is limited to the vicinity of the northeast drainageway as far downslope (east) as Crane Highway 165. Nitrates and nitrites were detected in Rockeye wells but at levels many times lower than the MCLs. There was no apparent correlation between distribution of nitrates and nitrites and the distribution of explosives.

Metals. Metals occurred in the groundwater of many wells in all three aquifers. Anomalously low pH in some wells or areas of the aquifers biased the level of several metals detected in those areas. Relatively high levels of the metals aluminum, beryllium, cobalt, lead, nickel, zinc, chromium and perhaps arsenic and cadmium corresponded directly to low pH. Barium was the only statistically significant metal not affected by the low pH factor that showed a

distribution similar to that of explosives. All of the anomalously high metals occurrences except barium were probably natural phenomena attributable to the low pH conditions produced by the Pennsylvanian facies comprising the aquifers.

Other parameters. Cyanides were detected in only a few wells and well below the MCL. Sulfides were detected in most wells. The field parameter pH was anomalously low (acidic) in certain wells of all three aquifers as discussed above. Other organic compounds including volatiles, semi-volatiles, pesticides and PCBs were determined not to be present in detectable amounts.

7 Conclusions and Recommendations

Conclusions

Hydrogeology

Groundwater flow beneath the Rockeye Facility is radially away from the site in three aquifers designated lower, middle and upper. The aquifers are Pennsylvanian sandstones and coals with variable flow characteristics. Flow within the lower aquifer is primarily to the north and northwest across the site. The middle and upper aquifers merge in the northern portion of the Rockeye Facility to form the uppermost aquifer. Flow in the upper aquifer is primarily to the northeast across the site, ultimately discharging vertically to the middle aquifer.

Surface flow off the site, especially from the vicinity of the operations buildings near the center of the site, is to the northeast and southeast. The northeast drainageway has carried contaminants from the operations buildings across the site on the ground surface and probably introduced contaminants by infiltration into the uppermost aquifer to the northeast. The projections of all three aquifers intercept the ground surface to the northwest, north, northeast, east and south on the slopes surrounding the Rockeye Facility.

Potential receptors of groundwater and surface water flowing away from Rockeye include Lake Greenwood, First Creek and Turkey Creek to the west and Sulphur Creek to the east. Deeper (Mississippian aged) aquifers in the valleys below Rockeye are susceptible to infiltration of water leaving the site.

Groundwater quality

Sampling and chemical analysis of groundwater from Rockeye wells detected metals and other inorganics and certain explosives compounds. Metals were detected in most wells in all three of the aquifers beneath Rockeye. Explosives were present in a small number of wells restricted to the northeast corner of the Rockeye site and offsite within a drainageway.

Statistically significant metals present included arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, lead, manganese, nickel, selenium and zinc. The uppermost aquifer (upper and middle aquifers combined) had higher mean levels of metals and more statistically significant metals than the lower aquifer.

All of the significant metals except perhaps barium were natural phenomena attributed to abnormally low pH produced by depositional conditions of the aquifer rock. The distribution of metals was not consistent with the locations of potential contaminant producing operations at Rockeye, nor with prevailing surface and groundwater flow paths. The distribution of barium in the monitoring wells was similar to that of explosives. Some metals were detected at levels at or above MCL.

The explosives HMX, RDX and TNT occurred regularly in wells of the uppermost aquifer within the drainageway in the northeast quadrant of the Rockeye Facility. All detected levels were below 1.0 mg/l. The compounds 2,4-DNT and TNB occurred at detected levels in only one well. Well 10-17, located approximately 300 ft northeast of the Rockeye boundary fence, had the highest levels of explosives.

The occurrence of explosives in the groundwater of the Rockeye Facility is concluded to be the result of past releases of wastewater from the operations buildings near the center of the facility. Explosives contamination is limited to the northeast drainageway as far downslope as Crane Highway 165. The presence and distribution of explosives in the groundwater at Rockeye is consistent with the results of the Phase II RFI for soils conducted and reported earlier.

Cyanides, sulfides, nitrates, and nitrites were detected in the groundwater but at levels much below their MCLs.

Organic compounds including volatiles, semi-volatiles, pesticides and PCBs were determined not to be present in the groundwater in detectable amounts.

Recommendations

Selected groundwater monitoring wells in the Rockeye study area should be monitored semiannually for the presence of explosives. Those wells in the northeast and southeast quadrants of the facility within the northeast and southeast drainageways should be monitored. Wells along Highway 165 northeast and downslope of Rockeye, in the valley of Sulphur Creek, should also be monitored. Proposed wells for monitoring are 10-01, 10-02, 10-07, 10-08, 10-17, 10-18, 10-21, 10C33, 10C33P2, 10C55, 10C55P2, 10C56, 10C57, and 10C60, all located to the northeast of the operations buildings near the drainageway and downslope toward Sulphur Creek. Wells 10C34, 10C35, 10C37, with one-time, low level occurrences of explosives, and 10-09, 10-10, 10C44, and 10C44P2, located in the southeast drainageway, should also be monitored. Wells 10-03, 10C42, 10C42P2, 10C43, 10C43P3, and 10C52, or a selected number of those six wells, should be monitored as background wells.

Efforts to prevent further contamination of the groundwater by infiltration from contaminated soils at and near Rockeye should continue. The operations buildings sumps are inoperative, but the soils surrounding the sumps and in other areas are contaminated. Removal of the soils and treatment by composting to remove explosives are recommended as a remedial action. Any runoff from the operations areas should be collected and treated. Consideration should be given to removal and treatment of the sediments in the drainageway to the northeast to prevent further leaching or infiltration of contaminants into the shallow aquifer.

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

Constituent Name	Class	Air (ug/m³)	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)phthlate	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

(Sheet 1 of 5)

[1] MCL available; see Appendix B.
[2] The air action level for asbestos is measured in units of fibers/milliliters.
[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/m³)	Water (mg/L)	Soils (mg/kg)
Chloroform[3]	B2	4E-02	6E-03	1E+02
2-Chlorophenol	D		2E-01	4E+02
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
Dichlorodifluoromethane	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

(Sheet 2 of 5)

[1] MCL available; see Appendix B.
[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/m³)	Water (mg/L)	Soils (mg/kg)
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
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			

(Sheet 3 of 5)

[1] MCL available; see Appendix B.

Table 1 (Continued)

Constituent Name	Class	Air (ug/m³)	Water (mg/L)	Soils (mg/kg)
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
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

(Sheet 4 of 5)

[1] MCL available; see Appendix B.

Table 1 (Concluded)

Constituent Name	Class	Air (ug/m³)	Water (mg/L)	Soils (mg/kg)
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
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)

[1] MCL available; see Appendix B.

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

Chemicals	Status[1] Reg.	MCLG (mg/l)	MCL (mg/l)	Sampled, SWMU 03
Organics				
Acrylamide	F	zero	TT[2]	
Acrylonitrile	L			X
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	
Benzene	F	zero	0.005	X
Benzo(a)pyrene (PAH)	P	zero	0.0002	
Benzo(b)fluoranthene (PAH)	P	zero	0.0002	
Benzo(k)fluoranthene (PAH)	P	zero	0.0002	
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	
Carbofuran	F	0.04	0.04	
Carbon Tetrachloride	F	zero	0.005	X
Chloral hydrate	L			
Chlordane	F	zero	0.002	
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	
Cyanazine	L			
Cyanogen chloride	L			
2,4-D	F	0.07	0.07	

(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 03
DCPA (Dacthal)	L			
Dalapon	P	0.2	0.2	
Di[2-ethylhexyl]adipate	P	0.4	0.4	
Dibenzo(a,h)anthracene (PAH)	P	zero	0.0003	
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	
Dichlorobenzene o-,m-	L	0.6	0.6	
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	
Dichloroethylene (trans-1,2-)	F	0.1	0.1	X
Dichloromethane (methylene chloride	P	zero	0.005	
Dichloropropane (1,2-)	F	zero	0.005	X
Dichloropropane (1,3-)	L			
Dichloropropane (2,2-)	L			
Dichloropropene (1,1-)	L			
Dichloropropene (1,3-)	L			X
Diethylhexyl phthalate (PAE)	P	zero	0.004	
Dinitrotoluene (2,4-)	L			
Dinitrotoluene (2,6-)	L			
Dinoseb	P	0.007	0.007	
Diquat	P	0.02	0.02	
Endothall	P	0.1	0.1	
Endrin	P	0.002	0.002	
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	
Heptachlor epoxide	F	zero	0.0002	

(Sheet 2 of 4)

Table 2 (Continued)

Chemicals	Status[1] Reg.	MCLG (mg/l)	MCL (mg/l)	Sampled, SWMU 03
Hexachlorobenzene	P	zero	0.001	
Hexachlorobutadiene	L			
Hexachlorocyclopentadiene	P	0.05	0.05	
Hexachloroethane	L			
Hypochlorite	L			
Indeno(1,2,3,-c,d)pyrene (PAH)	P	zero	0.0004	
Isophorone	L			
Lindane	F	0.0002	0.0002	
Methomyl	L			
Methoxychlor	F	0.04	0.04	
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	
Picloram	P	0.5	0.5	
Polychlorinated biphenyls (PCBs)	F	zero	0.0005	
Prometon	L			
Simazine	P	0.004	0.004	
Styrene	F	0.1	0.1	X
2,4,5-T	L			
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	
2,4,5-TP	F	0.05	0.05	
Trichloroacetic acid	L			
Trichloroacetonitrile	L			
Trichlorobenzene (1,2,4-)	P	0.007	0.007	
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			

(Sheet 3 of 4)

Table 2 (Continued)

Chemicals	Status[1] Reg.	MCLG (mg/l)	MCL (mg/l)	Sampled, SWMU 03
Trichloropropane (1,2,3-)	L			
Trifluralin	L			
Vinyl chloride	F	zero	0.002	X
Xylenes	F	10	10	X
Inorganics				
Aluminum	L			
Antimony	P	0.003	0.01/0.005	
Arsenic	under rev.		0.05	X
Asbestos (fibers > 10um)	F	7 MFL	7 MFL	
Barium	F	2	2	X
Beryllium	P	zero	0.001	
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	
Cyanide	P	0.2	0.2	
Fluoride (under review)	F	4	4	X
Lead (at tap)	F	zero	TT action level 0.015	X
Mercury	F	0.002	0.002	X
Molybdenum	L			
Nickel	P	0.1	0.1	
Nitrate (as N)	F	10	10	X
Nitrite (as N)	F	1	1	
Nitrate + Nitrite (both as N)	F	10	10	
Selenium	F	0.05	0.05	X
Strontium	L			
Sulfate	P	400/500	400/500	X
Thallium	P	0.0005	0.002/0.001	
Vanadium	L			
Zinc	L			

(Sheet 4 of 4)

Table 3
Monitoring Well Data for SWMU 10/15, Rockeye Facility

Well Number	Date Installed	Total Depth From TOC[1]	Elevation TOC NGVD[2]	Elevation Screen Top	Elevation Screen Bottom	Aquifer	Probable Water Producer[3]
10-01	20-NOV-81	33.5	621.81	602.43	593.63	Big Clifty	SS
10-02	22-NOV-81	27.9	622.46	608.88	599.66	Big Clifty	SS
10-03	01-JUL-83	32.5	811.98	794.15	784.83	Upper Penn	SS
10-04	02-JUL-83	43.3	830.41	801.61	792.58	Upper Penn	Coal/SS
10-05	05-JUL-83	38.3	832.03	808.55	799.21	Upper/Mid Penn	Coal
10-06	06-JUL-83	33.3	812.27	793.62	784.32	Upper/Mid Penn	SS
10-07	12-JUL-83	22.5	790.12	782.27	773.16	Upper/Mid Penn	SS/Coal
10-08	13-JUL-83	22.5	791.07	783.24	774.12	Upper/Mid Penn	SS/Coal
10-09	14-JUL-83	38.0	790.06	767.61	758.01	Upper/Mid Penn	SS/Coal
10-10	15-JUL-83	30.5	785.72	769.77	760.55	Upper/Mid Penn	SS/Coal
10-11	29-AUG-83	23.0	808.40	797.44	788.32	Upper/Mid Penn	SS/Coal
10-12	30-AUG-83	38.0	826.19	802.84	793.67	Upper Penn	SS
10-13	31-AUG-83	30.0	816.40	801.08	791.94	Upper/Mid Penn	SS
10-14	01-SEP-83	46.1	816.06	784.61	775.50	Upper/Mid Penn	SS/Coal
10-14A	21-SEP-83	33.0	816.81	792.66	783.81	Upper/Mid Penn	Coal
10-14B	21-SEP-83	23.1	816.28	804.83	795.71	Upper Penn	SS
10-15	02-SEP-83	41.0	793.14	766.78	757.60	Lower Penn	Coal
10-16	08-SEP-83	36.0	789.34	767.89	758.75	Upr/Low Penn[4]	SS
10-17	09-SEP-83	28.0	780.39	767.05	757.88	Upr/Low Penn[1]	SS
10-18	10-SEP-83	28.0	777.90	764.49	755.52	Upr/Low Penn[1]	SS
10-19	12-SEP-83	25.0	787.55	777.22	768.04	Upper/Mid Penn	SS/Coal
10-20	13-SEP-83	42.0	806.70	779.26	770.11	Upper/Mid Penn	SS
10-21	15-SEP-83	28.0	785.59	772.20	763.09	Upper/Mid Penn	SS
10-22	16-SEP-83	33.0	825.47	807.07	797.90	Upper/Mid Penn	SS
10C23	23-AUG-88	103.5	829.67	737.17	727.17	Lower Penn	SS
10C24	29-AUG-88	93.5	821.34	738.84	728.84	Lower Penn	SS
10C24P2	30-AUG-88	58.5	821.23	768.73	763.73	Lower Penn	Coal
10C24P3	30-AUG-88	32.5	820.90	799.40	789.40	Upper Penn	SS
10C25	03-SEP-88	90.5	817.02	737.52	727.52	Lower Penn	SS
10C25P2	06-SEP-88	62.5	816.99	760.49	755.49	Lower Penn	Coal
10C25P3	06-SEP-88	33.5	816.98	794.48	784.48	Upper Penn	SS
10C26	14-SEP-88	88.0	815.78	733.78	728.78	Lower Penn	SS
10C26P2	16-SEP-88	68.5	815.78	753.28	748.28	Lower Penn	Coal

(Sheet 1 of XX)

[1] TOC = Top of casing.
[2] All units of measurement are in feet.
[3] SS = Sandstone. Sh = Shale.
[4] These wells are downslope of ridge. The uppermost piezometric surface is equivalent in elevation to the lower piezometric surface atop the ridge.

Table 3 (Continued)

Well Number	Date Installed	Total Depth From TOC	Elevation TOC NGVD	Elevation Screen Top	Elevation Screen Bottom	Aquifer	Probable Water Producer
10C26P3	19-SEP-88	34.5	815.91	792.41	782.41	Upper Penn	SS
10C27	21-SEP-88	88.6	817.63	740.03	730.03	Lower Penn	SS
10C27P2	22-SEP-88	32.5	817.48	795.98	785.98	Upper Penn	SS
10C28	24-SEP-88	86.5	821.78	746.28	736.28	Lower Penn	SS
10C28P2	24-SEP-88	42.0	821.81	790.81	780.81	Upper Penn	SS
10C29	27-SEP-88	68.5	816.17	758.67	748.67	Lower Penn	SS
10C29P2	28-SEP-88	33.5	816.33	793.83	783.83	Upper Penn	SS
10C30	30-SEP-88	87.5	822.70	746.20	736.20	Lower Penn	Coal
10C30P2	30-SEP-88	28.5	822.74	805.24	795.24	Upper Penn	SS
10C31	06-OCT-88	66.5	820.60	765.10	755.10	Lower Penn	SS
10C31P2	07-OCT-88	45.5	820.74	786.24	776.24	Mid Penn (DRY)	SS
10C31P3	07-OCT-88	23.5	820.58	808.08	798.08	Upper Penn	SS
10C32	08-OCT-88	81.5	819.88	749.38	739.38	Lower Penn	SS
10C32P2	10-OCT-88	41.5	819.96	784.46	779.46	Upper Penn	SS
10C32P3	10-OCT-88	32.0	819.79	793.79	788.79	Upper Penn	SS/Coal
10C33	09-NOV-88	64.0	814.77	761.77	751.77	Lower Penn	SS
10C33P2	10-NOV-88	36.5	814.72	789.22	779.22	Middle Penn	SS
10C34	14-NOV-88	80.0	824.57	755.57	745.57	Lower Penn	SS
10C34P2	16-NOV-88	57.1	824.65	778.55	768.55	Middle Penn	SS
10C34P3	16-NOV-88	26.5	824.55	809.05	799.05	Upper Penn	SS
10C35	18-NOV-88	82.5	829.39	757.89	747.89	Lower Penn	SS
10C35P2	21-NOV-88	52.5	829.54	788.04	778.04	Upper/Mid Penn	SS
10C35P3	21-NOV-88	28.5	829.52	812.02	802.02	Upper Penn	Sh/SS
10C36	28-NOV-88	89.0	824.16	746.16	736.16	Lower Penn	Coal
10C36P2	30-NOV-88	52.5	824.29	782.79	772.79	Upper Penn	SS
10C36P3	30-NOV-88	29.5	824.17	805.67	795.67	Upper Penn	Sh/SS
10C37	05-DEC-88	94.5	820.73	737.23	727.23	Lower Penn	SS
10C37P2	07-DEC-88	62.5	820.74	764.24	759.24	Lower Penn	Coal
10C37P3	07-DEC-88	36.5	820.85	795.35	785.35	Upper Penn	SS
10C38	13-DEC-88	94.5	827.80	744.30	734.30	Lower Penn	SS
10C38P2	14-DEC-88	40.5	828.08	798.58	788.58	Upr Penn (DRY)	SS
10C39	16-DEC-88	105.0	829.92	735.92	725.92	Lower Penn	SS
10C39P2	19-JAN-89	45.5	829.90	795.40	785.40	Upper Penn	SS
10C40	04-FEB-89	288.5	829.49	551.99	541.99	Beech Creek	Limestone
10C40P2	06-FEB-89	86.5	829.63	754.13	744.13	Lower Penn	SS
10C40P3	08-FEB-89	54.5	829.62	786.12	776.12	Upr Penn (DRY)	SS/Coal
10C40P4	08-FEB-89	36.5	829.72	804.22	794.22	Upper Penn	SS
10C41	15-FEB-89	103.5	832.99	740.49	730.49	Lower Penn	SS

(Sheet 2 of 5)

Table 3 (Continued)

Well Number	Date Installed	Total Depth From TOC	Elevation TOC NGVD	Elevation Screen Top	Elevation Screen Bottom	Aquifer	Probable Water Producer
10C41P2	16-FEB-88	57.5	832.93	786.43	776.43	Upper Penn (DRY)	SS/Coal
10C41P3	16-FEB-89	39.5	833.10	804.60	794.60	Upper Penn	SS
10C42	28-FEB-89	89.5	834.76	756.26	746.26	Lower Penn	SS
10C42P2	28-FEB-89	31.5	834.93	814.43	804.43	Upper Penn	SS
10C43	14-MAR-89	87.5	820.69	744.19	734.19	Lower Penn	SS
10C43P2	15-MAR-89	55.5	820.58	771.08	766.08	Lower Penn	SS/Coal
10C43P3	16-MAR-89	39.5	820.77	792.27	782.27	Upper Penn	SS
10C44	23-MAR-89	47.5	794.61	758.11	748.11	Lower Penn	SS
10C44P2	24-MAR-89	22.5	794.78	778.28	773.28	Upper Penn	SS/Coal
10C45	22-APR-89	83.5	813.44	740.94	730.94	Lower Penn	SS
10C45P2	24-APR-89	34.5	813.56	790.06	780.06	Upper Penn	SS
10C46	27-APR-89	70.5	818.05	758.55	748.55	Lower Penn	SS
10C46P2	28-APR-89	39.5	818.46	789.96	779.96	Middle Penn	SS/Coal
10C46P3	28-APR-89	24.5	818.62	800.12	795.12	Upper Penn	Siltstone
10C47	02-MAY-89	80.5	821.96	752.46	742.46	Lower Penn	Coal/SS
10C47P2	03-MAY-89	61.0	822.11	772.11	762.11	Middle Penn	SS
10C47P3	03-MAY-89	25.5	822.06	807.56	797.56	Upr Penn (DRY)	SS
10C48	06-MAY-89	60.3	798.43	749.13	739.13	Lower Penn	SS
10C48P2	08-MAY-89	24.5	798.44	784.94	774.94	Middle Penn	SS
10C49	13-MAY-89	65.5	808.50	754.00	744.00	Lower Penn	SS
10C49P2	15-MAY-89	33.5	808.35	785.85	775.85	Middle Penn	SS
10C50	27-MAY-89	63.5	805.49	752.49	742.49	Lower Penn	SS
10C50P2	28-MAY-89	26.5	805.45	789.95	779.95	Upper/Mid Penn (DRY)	SS/Coal
10C51	02-JUN-89	56.5	810.41	764.91	754.91	Lower Penn	SS
10C51P2	03-JUN-89	26.5	810.64	795.14	785.14	Upper Penn (DRY)	SS
10C52	08-JUN-89	71.5	812.16	751.66	741.66	Lower Penn	SS/Coal
10C52P2	09-JUN-89	43.5	812.13	774.63	769.63	Lower Penn (DRY)	Coal
10C53	12-JUN-89	82.5	816.44	744.94	734.94	Lower Penn	SS
10C53P2	13-JUN-89	33.5	816.36	793.86	783.86	Upper Penn	SS
10C54	14-JUN-89	67.0	816.80	760.80	750.80	Lower Penn	SS
10C55	20-JUN-89	33.5	782.11	759.61	749.61	Lower Penn	SS
10C55P2	20-JUN-89	10.5	782.17	776.67	771.67	Fill (Middle Aquifer)	Clay and SS debris
10C56	22-JUN-89	28.5	770.71	753.21	743.21	Lower Penn	SS
10C57	22-JUN-89	22.5	770.72	759.22	749.22	Lower Penn	SS
10C60	14-AUG-90	24.5	651.91	636.91	626.91	Golconda/Haney	Limestone

(Sheet 3 of 5)

Table 3 (Continued)

Well Number	Date Installed	Total Depth From TOC[1]	Elevation TOC NGVD[2]	Elevation Screen Top	Elevation Screen Bottom	Aquifer	Probable Water Producer[3]
10C61	16-AUG-90	29.5	598.34	578.34	568.34	Sample Formation (?)	SS
10C37	05-DEC-88	94.5	820.73	737.23	727.23	Lower Penn	SS
10C37P2	07-DEC-88	62.5	820.74	764.24	759.24	Lower Penn	Coal
10C37P3	07-DEC-88	36.5	820.85	795.35	785.35	Upper Penn	SS
10C38	13-DEC-88	94.5	827.80	744.30	734.30	Lower Penn	SS
10C38P2	14-DEC-88	40.5	828.08	798.58	788.58	Upr Penn (DRY)	SS
10C39	16-DEC-88	105.0	829.92	735.92	725.92	Lower Penn	SS
10C39P2	19-JAN-89	45.5	829.90	795.40	785.40	Upper Penn	SS
10C40	04-FEB-89	288.5	829.49	551.99	541.99	Beech Creek	Limestone
10C40P2	06-FEB-89	86.5	829.63	754.13	744.13	Lower Penn	SS
10C40P3	08-FEB-89	54.5	829.62	786.12	776.12	Upr Penn (DRY)	SS/Coal
10C40P4	08-FEB-89	36.5	829.72	804.22	794.22	Upper Penn	SS
10C41	15-FEB-89	103.5	832.99	740.49	730.49	Lower Penn	SS
10C41P2	16-FEB-88	57.5	832.93	786.43	776.43	Upr Penn (DRY)	SS/Coal
10C41P3	16-FEB-89	39.5	833.10	804.60	794.60	Upper Penn	SS
10C42	28-FEB-89	89.5	834.76	756.26	746.26	Lower Penn	SS
10C42P2	28-FEB-89	31.5	834.93	814.43	804.43	Upper Penn	SS
10C43	14-MAR-89	87.5	820.69	744.19	734.19	Lower Penn	SS
10C43P2	15-MAR-89	55.5	820.58	771.08	766.08	Lower Penn	SS/Coal
10C43P3	16-MAR-89	39.5	820.77	792.27	782.27	Upper Penn	SS
10C44	23-MAR-89	47.5	794.61	758.11	748.11	Lower Penn	SS
10C44P2	24-MAR-89	22.5	794.78	778.28	773.28	Upper Penn	SS/Coal
10C45	22-APR-89	83.5	813.44	740.94	730.94	Lower Penn	SS
10C45P2	24-APR-89	34.5	813.56	790.06	780.06	Upper Penn	SS
10C46	27-APR-89	70.5	818.05	758.55	748.55	Lower Penn	SS
10C46P2	28-APR-89	39.5	818.46	789.96	779.96	Middle Penn	SS/Coal
10C46P3	28-APR-89	24.5	818.62	800.12	795.12	Upper Penn	Siltstone
10C47	02-MAY-89	80.5	821.96	752.46	742.46	Lower Penn	Coal/SS
10C47P2	03-MAY-89	61.0	822.11	772.11	762.11	Middle Penn	SS
10C47P3	03-MAY-89	25.5	822.06	807.56	797.56	Upr Penn (DRY)	SS
10C48	06-MAY-89	60.3	798.43	749.13	739.13	Lower Penn	SS
10C48P2	08-MAY-89	24.5	798.44	784.94	774.94	Middle Penn	SS
10C49	13-MAY-89	65.5	808.50	754.00	744.00	Lower Penn	SS
10C49P2	15-MAY-89	33.5	808.35	785.85	775.85	Middle Penn	SS
10C50	27-MAY-89	63.5	805.49	752.49	742.49	Lower Penn	SS
10C50P2	28-MAY-89	26.5	805.45	789.95	779.95	Upper/Mid Penn (DRY)	SS/Coal

Table 3 (Concluded)

Well Number	Date Installed	Total Depth From TOC	Elevation TOC NGVD	Elevation Screen Top	Elevation Screen Bottom	Aquifer	Probable Water Producer[3]
10C51	02-JUN-89	56.5	810.41	764.91	754.91	Lower Penn	SS
10C51P2	03-JUN-89	26.5	810.64	795.14	785.14	Upper Penn (DRY)	SS
10C52	08-JUN-89	71.5	812.16	751.66	741.66	Lower Penn	SS/Coal
10C52P2	09-JUN-89	43.5	812.13	774.63	769.63	Lower Penn (DRY)	Coal
10C53	12-JUN-89	82.5	816.44	744.94	734.94	Lower Penn	SS
10C53P2	13-JUN-89	33.5	816.36	793.86	783.86	Upper Penn	SS
10C54	14-JUN-89	67.0	816.80	760.80	750.80	Lower Penn	SS
10C55	20-JUN-89	33.5	782.11	759.61	749.61	Lower Penn	SS
10C55P2	20-JUN-89	10.5	782.17	776.67	771.67	Fill (Middle Aquifer)	Clay and SS debris
10C56	22-JUN-89	28.5	770.71	753.21	743.21	Lower Penn	SS
10C57	22-JUN-89	22.5	770.72	759.22	749.22	Lower Penn	SS
10C60	14-AUG-90	24.5	651.91	636.91	626.91	Golconda/Haney	Limestone
10C61	16-AUG-90	29.5	598.34	578.34	568.34	Sample Formation (?)	SS

(Sheet 5 of 5)

Table 4
Survey Data for SWMU 10/15 Rockeye Facility

Well Number	Date Installed	East Coordinate (ft)	North Coordinate (ft)	Elev TOC (ft NGVD)
10-01	20-NOV-81	595649	507473	621.81
10-02	22-NOV-81	595706	507436	622.46
10-03	01-JUL-83	591983	505974	811.98
10-04	02-JUL-83	590506	506998	830.41
10-05	05-JUL-83	591099	507946	832.03
10-06	06-JUL-83	592396	507411	812.27
10-07	12-JUL-83	592081	507507	790.12
10-08	13-JUL-83	592053	507517	791.07
10-09	14-JUL-83	591330	506495	790.06
10-10	15-JUL-83	591350	506436	785.72
10-11	29-AUG-83	591418	507782	808.40
10-12	30-AUG-83	591673	507674	826.19
10-13	31-AUG-83	591769	506292	816.94
10-14	01-SEP-83	592417	506650	816.06
10-14A	21-SEP-83	592409	506659	816.81
10-14B	21-SEP-83	592405	506640	816.28
10-15	02-SEP-83	592168	506057	793.14
10-16	08-SEP-83	592462	507012	789.34
10-17	09-SEP-83	592340	507685	780.39
10-18	10-SEP-83	592280	507703	777.90
10-19	12-SEP-83	592221	507465	787.55
10-20	13-SEP-83	591913	507572	806.70
10-21	15-SEP-83	592151	507635	785.59
10-22	16-SEP-83	590900	506734	825.47
10C23	23-AUG-88	590497	507000	829.67
10C24	29-AUG-88	590851	506859	821.34
10C24P2	30-AUG-88	590851	506859	821.23
10C24P3	30-AUG-88	590851	506859	820.90
10C25	03-SEP-88	591225	506716	817.02
10C25P2	06-SEP-88	591220	506718	816.99
10C25P3	06-SEP-88	591224	506721	816.98
10C26	14-SEP-88	591588	506562	815.78
10C26P2	16-SEP-88	591583	506564	815.78
10C26P3	19-SEP-88	591583	506560	815.91
10C27	21-SEP-88	591953	506397	817.63
10C27P2	22-SEP-88	591959	506397	817.48

(Sheet 1 of 3)

TOC - Top of Casing.
All units of measurement are in feet.
NGVD = National Geodetic Vertical Datum.

Table 4 (Continued)

Well Number	Date Installed	East Coordinate (ft)	North Coordinate (ft)	Elev TOC (ft NGVD)
10C28	24-SEP-88	592125	506751	821.78
10C28P2	24-SEP-88	592126	506756	821.81
10C29	27-SEP-88	592259	507126	816.17
10C29P2	28-SEP-88	592258	507121	816.33
10C30	30-SEP-88	591027	507197	822.70
10C30P2	30-SEP-88	591028	507202	822.74
10C31	06-OCT-88	591410	507206	820.60
10C31P2	07-OCT-88	591405	507207	820.74
10C31P3	07-OCT-88	591405	507212	820.58
10C32	08-OCT-88	591736	506914	819.88
10C32P2	10-OCT-88	591748	506912	819.96
10C32P3	10-OCT-88	591743	506913	819.79
10C33	09-NOV-88	591891	507276	814.77
10C33P2	10-NOV-88	591895	507280	814.72
10C34	14-NOV-88	591527	507432	824.57
10C34P2	16-NOV-88	591526	507437	824.65
10C34P3	16-NOV-88	591526	507441	824.55
10C35	18-NOV-88	591148	507582	829.39
10C35P2	21-NOV-88	591143	507580	829.54
10C35P3	21-NOV-88	591139	507577	829.52
10C36	28-NOV-88	590603	507374	824.16
10C36P2	30-NOV-88	590601	507369	824.29
10C36P3	30-NOV-88	590596	507367	824.17
10C37	05-DEC-88	590076	507164	820.73
10C37P2	07-DEC-88	590080	507161	820.74
10C37P3	07-DEC-88	590081	507157	820.85
10C38	13-DEC-88	589990	506730	827.80
10C38P2	14-DEC-88	589986	506726	828.08
10C39	16-DEC-88	590726	507748	829.92
10C39P2	19-JAN-89	590730	507745	829.90
10C40	04-FEB-89	590936	508107	829.49
10C40P2	06-FEB-89	590933	508103	829.63
10C40P3	08-FEB-89	590930	508100	829.62
10C40P4	08-FEB-89	590926	508095	829.72
10C41	15-FEB-89	590363	506619	832.99
10C41P2	16-FEB-88	590365	506615	832.93
10C41P3	16-FEB-89	590367	506611	833.10
10C42	28-FEB-89	590688	506504	834.76
10C43P2	15-MAR-89	591716	506081	820.58

(Sheet 2 of 3)

Table 4 (Concluded)

Well Number	Date Installed	East Coordinate (ft)	North Coordinate (ft)	Elev TOC (ft NGVD)
10C42P2	28-FEB-89	590700	506496	834.93
10C43	14-MAR-89	591721	506081	820.69
10C43P3	16-MAR-89	591711	506082	820.77
10C44	23-MAR-89	591403	506224	794.61
10C44P2	24-MAR-89	591406	506227	794.78
10C45	22-APR-89	591067	506374	813.44
10C45P2	24-APR-89	591062	506371	813.56
10C46	27-APR-89	591300	507957	818.05
10C46P2	28-APR-89	591296	507956	818.46
10C46P3	28-APR-89	591291	507954	818.62
10C47	02-MAY-89	591679	507839	821.96
10C47P2	03-MAY-89	591678	507834	822.11
10C47P3	03-MAY-89	591676	507829	822.06
10C48	06-MAY-89	592051	507678	798.43
10C48P2	08-MAY-89	592044	507680	798.44
10C49	13-MAY-89	592384	507520	808.50
10C49P2	15-MAY-89	592384	507516	808.35
10C50	27-MAY-89	592479	507091	805.49
10C50P2	28-MAY-89	592477	507097	805.45
10C51	02-JUN-89	592651	507389	810.41
10C51P2	03-JUN-89	592647	507392	810.64
10C52	08-JUN-89	591990	505981	812.16
10C52P2	09-JUN-89	591992	505986	812.13
10C53	12-JUN-89	592231	506293	816.44
10C53P2	13-JUN-89	592235	506296	816.36
10C54	14-JUN-89	592374	506649	816.80
10C55	20-JUN-89	592231	507586	782.11
10C55P2	20-JUN-89	592230	507592	782.17
10C56	22-JUN-89	592512	507976	770.71
10C57	22-JUN-89	592633	507831	770.72
10C58 (boring only, no well)	completed 09-AUG-90	594042	506757	672.90 (ground)
10C59 (boring only, no well)	completed 10-AUG-90	598515	505916	601.51 (ground)
10C60	14-AUG-90	594367	506896	651.91
10C61	16-AUG-90	597759	506289	598.34

(Sheet 3 of 3)

Table 5
Water Level Measurements for Rockeye

Well Number	Geologic Position or Aquifer	TOC Elev ft NGVD	Ground Water Elev, ft 12-Jul-89	Ground Water Elev, ft 11-Mar-91	Ground Water Elev, ft 28-Jun-91	Ground Water Elev, ft 10-Jan-92	Ground Water Elev, ft 20-May-92
10-01	Big Clifty	621.81	—	Dry	602.81	603.51	604.46
10-02	Big Clifty	622.46	—	Dry	601.66	602.66	605.26
10-03	Upper Pennsylvanian	811.98	795.18	797.60	795.08	794.73	794.98
10-04	Upper Pennsylvanian	830.41	814.21	813.81	814.76	812.86	813.31
10-05	Upper/Mid Penn	832.03	810.33	811.73	810.53	809.53	809.53
10-06	Upper/Mid Penn	812.27	797.17	800.42	797.12	795.42	796.62
10-07	Upper/Mid Penn	790.12	786.22	786.12	784.47	786.11	785.62
10-08	Upper/Mid Penn	791.07	785.67	786.52	784.07	786.22	785.47
10-09	Upper/Mid Penn	790.06	769.86	771.38	770.81	769.06	769.76
10-10	Upper/Mid Penn	785.72	770.22	771.87	767.22	769.32	770.17
10-11	Upper/Mid Penn	808.40	802.40	803.20	801.20	802.70	802.35
10-12	Upper Pennsylvanian	826.19	800.19	800.69	798.84	800.14	800.19
10-13	Upper/Mid Penn	816.94	800.84	801.54	800.94	800.54	800.44
10-14	Upper/Mid Penn	816.06	—	Dry	Dry	Dry	Dry
10-14A	Upper/Mid Penn	816.81	784.21	776.21	776.13	774.31	776.16
10-14B	Upper Pennsylvanian	816.28	802.28	802.43	801.48	800.06	801.03
10-15	Lower Pennsylvanian	793.14	771.24	772.54	771.94	770.39	770.99
10-16	Upper/Lower Penn.	789.34	774.24	774.99	774.19	772.69	772.94
10-17	Upper/Lower Penn.	780.39	767.79	768.19	767.89	766.98	767.49
10-18	Upper/Lower Penn.	777.90	768.10	768.37	768.15	767.18	767.65
10-19	Upper/Mid Penn	787.55	780.85	782.80	777.70	780.80	778.25
10-20	Upper/Mid Penn	806.70	780.20	782.10	781.95	781.40	781.60
10-21	Upper/Mid Penn.	785.59	770.19	772.69	769.84	769.44	769.59
10-22	Upper/Mid Penn	825.47	812.97	813.20	Dry	Dry	812.62
10C23	Lower Pennsylvanian	829.67	766.07	765.92	766.82	765.87	765.97
10C24	Lower Pennsylvanian	821.34	766.70	767.54	767.64	766.39	766.64
10C24P2	Lower Pennsylvanian	821.23	766.90	767.38	767.63	766.68	766.58
10C24P3	Upper Pennsylvanian	820.90	813.00	812.30	813.45	813.65	812.30
10C25	Lower Pennsylvanian	817.02	768.02	768.87	768.67	767.27	767.82
10C25P2	Lower Pennsylvanian	816.99	768.79	769.69	769.74	768.29	768.64
10C25P3	Upper Pennsylvanian	816.98	809.68	809.18	809.63	809.13	808.43
10C26	Lower Pennsylvanian	815.78	768.78	769.68	769.48	768.03	768.48
10C26P2	Lower Pennsylvanian	815.78	769.28	770.13	770.03	768.78	769.03
10C26P3	Upper Pennsylvanian	815.90	800.00	799.86	800.06	800.16	799.56
10C27	Lower Pennsylvanian	817.63	770.93	772.08	771.68	769.98	770.58
10C27P2	Upper Pennsylvanian	817.48	803.68	803.93	804.13	802.58	802.88
10C28	Lower Pennsylvanian	821.78	770.78	771.68	771.48	769.78	770.28

(Sheet 1 of 3)

Table 5 (Continued)

Well Number	Geologic Position or Aquifer	TOC Elev ft NGVD	Ground Water Elev, ft 12-Jul-89	Ground Water Elev, ft 11-Mar-91	Ground Water Elev, ft 28-Jun-91	Ground Water Elev, ft 10-Jan-92	Ground Water Elev, ft 20-May-92
10C28P2	Upper Pennsylvanian	821.81	806.01	806.06	806.06	804.86	805.06
10C29	Lower Pennsylvanian	816.17	767.27	768.42	768.22	766.72	766.87
10C29P2	Upper Pennsylvanian	816.33	797.23	797.33	797.73	796.48	796.58
10C30	Lower Pennsylvanian	822.70	766.90	767.70	767.65	766.45	766.60
10C30P2	Upper Pennsylvanian	822.74	814.40	813.84	815.44	812.89	813.49
10C31	Lower Pennsylvanian	820.60	767.90	769.05	768.90	767.35	767.60
10C31P2	Middle Pennsylvanian	820.74	Dry	Dry	Dry	Dry	Dry
10C31P3	Upper Pennsylvanian	820.58	800.48	801.28	801.38	801.13	800.43
10C32	Lower Pennsylvanian	819.88	768.90	769.78	770.43	768.38	768.63
10C32P2	Upper Pennsylvanian	819.96	800.30	801.21	801.21	801.06	800.11
10C32P3	Upper Pennsylvanian	819.79	805.19	805.44	805.69	804.54	804.59
10C33	Lower Pennsylvanian	814.77	767.57	768.72	768.72	767.07	767.12
10C33P2	Middle Pennsylvanian	814.72	784.02	784.92	784.67	783.92	783.92
10C34	Lower Pennsylvanian	824.57	768.07	769.17	768.92	767.52	767.57
10C34P2	Middle Pennsylvanian	824.65	778.15	779.15	778.65	778.20	778.00
10C34P3	Upper Pennsylvanian	824.55	807.55	807.85	810.05	806.00	808.50
10C35	Lower Pennsylvanian	829.39	763.19	763.94	764.39	763.14	763.24
10C35P2	Upper Pennsylvanian	829.54	806.54	807.34	808.54	807.89	808.34
10C35P3	Upper Pennsylvanian	829.52	812.32	811.62	812.67	810.47	811.12
10C36	Lower Pennsylvanian	824.16	766.06	767.16	766.31	765.36	765.71
10C36P2	Upper Pennsylvanian	824.29	811.69	812.39	812.29	810.64	811.29
10C36P3	Upper Pennsylvanian	824.17	813.27	813.52	813.32	811.47	812.37
10C37	Lower Pennsylvanian	820.73	762.13	763.13	763.28	761.98	761.98
10C37P2	Lower Pennsylvanian	820.74	765.44	766.19	766.19	765.24	765.19
10C37P3	Upper Pennsylvanian	820.85	798.75	799.05	799.10	799.20	797.90
10C38	Lower Pennsylvanian	827.80	761.10	762.25	763.20	760.65	759.80
10C38P2	Upper Pennsylvanian	828.08	Dry	Dry	Dry	Dry	Dry
10C39	Lower Pennsylvanian	829.92	765.70	765.67	766.97	765.02	765.57
10C39P2	Upper Pennsylvanian	829.90	803.50	803.45	803.55	802.60	803.10
10C40	Beech Creek	829.49	570.90	581.49	580.64	580.59	0.00
10C40P2	Lower Pennsylvanian	829.63	762.30	762.10	762.93	762.68	762.63
10C40P3	Upper Pennsylvanian	829.62	Dry	Dry	Dry	Dry	Dry
10C40P4	Upper Pennsylvanian	829.72	809.80	810.57	811.07	809.77	809.67
10C41	Lower Pennsylvanian	832.99	762.09	762.67	762.99	762.34	761.49
10C41P2	Upper Pennsylvanian	832.93	Dry	Dry	Dry	Dry	Dry
10C41P3	Upper Pennsylvanian	833.10	797.90	798.35	798.25	799.00	797.95
10C42	Lower Pennsylvanian	834.76	764.20	764.36	764.16	764.36	763.66
10C42P2	Upper Pennsylvanian	834.93	811.50	811.53	811.38	812.28	810.43

(Sheet 2 of 3)

Table 5 (Concluded)

Well Number	Geologic Position or Aquifer	TOC Elev ft NGVD	Ground Water Elev, ft 12-Jul-89	Ground Water Elev, ft 11-Mar-91	Ground Water Elev, ft 28-Jun-91	Ground Water Elev, ft 10-Jan-92	Ground Water Elev, ft 20-May-92
10C43	Lower Pennsylvanian	820.69	768.90	769.69	771.49	769.94	770.34
10C43P2	Lower Pennsylvanian	820.58	771.70	772.33	772.38	770.58	771.18
10C43P3	Upper Pennsylvanian	820.77	798.30	799.17	798.72	798.52	798.77
10C44	Lower Pennsylvanian	794.61	769.30	770.11	769.46	767.61	768.21
10C44P2	Upper Pennsylvanian	794.78	776.80	777.83	775.08	778.03	777.23
10C45	Lower Pennsylvanian	813.44	Dry	761.54	761.69	760.34	760.94
10C45P2	Upper Pennsylvanian	813.56	Dry	795.31	794.86	792.46	793.71
10C46	Lower Pennsylvanian	818.05	762.40	762.80	762.85	762.75	762.70
10C46P2	Middle Pennsylvanian	818.46	785.40	786.56	785.86	787.66	788.01
10C46P3	Upper Pennsylvanian	818.62	802.60	802.77	802.17	801.62	801.87
10C47	Lower Pennsylvanian	821.96	767.00	767.56	767.56	766.66	767.01
10C47P2	Middle Pennsylvanian	822.11	779.60	780.06	779.86	779.86	779.56
10C47P3	Upper Pennsylvanian	822.06	Dry	Dry	Dry	Dry	Dry
10C48	Lower Pennsylvanian	798.43	766.30	767.43	767.48	766.63	766.68
10C48P2	Middle Pennsylvanian	798.44	781.10	781.14	781.69	780.34	780.69
10C49	Lower Pennsylvanian	808.50	767.10	767.45	766.75	766.50	766.65
10C49P2	Middle Pennsylvanian	808.35	784.00	785.65	783.80	782.35	783.05
10C50	Lower Pennsylvanian	805.49	766.70	767.14	767.34	766.34	766.09
10C50P2	Upper/Mid Penn	805.45	782.00	Dry	Dry	Dry	Dry
10C51	Lower Pennsylvanian	810.41	766.40	766.71	766.96	763.91	765.86
10C51P2	Upper Pennsylvanian	810.64	Dry	Dry	Dry	Dry	Dry
10C52	Lower Pennsylvanian	812.16	779.86	771.86	771.46	769.91	770.41
10C52P2	Lower Pennsylvanian	812.13	771.70	Dry	Dry	Dry	Dry
10C53	Lower Pennsylvanian	816.44	763.40	763.94	763.64	762.79	763.29
10C53P2	Upper Pennsylvanian	816.36	806.10	805.96	806.06	804.76	804.96
10C54	Lower Pennsylvanian	816.80	772.00	773.10	772.10	770.30	770.80
10C55	Lower Pennsylvanian	782.11	767.90	768.11	768.46	767.36	767.41
10C55P2	Fill	782.17	777.00	777.37	774.72	777.12	776.32
10C56	Lower Pennsylvanian	770.71	761.60	761.71	761.46	760.26	760.91
10C57	Lower Pennsylvanian	770.72	760.20	760.57	760.67	758.42	758.17
10C60	Golconda/Haney	651.91	—	643.01	639.71	639.56	640.01
10C61	Sample Fm ?	598.34	—	593.04	591.89	591.39	591.99

(Sheet 3 of 3)

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

Parameter	IDL	MDL	CRQL
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

(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	CRQL
Explosives (Continued)			
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
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

(Sheet 2 of 5)

Table 6 (Continued)

Parameter	IDL	MDL	CRQL
	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
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

(Sheet 3 of 5)

Table 6 (Continued)

Parameter	IDL	MDL	CRQL
BNA (Continued)			
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
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

(Sheet 4 of 5)

Table 6 (Concluded)

Parameter	IDL	MDL	CRQL
Pesticides, Herbicides and PCBs (Continued)			
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
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 7a
Preservatives and Holding Times for Groundwater Samples

Parameters	Preservation	Holding Time
Metals except Mercury	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[1]
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] 7 days until extraction, 40 days after extraction.

Table 7b
Blind Samples and Associated Well Numbers

Round Number	Well Number	Blind Sample Number
1	10C28	10C28P4
	10C25P3	10C25P4
	10-22	10A1
	10C56	10C56P2
2	none	none
3	02C12P2[1]	02C12P4
	02C14	02C14P4
	02C17P2	02C17P4
4	02C15P2	02C15P3

[1] SWMUs 02 and 10 were sampled as the same event. Blinds from either SWMU were used.

Table 8
Total Depth and Feet of Pennsylvanian Core Recovered from 35 Rockeye Well Borings Examined by Indiana Geological Survey

Well Number	Total Depth (ft)	Ft of Pennsylvanian Core
10C23	263	246
10C24	93	84
10C25	91	74
10C26	88	71
10C27	87	77
10C28	86	76
10C29	80	69
10C30	98	86
10C31	87	77
10C32	93	70
10C33	86	74
10C34	99	87
10C35	99	89
10C36	99	73
10C37	105	95
10C38	115	103
10C39	103	97
10C40	288	190
10C41	113	95
10C42	112	102
10C43	94	84
10C44	63	53
10C45	92	80
10C46	82	68
10C47	94	86
10C48	64	54
10C49	79	63
10C50	64	54
10C51	72	63
10C52	83	73
10C53	91	79
10C54	73	59
10C55	33	24
10C56	32	21
10C57	23	13

Table 9
Laboratory Measured Gas Permeabilities and Hydraulic Conductivities of Core Samples from Rockeye Wells

Well Number	Depth (ft below surface)	Porosity %	Intrinsic Permeability (mDarcies)	Intrinsic Permeability m^2	Facies	Hydraulic Conductivity (cm/s) 60°F
10C52	20.0	23.3	178	1.76e-13	CBSF	1.51e-04
10C55	20.0	21.7	12.3	1.21e-14	CBSF	1.04e-05
10C54	21.0	27.2	584	5.76e-13	CBSF	4.96e-04
10C33	31.0	19.7	138	1.36e-13	CBSF	1.17e-04
10C48	40.5	17.7	124	1.22e-13	CBSF	1.05e-04
10C47	41.5	18.8	22.5	2.22e-14	CBSF	1.91e-05
10C51	44.0	21.7	580	5.72e-13	CBSF	4.92e-04
10C49	49.0	22.6	199	1.96e-13	CBSF	1.69e-04
10C33	52.0	20.1	33.5	3.31e-14	CBSF	2.84e-05
10C50	53.0	22.9	41.8	4.13e-14	CBSF	3.55e-05
10C29	59.0	23.8	1100	1.08e-12	CBSF	9.32e-04
10C31	59.5	20.2	318	3.14e-13	CBSF	2.70e-04
10C54	61.0	22.7	223	2.20e-13	CBSF	1.89e-04
10C34	65.0	21.6	57.9	5.71e-14	CBSF	4.92e-05
10C28	69.0	21.8	88.9	8.77e-14	CBSF	7.55e-05
10C32	81.0	19.9	179	1.77e-13	CBSF	1.52e-04
10C42	20.0	22.1	0.738	7.28e-16	CBSF	6.27e-07
10C27	76.0	15.0	0.431	4.25e-16	CBSF	3.66e-07
10C24	83.0	12.6	48.2	4.76e-14	CBSF	4.09e-05
10C31	76.0	30.2	145	1.43e-13	CBSF	1.23e-04
10C42	82.0	16.4	1.66	1.64e-15	CBSF	1.41e-06
10C47	82.5	15.6	0.214	2.11e-16	CBSF	1.82e-07

CBSF = Cross-bedded sandstone facies.
RSF = Rooted sandstone facies.
RBSF = Ripple-bedded sandstone facies.
WBSF = Wavy-bedded sandstone facies.
MSF = Massive sandstone facies.
LSLF = Low-angle bedded siltstone facies.
LSAF = Low-angle bedded sandstone facies.
FBSF = Flaser-bedded sandstone facies.

Properties for Intrinsic Permeability-- Hydraulic Conductivity conversion:

Temperature (°F)	Specific weight (N/m^3)	Dynamic Viscosity (Pa-s)
50	9.80e+03	1.31e-03
60	9.80e+03	1.14e-03
70	9.79e+03	1.00e-03

Where: hydraulic conductivity = intrinsic permeability X (specific weight)/dynamic viscosity.

Table 10
Results of Slug Testing in Rockeye Wells (from Fisher 1996)

Well ID	Test ID	Thickness of Screened Interval (m)	S	T (m^2/s)	K_b (cm/s)	Curve Fit Quality	Comments
10-03	1	2.856	1.29e-01	1.37e-06	4.79e-05	Fair	Unconfined?
	2	2.856	1.05e-01	1.03e-06	3.59e-05	Good	
10-04	1	2.743	2.55e-03	2.05e-06	7.47e-05	Excellent	
10-05	1	2.841	1.90e-01	9.24e-06	3.25e-04	Excellent	Unconfined?
	2	2.841	1.88e-01	1.02e-05	3.58e-04	Excellent	
10-06	1	2.819	3.40e-07	1.13e-05	4.01e-04	Excellent	
	2	2.819	5.12e-03	5.02e-06	1.78e-04	Excellent	
10-07	1	2.789	1.00e-10	1.46e-05	5.24e-04	Excellent	S at lower limit
	2	2.789	4.77e-09	1.03e-05	3.69e-04	Excellent	
10-08	1	2.795	4.24e-10	1.61e-05	5.77e-04	Excellent	
	2	2.795	9.93e-06	7.31e-06	2.61e-04	Excellent	
10-09	1	2.941	1.00e-10	2.60e-06	8.83e-05	Good	S at lower limit
10-10	1	2.819	1.00e-10	4.77e-06	1.69e-04	Good	S at lower limit
10-11	1	2.786	8.11e-05	1.88e-06	6.76e-05	Good	
10-15	1	2.786	1.80e-10	3.58e-05	1.29e-03	Excellent	Scatter in early data
	2	2.786	1.70e-07	2.89e-05	1.04e-03	Excellent	
10-16	1	2.789	1.38e-04	4.83e-06	1.73e-04	Excellent	
10-17	1	2.792	3.01e-03	7.13e-06	2.55e-04	Excellent	
	2	2.792	3.70e-03	7.55e-06	2.70e-04	Excellent	
10-18	1	2.74	8.11e-03	5.41e-06	1.97e-04	Excellent	S at lower limit
	2	2.74	1.04e-02	5.69e-06	2.08e-04	Excellent	
10-19	1	2.795	1.37e-07	1.67e-06	5.96e-05	Excellent	
10-20	1	2.792	1.67e-03	3.56e-06	1.28e-04	Excellent	
	2	2.729	5.88e-02	8.28e-07	2.96e-05	Good	Inconsistent result
10-22	1	2.804	2.56e-03	2.61e-07	9.32e-06	Excellent	
10C23	1	3.048	1.00e-10	1.46e-06	4.80e-05	Good	
10C24	1	3.048	2.12e-04	1.03e-05	3.39e-04	Excellent	
	2	3.048	3.57e-04	7.43e-06	2.44e-04	Excellent	
10C24P	1	3.048	5.50e-06	3.06e-07	1.00e-05	Excellent	
10C25	1	3.048	1.00e-10	1.49e-05	4.90e-04	Excellent	
	2	3.048	5.20e-05	5.21e-06	1.71e-04	Excellent	

(Sheet 1 of 4)

Notes:
S = Storativity predicted by non-linear best fit to data to the model.
T = Transmissivity predicted by non-linear best fit of data to the model.
K_b = Apparent bulk conductivity = T/thickness of screened interval.
Curve fit quality is based on a subjective assessment; see text for discussion.
Comments include an assessment of likely unconfined conditions (based on calculated S and visual inspection of data), S at a lower limit of 1.e-10 *(corresponding to the approximate compressibility of water), slow well recovery (probably due to clogging of the screen), or the presence of an unusual facies in the screened interval.

Table 10 (Continued)

Well ID	Test ID	Thickness of Screened Interval (m)	S	T (m^2/s)	K_b (cm/s)	Curve Fit Quality	Comments
10C25P	1	1.524	1.00e-10	2.00e-06	1.31e-04	Excellent	
	2	1.524	6.77e-06	2.03e-06	1.33e-04	Excellent	
10C25P	1	3.048	2.23e-02	3.97e-08	1.30e-06	Excellent	Partially unconfined?
10C26	1	1.524	1.00e-10	3.15e-06	2.07e-04	Good	S at lower limit
10C26P	1	1.524	1.00e-10	1.95e-06	1.28e-04	Good	
	2	1.524	1.99e-03	1.89e-07	1.24e-05	Good	Inconsistent result
	3	1.524	1.00e-10	1.63e-06	1.07e-04	Excellent	
10C26P	1	3.048	4.72e-01	2.83e-07	9.28e-06	Poor	Unconfined?
	2	3.048	2.21e-01	4.61e-07	1.51e-05	Fair	
10C27	1	3.048	1.00e-10	5.71e-05	1.87e-03	Excellent	
	2	3.048	1.00e-10	5.57e-05	1.83e-03	Excellent	
10C27P	1	3.048	9.79e-03	1.40e-05	4.61e-04	Good	Partially unconfined?
	2	3.048	3.10e-02	9.46e-06	3.10e-04	Good	
10C28	1	3.048	9.89e-06	3.18e-06	1.04e-04	Good	
10C28P	1	3.048	2.95e-04	5.86e-06	1.92e-04	Good	
	2	3.048	1.53e-03	4.38e-06	1.44e-04	Good	
10C29	1	3.048	1.00e-10	5.82e-05	1.91e-03	Excellent	
	2	3.048	1.00e-10	8.56e-04	2.81e-02	Good	
	3	3.048	7.47e-03	3.21e-04	1.05e-02	Good	
	4	3.048	3.47e-09	9.11e-04	2.99e-02	Excellent	
	5	3.048	1.00e-10	9.05e-04	2.97e-02	Good	
	6	3.048	1.00e-10	9.31e-04	3.05e-02	Excellent	
	7	3.048	1.00e-10	8.65e-04	2.84e-02	Excellent	
	8	3.048	2.08e-07	6.21e-04	2.04e-02	Excellent	
	9	3.048	1.00e-10	8.94e-04	2.93e-02	Excellent	
10C29P	1	3.048	5.00e-01	5.68e-07	1.86e-05	Poor	Boundary effect?
	2	3.048	5.00e-01	1.14e-06	3.73e-05	Poor	
	3	3.048	5.00e-01	1.32e-06	4.33e-05	Poor	
10C30	1	3.048	3.04e-09	7.72e-06	2.53e-04	Excellent	
	2	3.048	2.53e-04	2.43e-06	7.96e-05	Excellent	
10C30P	1	3.048	3.91e-06	3.37e-06	1.10e-04	Good	
	2	3.048	5.00e-01	1.88e-05	6.17e-04	Good	
	3	3.048	1.00e-10	7.82e-06	2.57e-04	Good	
10C31	1	3.048	1.00e-10	3.49e-04	1.15e-02	Fair	
	2	3.048	1.00e-10	3.49e-04	1.15e-02	Fair	
10C32	1	3.048	5.00e-03	7.11e-05	2.33e-03	Excellent	
	2	3.048	1.32e-04	1.00e-04	3.28e-03	Excellent	

(Sheet 2 of 4)

Table 10 (Continued)

Well ID	Test ID	Thickness of Screened Interval (m)	S	T (m^2/s)	K_h (cm/s)	Curve Fit Quality	Comments
10C32P	1	1.524	1.92e-01	1.20e-05	7.85e-04	Fair	Unconfined
	2	1.524	1.92e-01	2.82e-05	1.85e-03	Fair	Unconfined
10C32P	1	1.524	6.00e-08	1.95e-06	1.28e-04	Excellent	
10C33	2	3.048	6.36e-04	1.16e-06	3.80e-05	Excellent	
	3	3.048	6.77e-05	1.40e-06	4.61e-05	Excellent	
10C34	1	3.048	1.00e-10	1.36e-04	4.45e-03	Good	S at lower limit
	2	3.048	1.00e-10	1.48e-04	4.86e-03	Good	
10C35	1	3.048	5.00e-05	3.01e-05	9.87e-04	Good	
	2	3.048	3.66e-04	2.96e-05	9.71e-04	Excellent	
10C35P	1	3.048	6.23e-05	3.97e-06	1.30e-04	Excellent	
	2	3.048	1.00e-08	7.12e-06	2.34e-04	Good	
10C35P	1	3.048	2.66e-03	2.07e-06	6.80e-05	Good	
	2	3.048	5.00e-01	1.53e-07	5.02e-06	Poor	Water table in screen
10C36	1	3.048	2.62e-07	8.17e-05	2.68e-03	Excellent	
	2	3.048	2.00e-08	9.58e-05	3.14e-03	Excellent	
10C36P	1	3.048	5.66e-04	4.51e-05	1.48e-03	Excellent	
	2	3.048	1.56e-02	6.00e-05	1.97e-03	Fair	
10C36P	1	3.048	1.50e-08	3.17e-06	1.04e-04	Excellent	
	2	3.048	5.66e-04	9.52e-07	3.12e-05	Excellent	
10C37	1	3.048	1.00e-10	6.14e-06	2.01e-04	Excellent	
	2	3.048	6.01e-08	3.68e-06	1.21e-04	Excellent	
10C37P	1	1.524	1.00e-10	1.05e-05	6.87e-04	Excellent	
	2	1.524	1.00e-09	9.64e-06	6.33e-04	Excellent	
10C37P	1	3.048	8.84e-05	4.78e-07	1.57e-05	Excellent	
10C38	1	3.048	1.00e-10	8.28e-05	2.72e-03	Good	
	2	3.048	1.00e-10	7.83e-05	2.57e-03	Good	
10C39	1	3.048	1.00e-10	5.58e-06	1.83e-04	Fair	S at lower limit
10C39P	1	3.048	2.77e-04	3.97e-07	1.30e-05	Good	
10C40P	1	3.048	2.62e-03	4.06e-06	1.33e-04	Good	
	2	3.048	7.82e-03	1.94e-06	6.37e-05	Good	
10C40P	1	3.048	2.85e-05	5.01e-06	1.64e-04	Excellent	
	2	3.048	2.32e-03	2.40e-06	7.87e-05	Good	
10C41	1	3.048	1.26e-01	4.35e-07	1.43e-05	Poor	Unconfined?
	2	3.048	1.64e-01	3.34e-07	1.09e-05	Fair	
10C42	1	3.048	6.39e-02	2.17e-06	7.11e-05	Poor	Unconfined?
	2	3.048	5.00e-01	4.18e-07	1.37e-05	Poor	
10C43	1	3.048	3.72e-06	2.32e-05	7.80e-04	Excellent	
	3	3.048	1.00e-10	4.64e-05	1.52e-03	Good	

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Table 10 (Concluded)

Well ID	Test ID	Thickness of Screened Interval (m)	S	T (m^2/s)	K_b (cm/s)	Curve Fit Quality	Comments
10C43P	1	1.524	1.00e-10	1.44e-05	9.48e-04	Excellent	
	2	1.524	2.05e-04	5.09e-06	3.34e-04	Good	
10C43P	1	3.048	7.32e-04	2.72e-05	8.91e-04	Excellent	
	2	3.048	1.01e-03	2.98e-05	9.79e-04	Excellent	
10C44	1	3.048	1.00e-05	4.06e-06	1.33e-04	Excellent	
	2	3.048	5.38e-04	2.34e-06	7.66e-05	Excellent	
10C45	1	3.048	3.31e-01	4.62e-06	1.52e-04	Good	Unconfined?
	2	3.048	5.50e-02	1.77e-05	5.80e-04	Excellent	
10C45P	1	3.048	5.00e-01	7.00e-07	2.30e-05	Fair	Unconfined?
	2	3.048	5.00e-01	7.01e-07	2.30e-05	Fair	
10C46	1	3.048	1.00e-10	1.56e-04	5.10e-03	Good	S at lower limit
	2	3.048	2.00e-10	1.56e-04	5.13e-03	Excellent	
10C46P	1	1.524	1.00e-10	4.35e-07	2.85e-05	Good	
10C47	1	3.048	2.39e-09	1.43e-05	4.70e-04	Excellent	
	2	3.048	2.78e-06	1.68e-05	5.50e-04	Excellent	
10C47P	1	3.048	1.88e-01	1.16e-06	3.79e-05	Poor	Unconfined?
	2	3.048	2.39e-01	1.41e-06	4.63e-05	Poor	
10C48	1	3.048	6.25e-07	5.14e-05	1.69e-03	Excellent	
	2	3.048	5.71e-09	7.61e-05	2.50e-03	Excellent	
10C49	1	3.048	5.08e-04	1.45e-05	4.77e-04	Excellent	
	2	3.048	5.65e-04	1.47e-05	4.81e-04	Excellent	
	3	3.048	1.07e-03	1.36e-05	4.45e-04	Excellent	
10C50	1	3.048	1.00e-10	4.39e-05	1.44e-03 +	Excellent	
	2	3.048	1.78e-08	3.48e-05	1.14e-03	Excellent	
10C51	1	3.048	3.93e-01	7.88e-07	2.59e-05	Poor	Unconfined?
	2	3.048	3.91e-01	6.44e-07	2.11e-05	Poor	
10C52	1	3.048	1.00e-10	4.30e-05	1.41e-03	Excellent	
	2	3.048	1.53e-08	3.19e-05	1.04e-03	Excellent	
10C53	1	3.048	3.98e-03	2.30e-07	7.54e-06	Good	
10C53P	1	3.048	6.90e-04	4.44e-05	1.46e-03	Good	
	2	3.048	4.17e-03	4.36e-05	1.43e-03	Excellent	
10C54	1	3.048	1.82e-03	2.10e-06	6.87e-05	Good	
	2	3.048	2.15e-02	1.48e-06	4.86e-05	Good	
10C55	1	3.048	2.97e-03	6.98e-06	2.29e-04	Good	
	2	3.048	2.49e-03	7.14e-06	2.34e-04	Good	
10C56	1	3.048	2.92e-02	1.10e-06	3.62e-05	Excellent	
	2	3.048	4.82e-02	1.03e-06	3.37e-05	Good	
10C57	1	3.048	5.00e-03	6.78e-09	2.23e-07	Fair	20% Recovery
	2	3.048	2.50e-05	3.46e-08	1.13e-06	Fair	40% Recovery

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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
Nitrates	Cadmium Reduction	USEPA Method 353.2
Nitrites	Colorimetric	USEPA Method 353.2

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

Table 12
Summary of Tentatively Identified Compounds (TIC), NSWCC Rockeye, March 1991-May 1992

Compound	Well Number and Sampling Round(s)								
Formic acid	10-11 (1)								
Hexadecanoic acid	10C30P2 (3)	10C33 (1)	10C34 (1)	10C34P2 (3)	10C36 (3)	10C39 (3)			
Octadecanoic acid	10C30 (2)	10C33 (1,3)	10C33P2 (3)	10C34 (3)	10C34P4 (1)	10C36 (1)	10C60 (3)		
Phthalate	10-04 (1)	10C23 (1)	10C24 (1)	10C25 (1)	10C39 (1)	10C42P2 (1)	10C44 (1)	10C46P2 (1)	
Sulfur (SB)	10-04 (1)	10-10 (1,2,3)	10-14B (3)	10-15 (3)	10-22 (1)	10C26P2 (1)			
2(2-butoxyethoxy)ethanol	10-01 (1)	10-20 (2)	10C23 (1)	10C26P2 (3)	10C29P2 (1)	10C30 (2)	10C34P4 (1)	10C36 (3)	10C37 (3)
	10C38 (3)	10C39 (3)	10C39P2 (1)	10C41 (3)	10C42 (3)	10C42P2 (3)	10C44 (2)	10C44P2 (1)	10C45 (1,3)
	10C48 (1)	10C54 (3)	10C60 (1)	10C61 (2)					
1-methyl,-2-pyrrolidinone	10C31P3 (1)	10C33 (1)	10C33P2 (1)	10C34 (1)	10C34P2 (1)	10C34P3 (1)	10C34P4 (1)	10C37P3 (1)	10C40 (1)
Dodecane	10C40P4 (1)								
Eicosane	10C40P4 (1)								
Heptadecane	10C40P4 (1)								
Nonadecane	10C40P4 (1)								
Pentadecane	10C40P4 (1)								
2,7,10-trimethyl dodecane	10C40P4 (1)								

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Table 12 (Continued)

Compound	Well Number and Sampling Round(s)								
6-ethyl-2-methyl decane	10C40P4 (1)								
Tetradecanoic acid, 1-methyethylester	10C46P2 (1)								
Caprolactam	10-03 (2)	10-09 (3)	10-13 (3)	10-16 (3)	10-18 (3)	10-19 (3)	10-20 (3)	10C26P3 (3)	10C32P 3 (3)
	10C40P2 (3)	10C40P4 (3)	10C43P2 (3)	10C43P3 (3)	10C44 (3)	10C46P2 (3)	10C51 (3)		
	10C55 (3)	10C60 (3)	10C61 (3)						
Hexanedioic acid, dioethylester	R3F (3)	10-09 (3)	10-11 (3)	10C26P2 (3)	10C26P3 (3)	10C33 (2)	10C35P2 (2)	10C35P3 (2)	10C36 (2)
	10C43P2 (3)	10C43P3 (3)	10C44 (3)	10C44P2 (3)	10C45 (3)	10C46P3 (3)	10C47 (2)	10C52 (3)	10C55 (2)
	10C55P2 (2)								
4,4-butylidenebis[2-(1,1-dimethylethy-5-methylphenol)]	10C30 (2)								
Pentatriacontane	10C46 (2)								
6-methyl-5-hepten-2-ol	10C41 (2)								
1-ethyl-4-methylbenzene	10C54 (2)								
1,3-trimethylbenzene	10C47 (2)								
Hexanedioic acid, dioctylester	10-02 (3)								
5-Octadecene	10-18 (3)	10C23 (3)							

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Table 12 (Concluded)

Compound	Well Number and Sampling Round(s)								
9-Octadecene	R5F (3)	10-04 (3)							
Decanoic acid	10C30 (3)	10C40P2 (3)	10C40P4 (3)						
Dodecanamide,N,N-bis(2-hydroxyethyl)	10C31 (3)	10C34 (3)	10C39 (3)						
Hexahydro-1,3,5-trinitro-1,3,5-triazine	10-17 (3)	10C55P2 (3)							
Octadecanoic acid-9	10C34 (3)								
Acetaldehyde	R2F (3)	R5F (3)							
Phosphine oxide, triphenyl	10C46 (3)	10C46P2 (3)	10C46P3 (3)						
2-methyl-1,3,5-trinitrobenzene	10-17 (3)	10C55 (3)	10C55P2 (3)						
Hexanedioic acid, mono(2-ethylhexyl)ester	10C42 (3)	10C42P2 (3)	10C43 (3)						
Benzene,1,1'-sulfonylbis(4-chloro-)	10C46 (3)	10C46P3 (3)	10C47 (3)						
1,3-trimethylbenzene	10C51 (3)								
5,5-dimethylundecane	10C51 (3)								

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Table 13
Metals and Corresponding Detection Limits Used in ANOVA Calculations, Rockeye

Parameter Name	Detection Limit (ppb)	Printed Order
Al	30.00	1
Ba	20.00	2
Sb	3.00	3
As	2.00	4
Be	1.00	5
Cd	0.20	6
Cr	5.00	7
Co	20.00	8
Cu	5.00	9
Pb	1.00	10
Mn	5.00	11
Hg	0.20	12
Ni	5.00	13
Se	2.00	14
Ag	1.00	15
Tl	2.00	16
Sn	50.00	17
Va	10.00	18
Zn	5.00	19

Table 14
Wells and Data Availability for Statistical Analysis of Metals in the Uppermost Aquifer, Rockeye[1]

Well ID	16 Mar 1991	01 June 1991	09 Jan 1992	14 May 1992
10-03	X	X	X	X
10-04	X	X	X	X
10-05	X	X	X	X
10-06	X	X	X	X
10-07	X	X	X	X
10-08	X	X	X	X
10-09	X	X	X	X
10-10	X	X	X	X
10-11	X	X	X	X
10-13	X	X	X	X
10-14B	X	X	X	X
10-16	X	X	X	X
10-17	X	X	X	X
10-18	X	X	X	X
10-19	X	X		X
10-20	X	X	X	X
10-21	X		X	X
10-22	X	X		X
10C24P3	X	X	X	X
10C25P3	X	X	X	X
10C26P3	X	X	X	X
10C27P2	X	X	X	X
10C28P2	X	X	X	X
10C29P2	X	X	X	X
10C30P2	X	X	X	X
10C31P3	X	X	X	X
10C32P3	X	X	X	X
10C33P2	X	X	X	X
10C34P3	X	X	X	X
10C35P3	X	X	X	X
10C36P3	X	X	X	X
10C37P3	X	X	X	X
10C39P2	X	X	X	X
10C40P4	X	X	X	X
10C41P3	X	X	X	X

(Continued)

[1] X = data present, [blank] = data not present.

Table 14 (Concluded)

Well ID	16 Mar 1991	01 June 1991	09 Jan 1992	14 May 1992
10C42P2	X	X	X	X
10C43P3	X	X	X	X
10C44P2	X	X	X	X
10C45P2	X	X	X	X
10C46P3	X	X	X	X
10C47P2	X	X	X	X
10C48P2	X	X	X	X
10C49P2	X	X	X	X
10C53P2	X	X	X	X
10C55P2	X	X	X	X

Table 15
Statistically Significant Metals (X) in Wells of the Uppermost Aquifer, Rockeye

Well No.	Al	As	Ba	Be	Cd	Cr	Co	Cu	Pb	Mn	Ni	Se	Zn
10-04				X			X			X			X
10-05													
10-06													
10-07													
10-08													
10-09													
10-10		X											
10-11		X											
10-13													
10-14B													
10-16	X			X	X		X		X		X		X
10-17			X										
10-18			X										
10-19													
10-20													
10-21								X					
10-22													
10C24P3													
10C25P3	X			X			X		X		X		X
10C26P3													
10C27P2													
10C28P2												X	
10C29P2	X			X	X			X	X				X
10C30P2	X			X			X	X	X		X		
10C31P3	X					X		X		X	X		
10C32P3													
10C33P2		X											
10C34P3													
10C35P3													
10C36P3													
10C37P3	X			X									
10C39P2	X			X	X	X	X	X	X		X		X
10C40P4	X			X	X				X				
10C41P3													
10C42P2													
10C43P3													

(Continued)

Table 15 (Concluded)

Well No.	Al	As	Ba	Be	Cd	Cr	Co	Cu	Pb	Mn	Ni	Se	Zn
10C44P2													
10C45P2													
10C46P3	X			X					X				
10C47P2	X												
10C48P2													
10C49P2													
10C53P2													
10C55P2													
Mean of all wells, ppb	5,237	2.19	25.4	2.53	2.69	3.52	126.4	25.3	1.98	4,162	238.8	1.26	284

Table 16
Wells and Data Availability for Statistical Analysis of Metals in the Middle Aquifer, Rockeye[1]

Well ID	16 Mar 1991	01 June 1991	09 Jan 1992	14 May 1992
10-03	X	X	X	X
10C33P2	X	X	X	X
10C34P2	X	X	X	X
10C42P2	X	X	X	X
10C43P3	X	X	X	X
10C46P2	X	X	X	X
10C47P2	X	X	X	X
10C48P2	X	X	X	X
10C49P2	X	X	X	X
1055P2	X	X	X	X

[1] X = data present, [blank] = data not present.

Table 17
Statistically Significant Metals in Wells of the Middle Aquifer, Rockeye[1]

Well No.	Al	As	Be	Co	Pb	Mn	Ni	Zn
10-03								
10C33P2		X				X		
10C34P2	X							
10C42P2								
10C43P3								
10C46P2	X		X	X	X		X	X
10C47P2	X		X					
10C48P2								
10C49P2								
10C55P2								

[1] Wells 10-03, 10C42P2, and 10C43P3 served as background wells for the middle aquifer.

Table 18
Wells and Data Availability for Statistical Analysis of Metals in the Middle Aquifer, Rockeye[1]

Well ID	16 Mar 1991	01 June 1991	09 Jan 1992	14 May 1992
10C23	X	X	X	X
10C24	X	X	X	X
10C25	X	X	X	X
10C26	X	X	X	X
10C27	X	X	X	X
10C28	X	X	X	X
10C29	X	X	X	X
10C30	X	X	X	X
10C31	X	X	X	X
10C32	X	X	X	X
10C33	X	X	X	X
10C34	X	X	X	X
10C35	X	X	X	X
10C36	X	X	X	X
10C37	X	X	X	X
10C38	X	X	X	X
10C39	X	X	X	X
10C40P2	X	X	X	X
10C41	X	X	X	X
10C42	X	X	X	X
10C43	X	X	X	X
10C44	X	X	X	X
10C45	X	X	X	X
10C46	X	X	X	X
10C47	X	X	X	X
10C48	X	X	X	X
10C49	X	X	X	X
10C50	X	X	X	X
10C51	X	X	X	X
10C52	X	X	X	X
10C53	X	X	X	X
10C54	X	X	X	X
10C55	X	X	X	X
10C56	X	X	X	X
10C57	X	X		X

[1] X = data present, [blank] = data not present.

Table 19
Statistically Significant Metals in Wells of the Lower Aquifer[1]

Well No.	Al	As	Ba	Be	Co	Pb	Mn	Ni	Zn
10C23									
10C24									
10C25									
10C26									
10C27		X							
10C28		X			X				
10C29					X				
10C30									
10C31									
10C32	X								
10C33			X						
10C34	X	X		X	X	X		X	X
10C35	X			X	X		X	X	X
10C36									
10C37									
10C38	X			X	X		X	X	X
10C39		X							
10C40P2					X			X	
10C41					X		X	X	X
10C42									
10C43									
10C44	X	X							
10C45									
10C46	X			X	X		X	X	X
10C47	X	X		X	X	X		X	X
10C48					X		X	X	X
10C49					X			X	X
10C50	X			X	X		X	X	X
10C51					X			X	X
10C52									
10C53			X						
10C54									
10C55									
10C56	X				X			X	X
Mean of all wells, ppb	1,103	2.08	17.9	2.06	85.8	1.03	4,098	176.9	206

X = metal was statistically significant for given well.

[1] Wells 10C42, 10C43, and 10C52 served as background wells for the lower aquifer.

Table 20
Database Printout Showing Rockeye Wells with Detected Explosives and Amounts Detected

Well Number	Date Sampled	Parameter (Analyte)	Qualifier	Amount Detected (mg/l)
10-01	01/09/92	HMX		0.032
10-01	05/14/92	HMX		0.051
10-01	01/09/92	RDX		0.056
10-01	05/14/92	RDX		0.046
10-02	01/09/92	HMX		0.037
10-02	03/16/91	HMX		0.030
10-02	05/14/92	HMX		0.055
10-02	01/09/92	RDX		0.034
10-02	05/14/92	RDX		0.044
10-07	01/09/92	HMX		0.066
10-07	03/16/91	HMX		0.055
10-07	05/14/92	HMX		0.119
10-07	06/01/91	HMX		0.100
10-07	01/09/92	RDX		0.035
10-07	03/16/91	RDX		0.022
10-07	05/14/92	RDX		0.082
10-07	06/01/91	RDX		0.032
10-07	05/14/92	TNT	J	0.009
10-08	01/09/92	HMX		0.056
10-08	03/16/91	HMX		0.028
10-08	05/14/92	HMX		0.151
10-08	06/01/91	HMX		0.215
10-08	01/09/92	RDX		0.041
10-08	03/16/91	RDX		0.022
10-08	05/14/92	RDX		0.135
10-08	06/01/91	RDX		0.134
10-08	01/09/92	TNT	J	0.006
10-08	03/16/91	TNT	J	0.015
10-08	05/14/92	TNT		0.033
10-17	01/09/92	2,4-DNT		0.020
10-17	01/09/92	HMX		0.334
10-17	03/16/91	HMX		0.518
10-17	05/14/92	HMX		0.368
10-17	06/01/91	HMX		0.352

(Sheet 1 of 3)

Table 20 (Continued)

Well Number	Date Sampled	Parameter (Analyte)	Qualifier	Amount Detected (mg/l)
10-17	01/09/92	RDX		0.422
10-17	03/16/91	RDX		0.806
10-17	05/14/92	RDX		0.618
10-17	06/01/91	RDX		0.632
10-17	01/09/92	TNB		0.025
10-17	03/16/91	TNB		0.034
10-17	05/14/92	TNB	J	0.019
10-17	06/01/91	TNB		0.029
10-17	01/09/92	TNT		0.260
10-17	03/16/91	TNT		0.379
10-17	05/14/92	TNT		0.284
10-17	06/01/91	TNT		0.329
10-18	01/09/92	HMX		0.147
10-18	03/16/91	HMX		0.098
10-18	05/14/92	HMX		0.070
10-18	06/01/91	HMX		0.044
10-18	03/16/91	RDX		0.043
10-18	05/14/92	RDX		0.037
10-21	01/09/92	RDX	J	0.012
10-21	03/16/91	RDX		0.023
10-21	05/14/92	RDX		0.026
10C33	03/16/91	TNT		0.027
10C34	03/16/91	TNT		0.027
10C35	01/09/92	RDX	J	0.006
10C35	03/16/91	TNT	J	0.018
10C37	03/16/91	RDX	J	0.018
10C37	03/16/91	TNT	J	0.014
10C55	01/09/92	HMX		0.042
10C55	03/16/91	HMX		0.120
10C55	05/14/92	HMX		0.026
10C55	06/01/91	HMX		0.050
10C55	01/09/92	RDX		0.278
10C55	03/16/91	RDX		0.548
10C55	05/14/92	RDX		0.160
10C55	06/01/91	RDX		0.244
10C55	01/09/92	TNT		0.066

(Sheet 2 of 3)

Table 20 (Concluded)

Well Number	Date Sampled	Parameter (Analyte)	Qualifier	Amount Detected (mg/l)
10C55	03/16/91	TNT		0.190
10C55	05/14/92	TNT		0.042
10C55P2	01/09/92	HMX		0.220
10C55P2	03/16/91	HMX		0.396
10C55P2	05/14/92	HMX		0.281
10C55P2	06/01/91	HMX		0.412
10C55P2	01/09/92	RDX		0.116
10C55P2	03/16/91	RDX		0.088
10C55P2	05/14/92	RDX		0.094
10C55P2	06/01/91	RDX		0.115
10C55P2	01/09/92	TNT	J	0.014
10C55P2	03/16/91	TNT		0.034
10C55P2	05/14/92	TNT		0.021
10C55P2	06/01/91	TNT		0.044
10C57	03/16/91	TNT	J	0.015
10C60	03/16/91	HMX		0.050
10C60	01/09/92	RDX	J	0.012
10C60	03/16/91	RDX		0.051

(Sheet 3 of 3)

Table 21
Mean Detected Amounts of Explosives, Four Rounds, Rockeye in mg/l

Well No.	DNB	HMX	RDX	TET-RYL	TNB	TNT	2,4-DNT	2,6-DNT
10-01	—	0.0310	0.0373	—	—	—	—	—
10-02	—	0.0407	0.0293	—	—	—	—	—
10-03	—	—	—	—	—	—	—	—
10-04	—	—	—	—	—	—	—	—
10-05	—	—	—	—	—	—	—	—
10-06	—	—	—	—	—	—	—	—
10-07	—	0.08500	0.04275	—	—	0.00975	—	—
10-08	—	0.11250	0.08300	—	—	0.01600	—	—
10-09	—	—	—	—	—	—	—	—
10-10	—	—	—	—	—	—	—	—
10-11	—	—	—	—	—	—	—	—
10-12	—	—	—	—	—	—	—	—
10-13	—	—	—	—	—	—	—	—
10-14	—	—	—	—	—	—	—	—
10-14B	—	—	—	—	—	—	—	—
10-15	—	—	—	—	—	—	—	—
10-16	—	—	—	—	—	—	—	—
10-17	—	0.39300	0.61950	—	0.02675	0.31300	0.01250	—
10-18	—	0.08975	0.02500	—	—	—	—	—
10-19	—	—	—	—	—	—	—	—
10-20	—	—	—	—	—	—	—	—
10-21	—	—	0.01775	—	—	—	—	—
10-22	—	—	—	—	—	—	—	—
10C23	—	—	—	—	—	—	—	—
10C24	—	—	—	—	—	—	—	—
10C24P2	—	—	—	—	—	—	—	—
10C24P3	—	—	—	—	—	—	—	—
10C25	—	—	—	—	—	—	—	—
10C25P2	—	—	—	—	—	—	—	—
10C25P3	—	—	—	—	—	—	—	—
10C26	—	—	—	—	—	—	—	—
10C26P2	—	—	—	—	—	—	—	—
10C26P3	—	—	—	—	—	—	—	—
10C27	—	—	—	—	—	—	—	—
10C27P2	—	—	—	—	—	—	—	—
10C28	—	—	—	—	—	—	—	—

(Sheet 1 of 3)

Table 21 (Continued)

Well No.	DNB	HMX	RDX	TET-RYL	TNB	TNT	2,4-DNT	2,6-DNT
10C28P2	—	—	—	—	—	—	—	—
10C29	—	—	—	—	—	—	—	—
10C29P2	—	—	—	—	—	—	—	—
10C30	—	—	—	—	—	—	—	—
10C30P2	—	—	—	—	—	—	—	—
10C31	—	—	—	—	—	—	—	—
10C31P2	—	—	—	—	—	—	—	—
10C31P3	—	—	—	—	—	—	—	—
10C32	—	—	—	—	—	—	—	—
10C32P2	—	—	—	—	—	—	—	—
10C32P3	—	—	—	—	—	—	—	—
10C33	—	—	—	—	—	0.01425	—	—
10C33P2	—	—	—	—	—	—	—	—
10C34	—	—	—	—	—	0.01425	—	—
10C34P2	—	—	—	—	—	—	—	—
10C34P3	—	—	—	—	—	—	—	—
10C35	—	—	0.00900	—	—	0.01200	—	—
10C35P2	—	—	—	—	—	—	—	—
10C35P3	—	—	—	—	—	—	—	—
10C36	—	—	—	—	—	—	—	—
10C36P2	—	—	—	—	—	—	—	—
10C36P3	—	—	—	—	—	—	—	—
10C37	—	—	0.012	—	—	0.01100	—	—
10C37P2	—	—	—	—	—	—	—	—
10C37P3	—	—	—	—	—	—	—	—
10C38	—	—	—	—	—	—	—	—
10C38P2	—	—	—	—	—	—	—	—
10C39	—	—	—	—	—	—	—	—
10C39P2	—	—	—	—	—	—	—	—
10C40	—	—	—	—	—	—	—	—
10C40P2	—	—	—	—	—	—	—	—
10C40P3	—	—	—	—	—	—	—	—
10C40P4	—	—	—	—	—	—	—	—
10C41	—	—	—	—	—	—	—	—
10C41P2	—	—	—	—	—	—	—	—

(Sheet 2 of 3)

Table 21 (Concluded)

Well No.	DNB	HMX	RDX	TET-RYL	TNB	TNT	2,4-DNT	2,6-DNT
10C41P3	—	—	—	—	—	—	—	—
10C42	—	—	—	—	—	—	—	—
10C42P2	—	—	—	—	—	—	—	—
10C43	—	—	—	—	—	—	—	—
10C43P2	—	—	—	—	—	—	—	—
10C43P3	—	—	—	—	—	—	—	—
10C44	—	—	—	—	—	—	—	—
10C44P2	—	—	—	—	—	—	—	—
10C45	—	—	—	—	—	—	—	—
10C45P2	—	—	—	—	—	—	—	—
10C46	—	—	—	—	—	—	—	—
10C46P2	—	—	—	—	—	—	—	—
10C46P3	—	—	—	—	—	—	—	—
10C47	—	—	—	—	—	—	—	—
10C47P2	—	—	—	—	—	—	—	—
10C47P3	—	—	—	—	—	—	—	—
10C48	—	—	—	—	—	—	—	—
10C48P2	—	—	—	—	—	—	—	—
10C49	—	—	—	—	—	—	—	—
10C49P2	—	—	—	—	—	—	—	—
10C50	—	—	—	—	—	—	—	—
10C50P2	—	—	—	—	—	—	—	—
10C51	—	—	—	—	—	—	—	—
10C51P2	—	—	—	—	—	—	—	—
10C52	—	—	—	—	—	—	—	—
10C52P2	—	—	—	—	—	—	—	—
10C53	—	—	—	—	—	—	—	—
10C53P2	—	—	—	—	—	—	—	—
10C54	—	—	—	—	—	—	—	—
10C55	—	0.05950	0.30750	—	—	0.07700	—	—
10C55P2	—	0.32725	0.10325	—	—	0.02825	—	—
10C56	—	—	—	—	—	—	—	—
10C57	—	—	—	—	—	0.01167	—	—
10C60	—	0.0233	0.0243	—	—	—	—	—
10C61	—	—	—	—	—	—	—	—

(Sheet 3 of 3)

Table 22
Amounts Detected of Nitrites and Nitrates in Ground Water in Round 4 at Rockeye in mg/l

Well Number	Amount Detected in Round 4	
	Nitrite Nitrogen (D.L. = 0.00500)	Nitrate Nitrogen (D.L. = 0.02000)
10-01	0.01300	0.46100
10-02	ND	0.68000
10-03	ND	0.03400
10-04	0.01500	ND
10-05	ND	0.02400
10-06	0.00600	0.17400
10-07	0.00700	0.58400
10-08	0.00500	0.06100
10-09	ND	ND
10-10	0.00600	0.04400
10-11	0.00900	0.03900
10-13	0.00900	0.23400
10-14B	0.00700	0.65800
10-15	No value	No value
10-16	0.00900	0.0400
10-17	0.01600	0.08600
10-18	0.00700	0.05400
10-19	ND	0.02800
10-20	ND	0.05800
10-21	0.00700	ND
10-22	ND	ND
10C23	ND	0.19800
10C24	ND	0.03600
10C24P2	0.00700	ND
10C24P3	0.00600	0.24200
10C25	ND	0.03800
10C25P2	ND	0.02200
10C25P3	ND	0.02200
10C26	0.00500	0.02900
10C26P2	0.00500	0.06100
10C26P3	0.00500	0.02100

(Sheet 1 of 3)

Table 22 (Continued)

Well Number	Amount Detected in Round 4	
	Nitrite Nitrogen (D.L. = 0.00500)	Nitrate Nitrogen (D.L. = 0.02000)
10C27	ND	ND
10C27P2	ND	0.98900
10C28	0.00600	0.02100
10C28P2	0.00500	0.70500
10C29	ND	0.02100
10C29P2	0.01000	ND
10C30	0.00500	0.10300
10C30P2	ND	0.09100
10C31	ND	ND
10C31P3	0.00600	0.12000
10C32	0.01100	ND
10C32P2	0.00600	ND
10C32P3	ND	0.08300
10C33	ND	0.03300
10C33P2	ND	ND
10C34	ND	ND
10C34P2	ND	0.31000
10C34P3	ND	0.0900
10C35	0.01200	0.02500
10C35P2	0.00600	ND
10C35P3	0.00700	0.03300
10C36	0.0100	ND
10C36P2	0.03300	ND
10C36P3	ND	0.03200
10C37	ND	0.08100
10C37P2	ND	0.03800
10C37P3	0.08200	ND
10C38	0.01600	0.02800
10C39	0.01000	0.05800
10C39P2	0.01000	0.05600
10C40P2	0.01800	0.07800
10C40P4	0.00700	0.26400
10C41	ND	0.11700

(Sheet 2 of 3)

Table 22 (Concluded)

Well Number	Amount Detected in Round 4	
	Nitrite Nitrogen (D.L. = 0.00500)	Nitrate Nitrogen (D.L. = 0.02000)
10C41P3	ND	0.22100
10C42	ND	0.02100
10C42P2	0.00800	0.18800
10C43	0.00800	0.02400
10C43P2	0.00500	0.04000
10C43P3	0.00700	0.06700
10C44	ND	0.02300
10C44P2	ND	0.06900
10C45	ND	ND
10C45P2	ND	0.1300
10C46	0.01100	0.07400
10C46P2	ND	0.07500
10C46P3	ND	0.05700
10C47	0.00600	ND
10C47P2	0.01700	0.19800
10C48	0.01500	ND
10C48P2	0.01200	0.02300
10C49	0.00500	0.11000
10C49P2	0.00600	0.06700
10C50	0.00500	0.04300
10C51	0.00700	0.10600
10C52	ND	0.02200
10C53	ND	0.03500
10C53P2	0.00600	0.90700
10C54	ND	0.03000
10C55	0.00800	0.04300
10C55P2	0.00700	0.832
10C56	0.01300	.0800
10C57	0.01200	ND
10C60	0.00500	0.0440
10C61	ND	ND

(Sheet 3 of 3)

Table 23
Mean Detected Amounts of Cyanide and Sulfides over Four Rounds, Rockeye

Well Number	Avg. Amount Detected	
	Cyanide (I.D.L. = 0.00500)	Sulfide (I.D.L. = 0.02000)
10-01	0.00313	—
10-04	—	0.02825
10-05	—	0.02900
10-07	—	0.05625
10-08	0.00388	0.27500
10-09	—	0.01350
10-10	—	0.02025
10-11	—	0.01650
10-14B	—	0.04925
10-15	—	0.02150
10-16	0.00363	—
10-17	0.00775	—
10-18	—	0.03150
10-19	—	0.08867
10-21	0.00313	—
10C23	—	0.01275
10C24P2	—	0.02850
10C26	0.00363	—
10C27	0.00338	0.03240
10C27P2	—	0.04600
10C28	—	0.02250
10C28P2	—	0.09675
10C29	—	0.02075
10C29P2	—	0.03300
10C30	—	0.01300
10C30P2	—	0.02625
10C31	—	0.01600
10C31P3	—	0.01325
10C32P2	—	0.01300
10C33	—	0.01325
10C33P2	—	0.03575
10C34	—	0.01250
10C34P2	—	0.01500

(Continued)

Table 23 (Concluded)

Well Number	Avg. Amount Detected	
	Cyanide (I.D.L. = 0.00500)	Sulfide (I.D.L. = 0.02000)
10C34P3	—	0.01500
10C35	—	0.00950
10C35P2	—	0.01050
10C35P3	—	0.03200
10C36	—	0.01223
10C36P2	—	0.02300
10C36P3	—	0.02300
10C37	—	0.00733
10C37P2	—	0.01067
10C39	—	0.01425
10C39P2	—	0.01225
10C40	—	0.05100
10C40P2	—	0.00950
10C40P4	—	0.01300
10C41	—	0.01725
10C41P3	—	0.01350
10C42	—	0.01300
10C42P2	—	0.01250
10C43	—	0.01250
10C43P2	—	0.02875
10C43P3	—	0.32800
10C44	—	0.01400
10C45P2	—	0.01250
10C46	—	0.01250
10C46P3	—	0.01275
10C48P2	—	0.02725
10C49P2	—	0.01975
10C53	—	0.0135
10C53P2	—	0.05800
10C54	—	0.31250
10C55	0.00363	—
10C55P2	0.00538	—

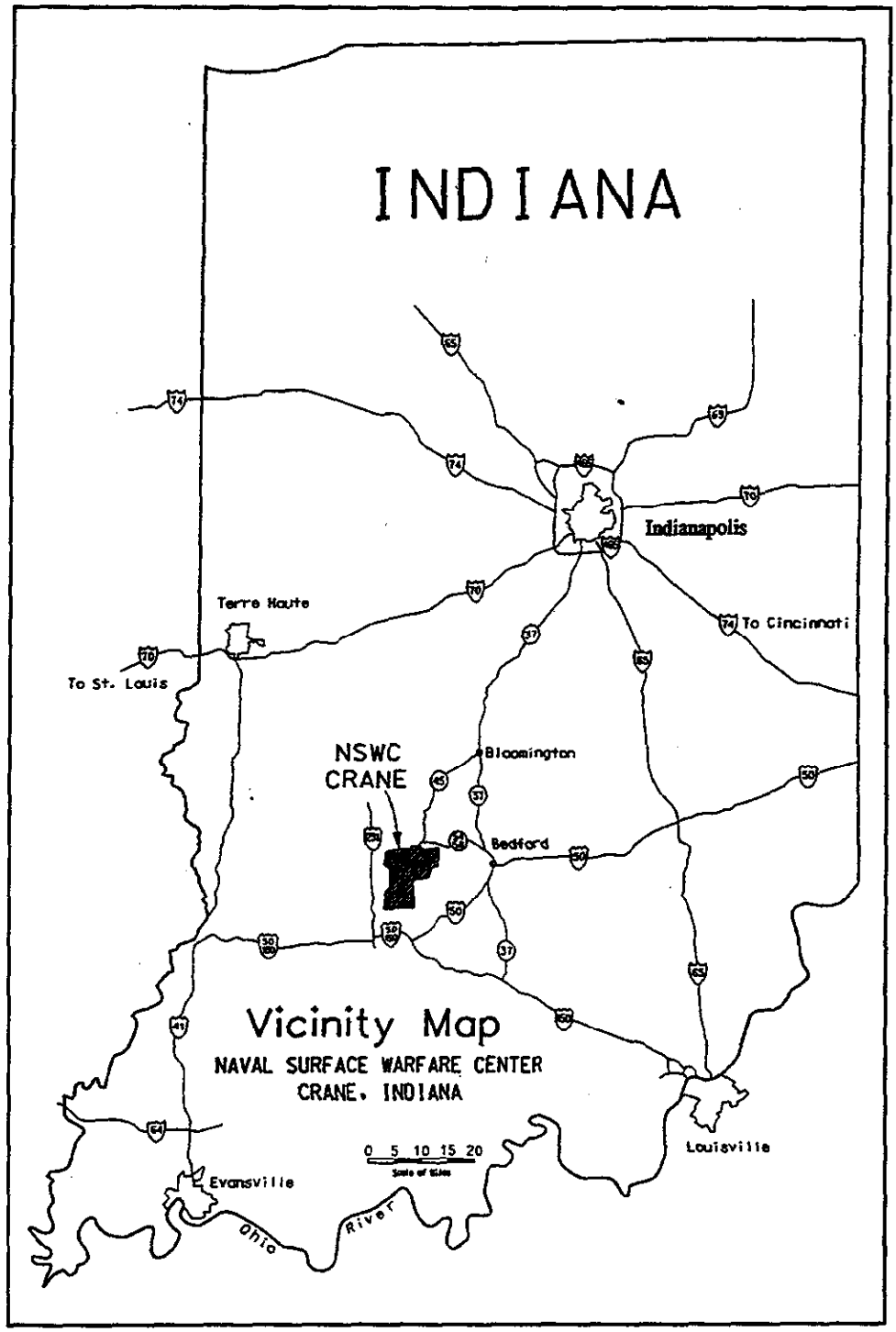


Figure 1. Location of NSWC Crane, Indiana

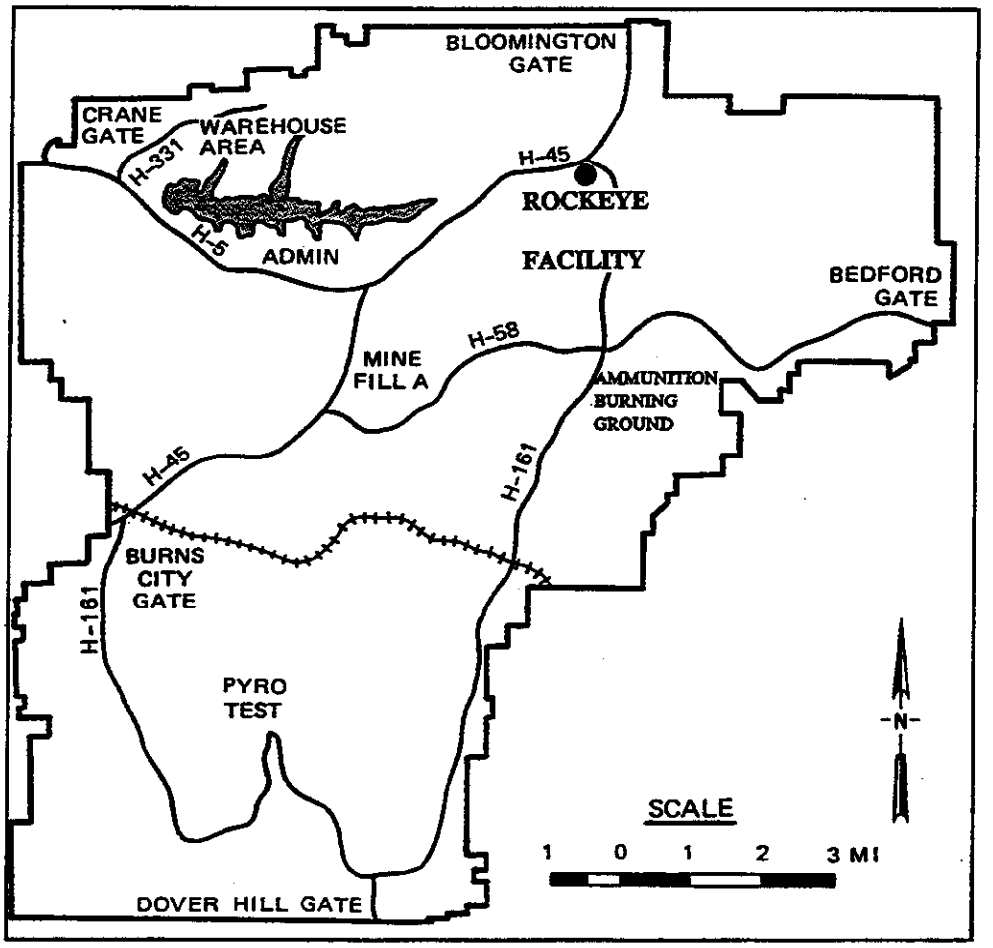


Figure 2. Location of the Rockeye Facility at the Naval Surface Warfare Center Crane, Indiana.

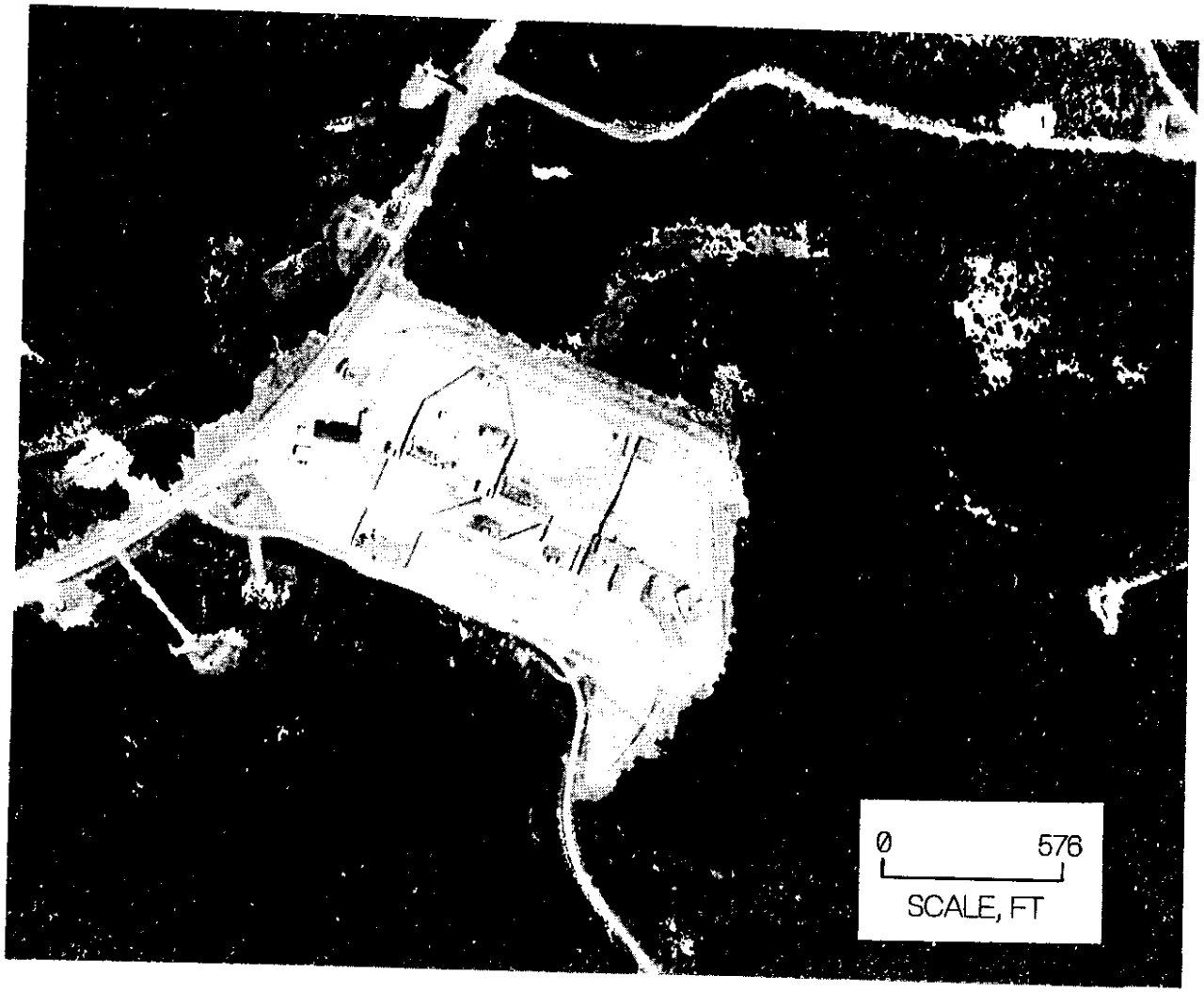


Figure 3A. High altitude color-infrared (in monochrome) aerial photograph of the Rockeye Facility, taken in May, 1988.

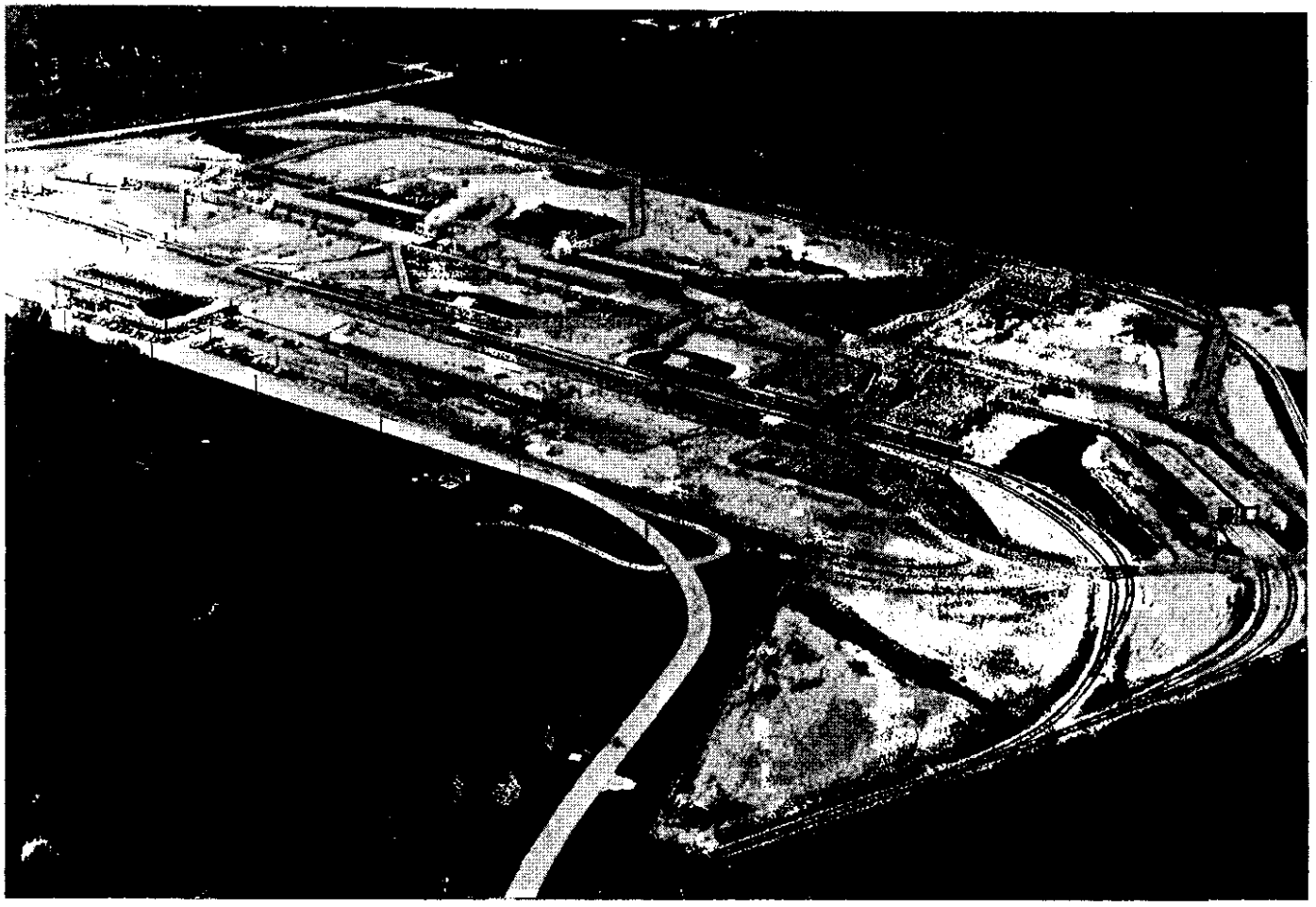


Figure 3B. Oblique aerial view of the Rockeye Facility in April, 1988, looking north-northwest.

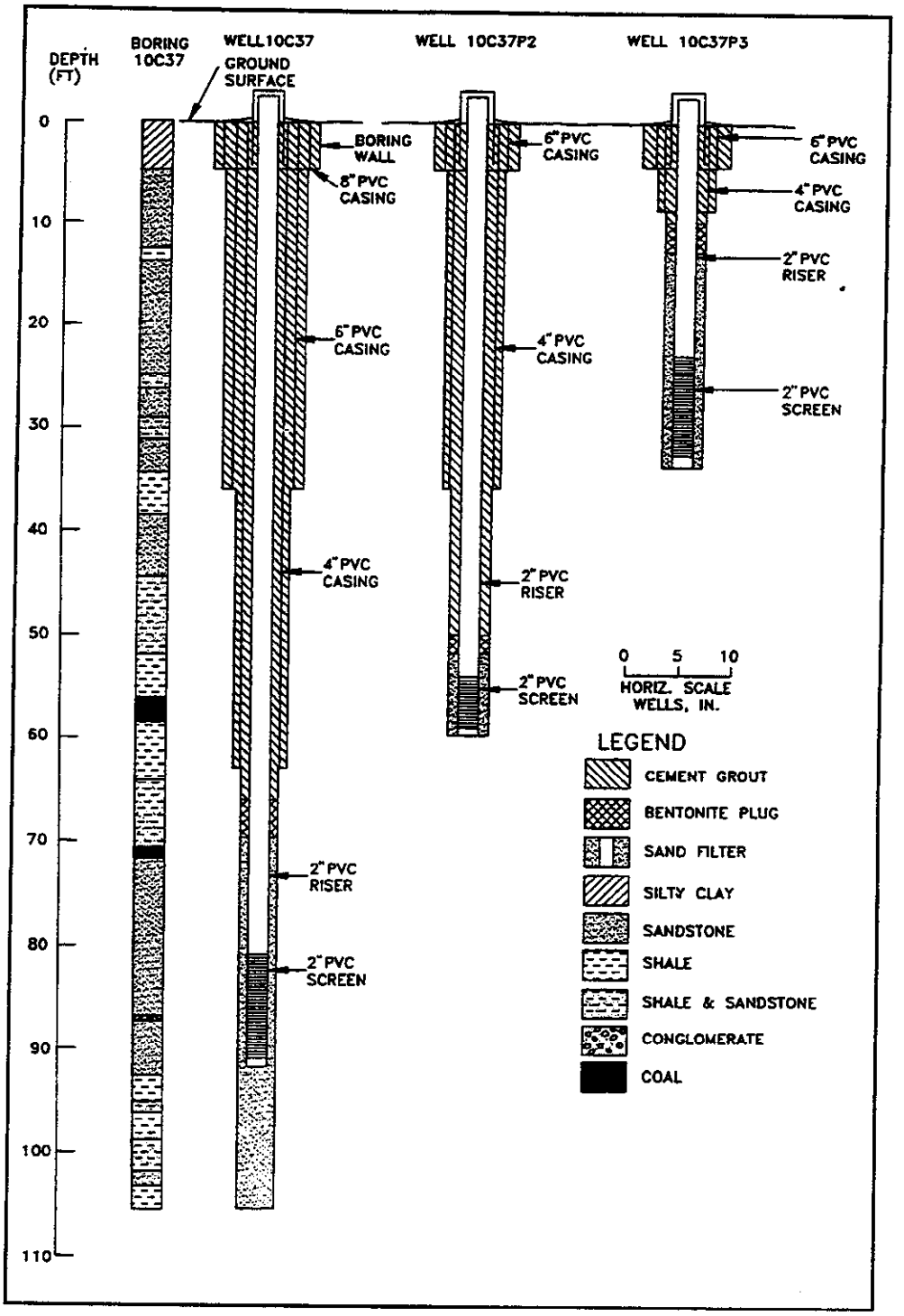


Figure 4. Typical well installation and accompanying boring log for Rockeye RFI wells.

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 — Proponent: CEMP-RT

Figure 5. Chain-of-custody form for groundwater sampling

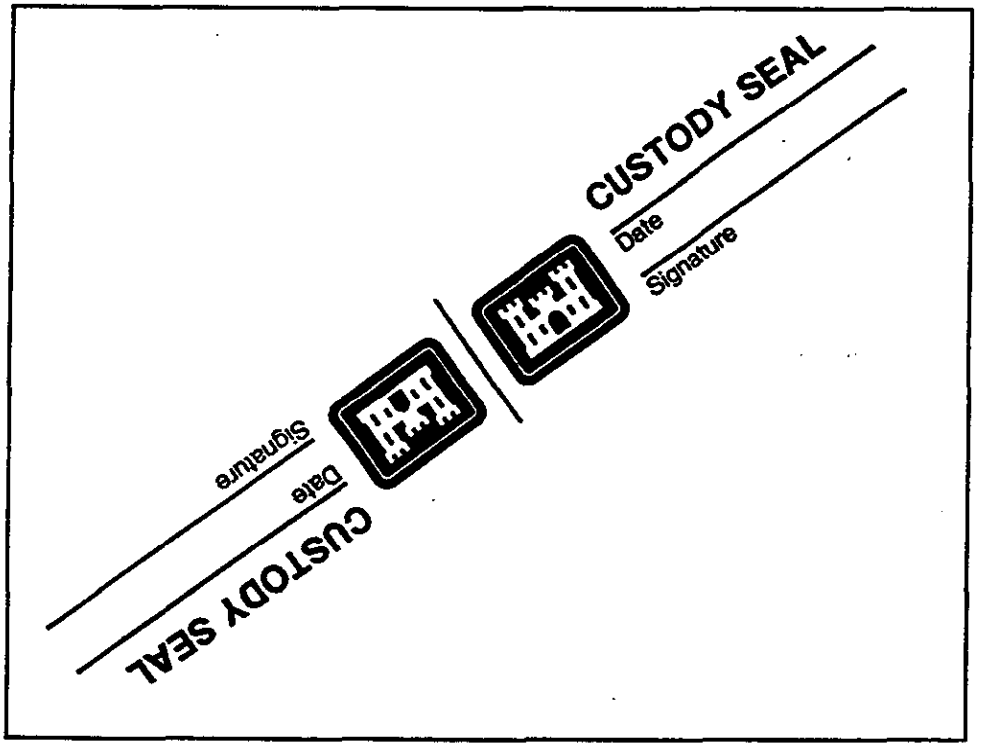


Figure 6. Example of chain-of-custody sample tag

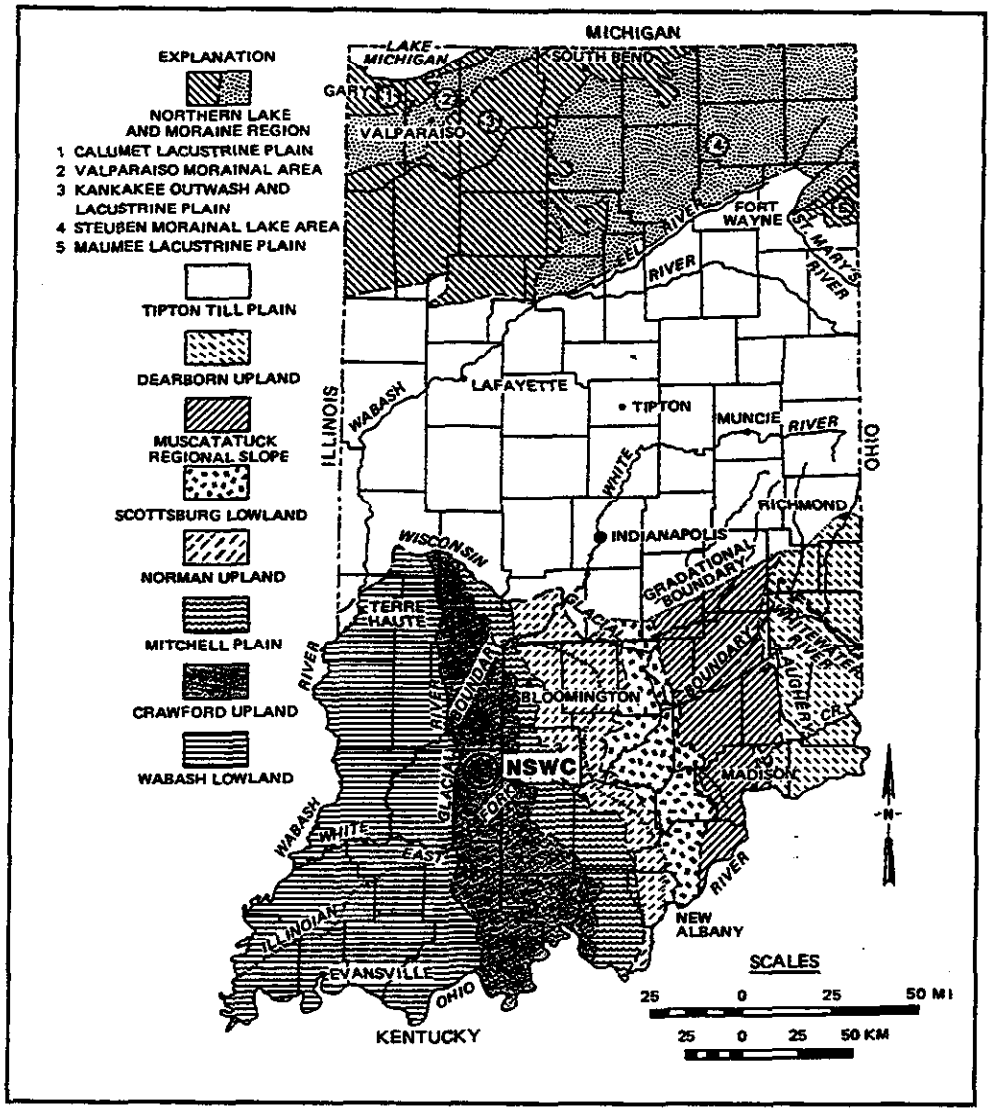


Figure 7. Physiographic divisions of the State of Indiana (Perry and Smith, 1958)

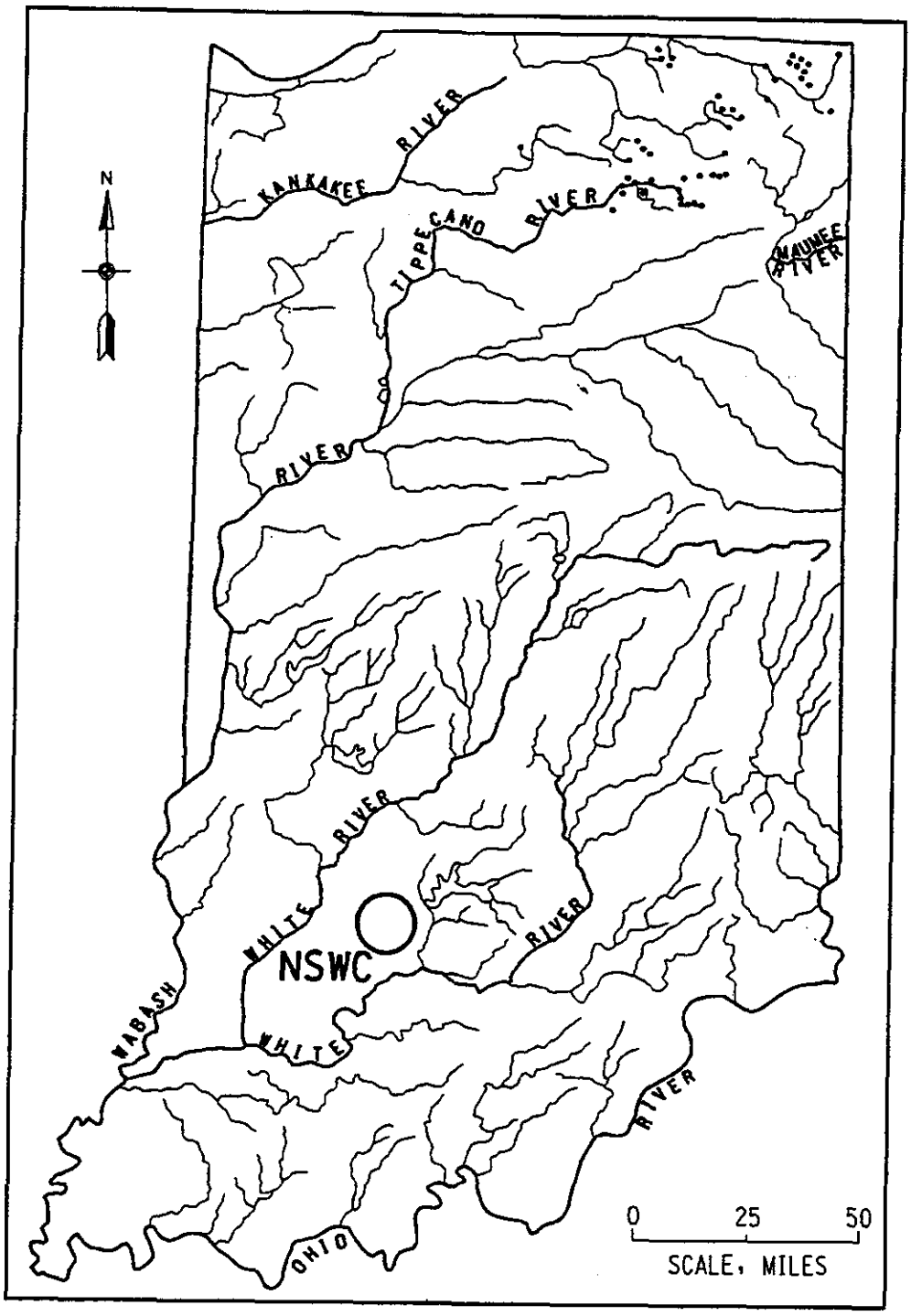


Figure 8. The stream system in Indiana (after Indiana Academy of Science, 1966)

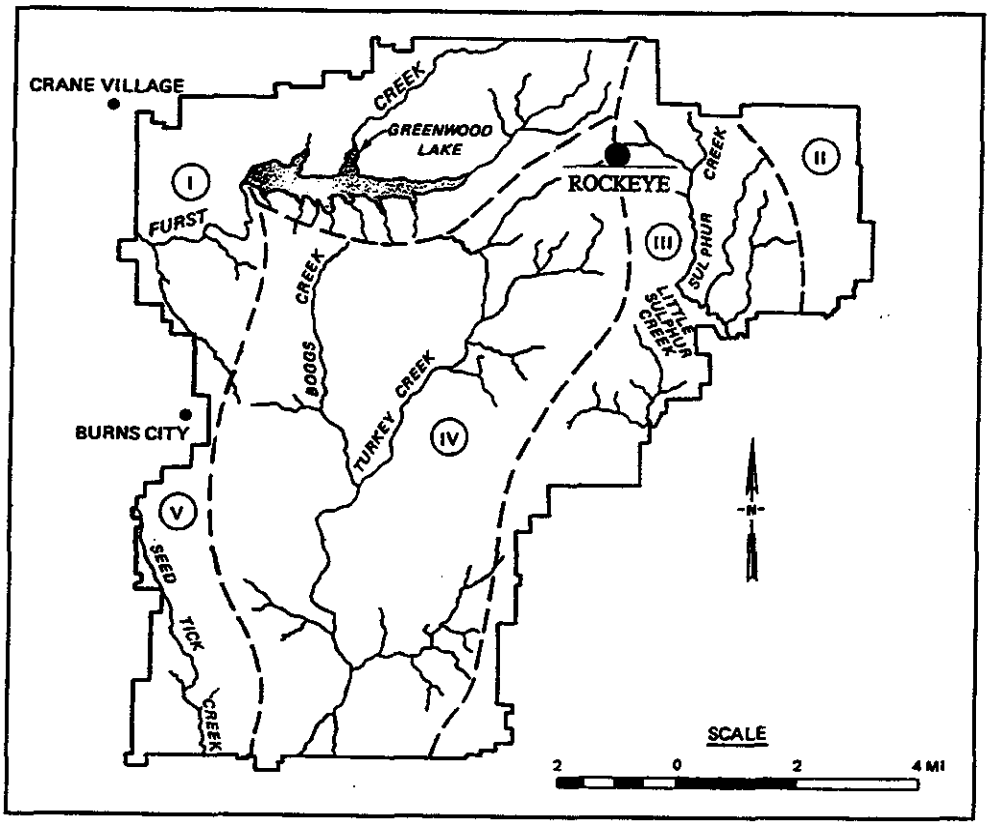


Figure 9. Major surface drainage basins at the Naval Surface Warfare Center Crane, Indiana (Chesapeake Division Naval Facilities Engineering Command, 1979).

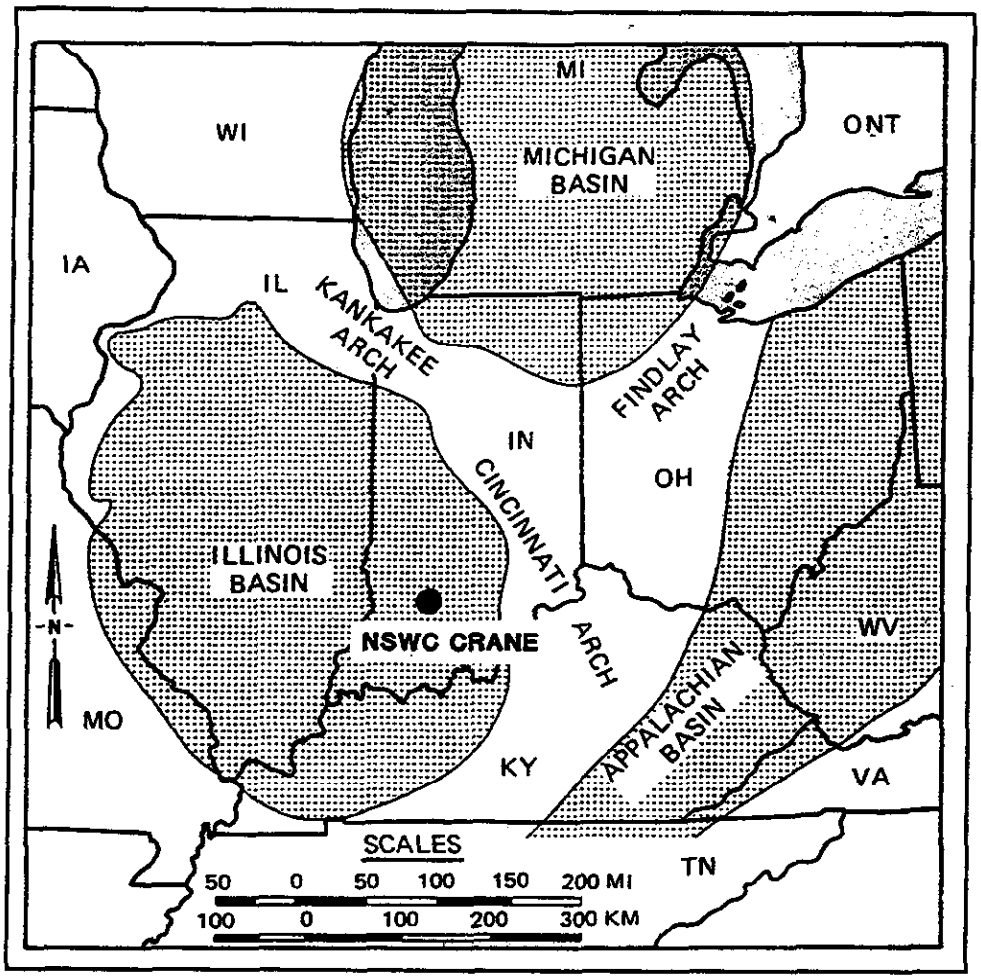


Figure 10. Major structural provinces of the Midwestern United States (Carpenter et al, 1975)

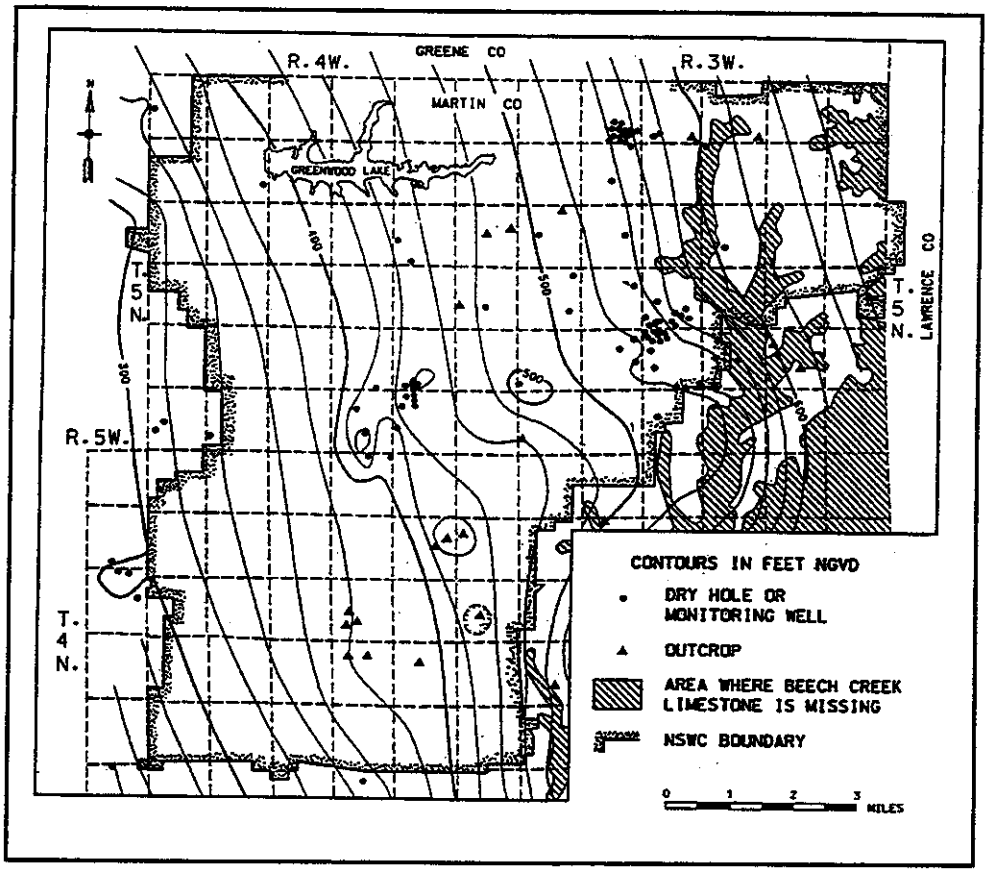


Figure 11. Structural contours on the base of the Beech Creek limestone, NSWC Crane

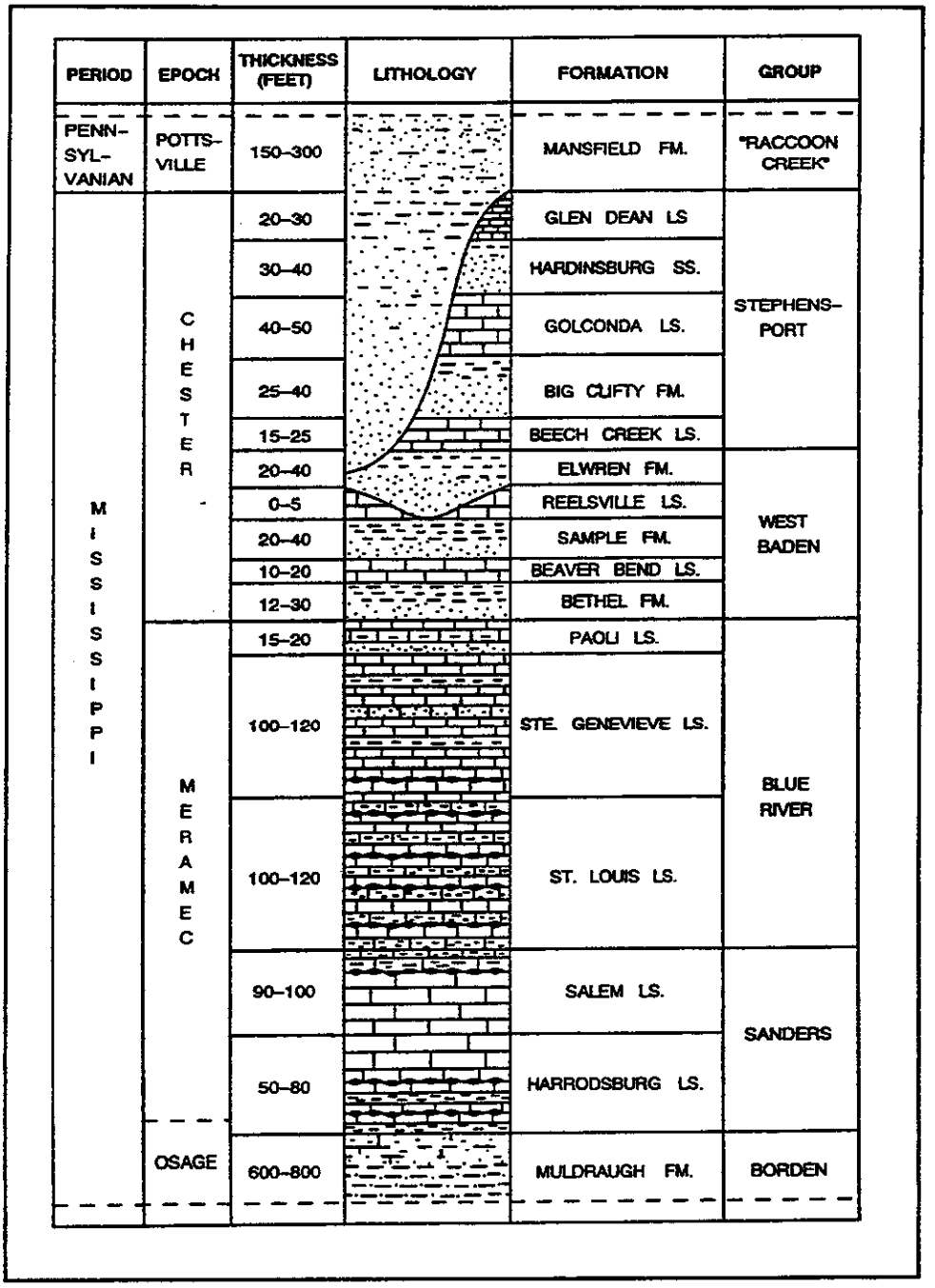


Figure 12. Stratigraphic column of Pennsylvanian and Mississippian Periods in southern Indiana

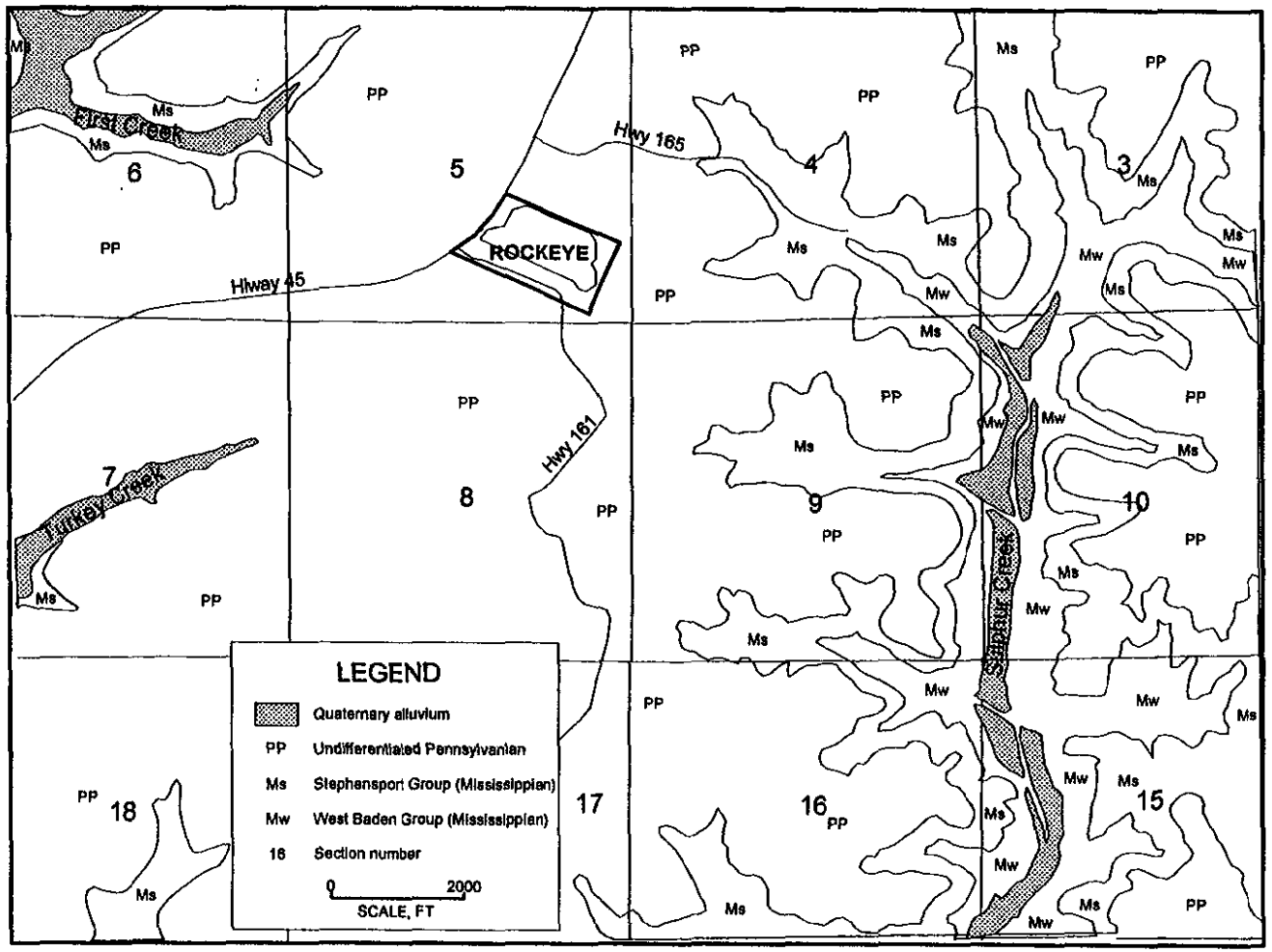


Figure 13. Surface geologic contacts in Rockeye study area.

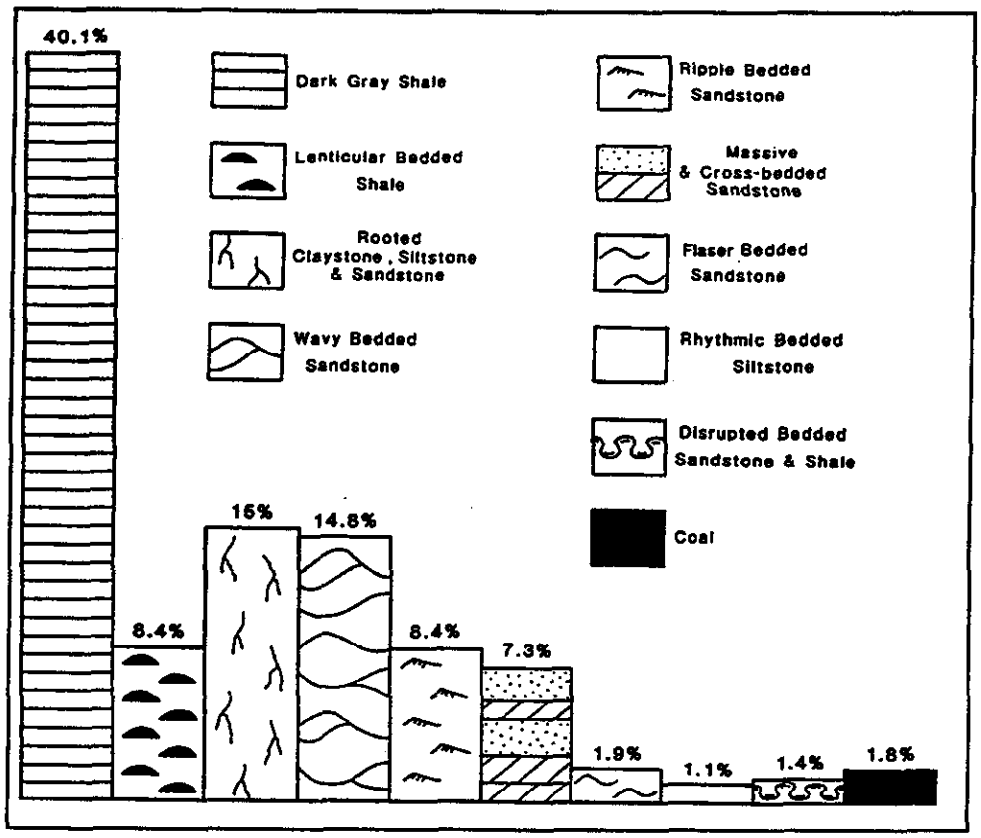


Figure 14. Relative percent of occurrence of Pennsylvanian facies in core from NSWC Crane (Barnhill, 1992).

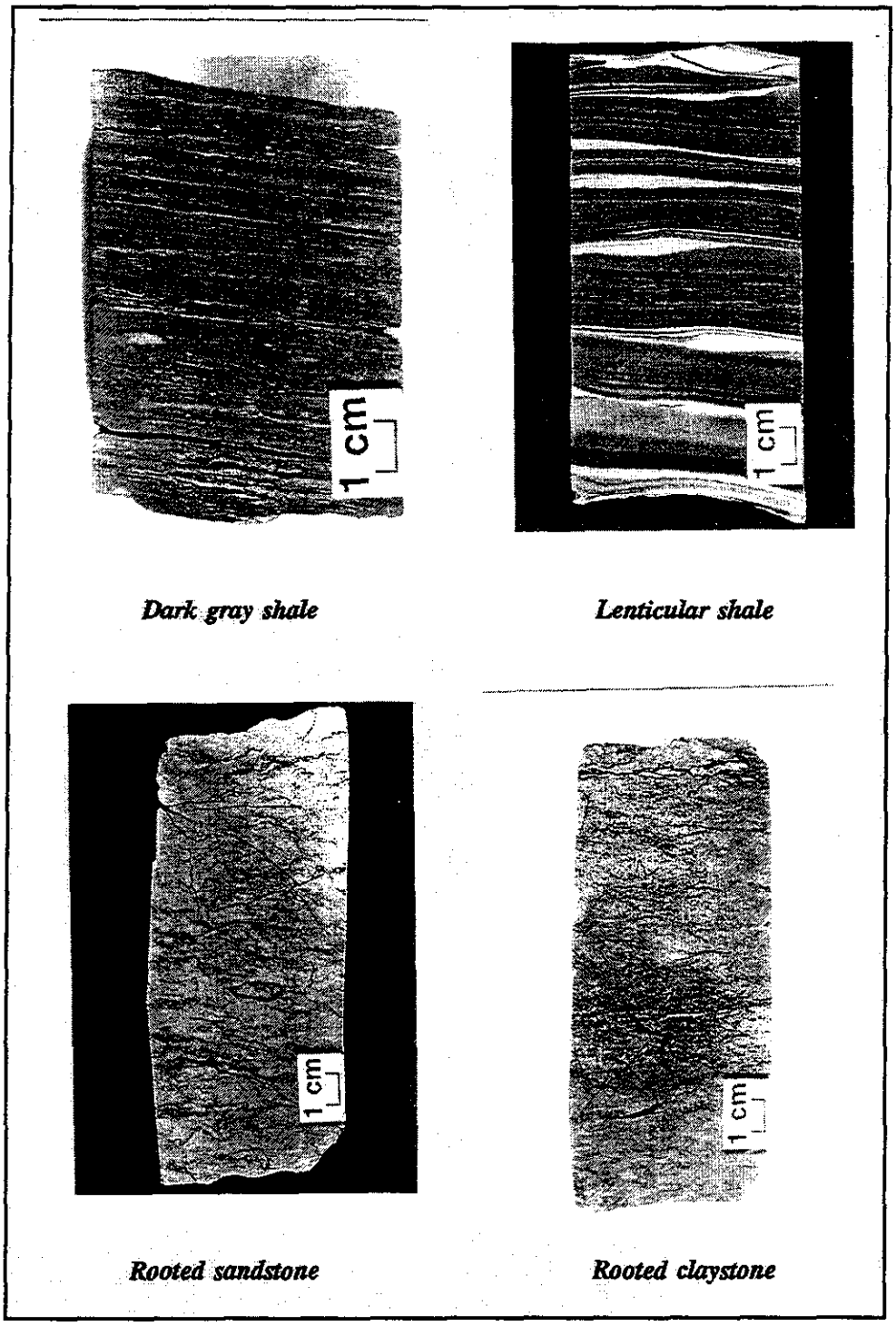


Figure 15. Facies described in core from Rockeye Facility (Barnhill, 1992).

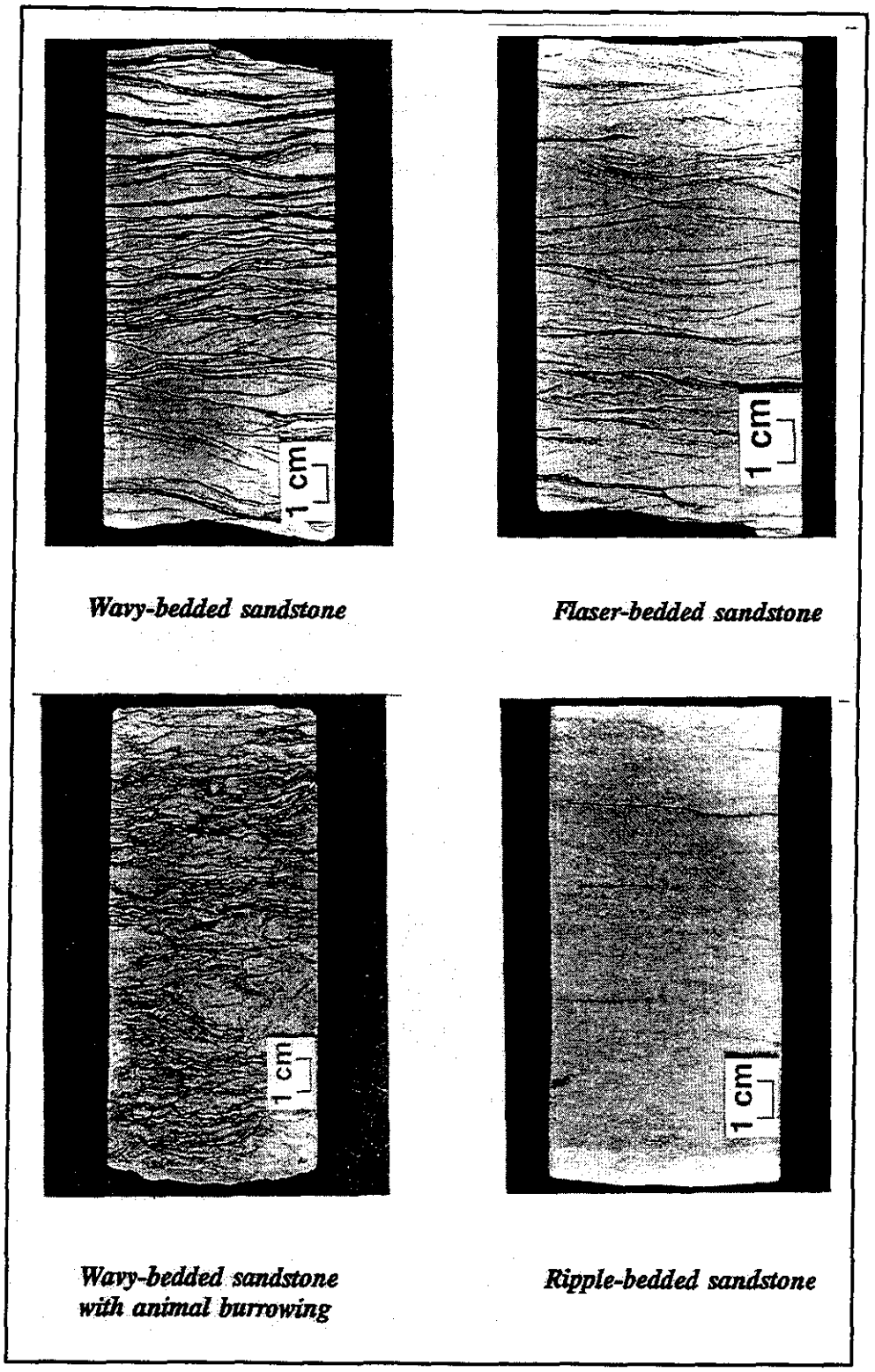


Figure 16. Facies described in core from Rockeye Facility (Barnhill, 1992).

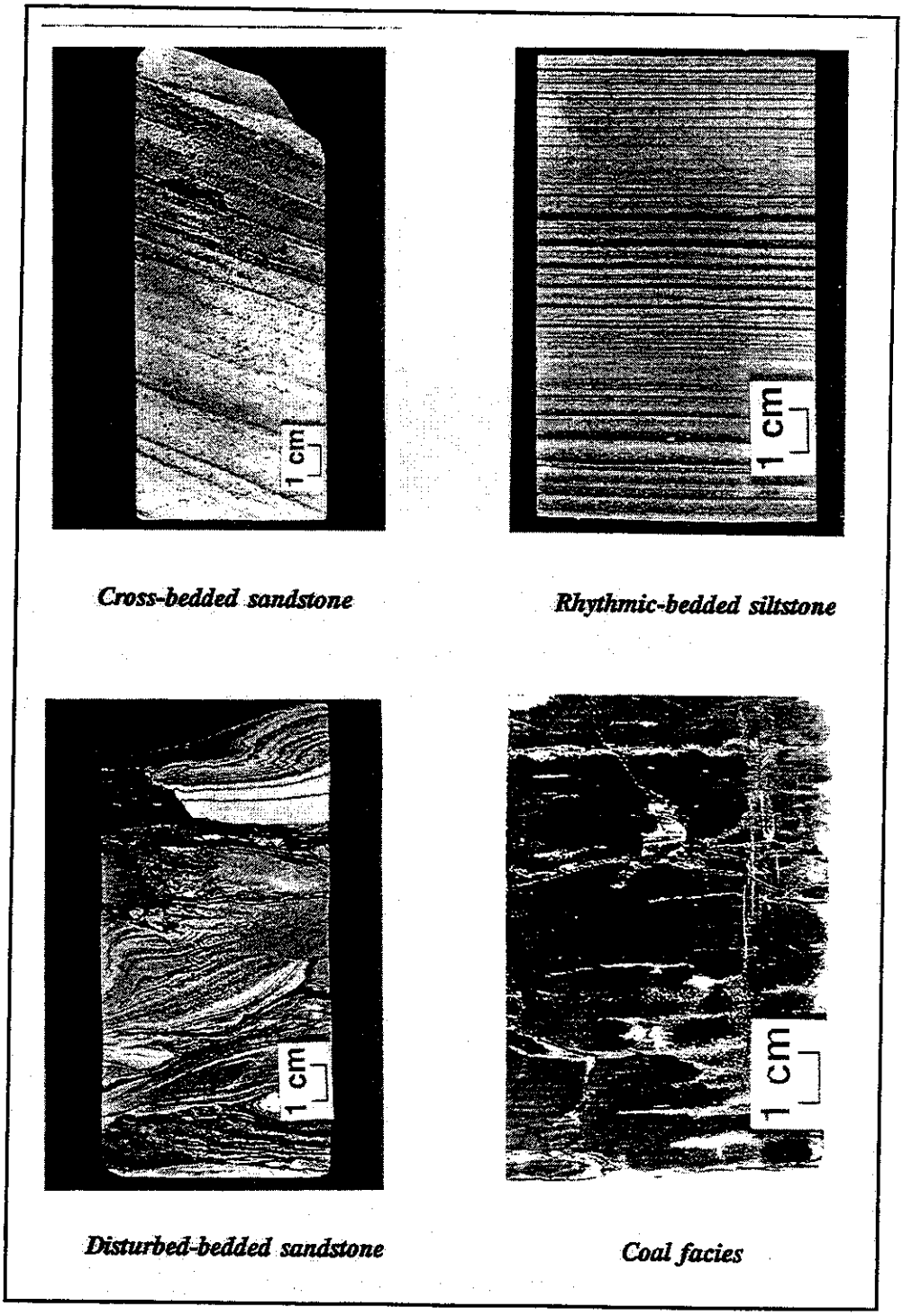


Figure 17. Facies described in core from Rockeye Facility (Barnhill, 1992).

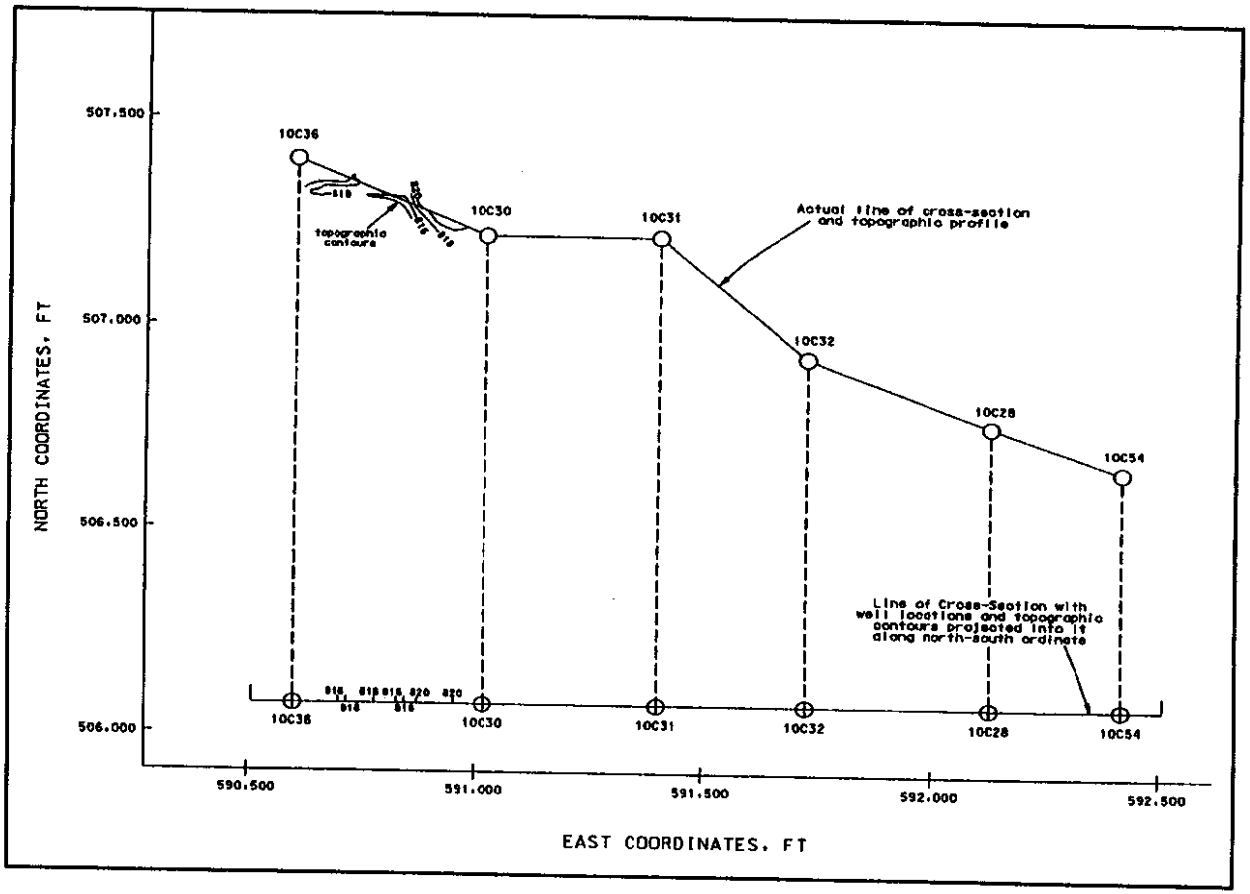


Figure 18. Diagram illustrating method of projecting vertical data into geologic cross sections at Rockeye.

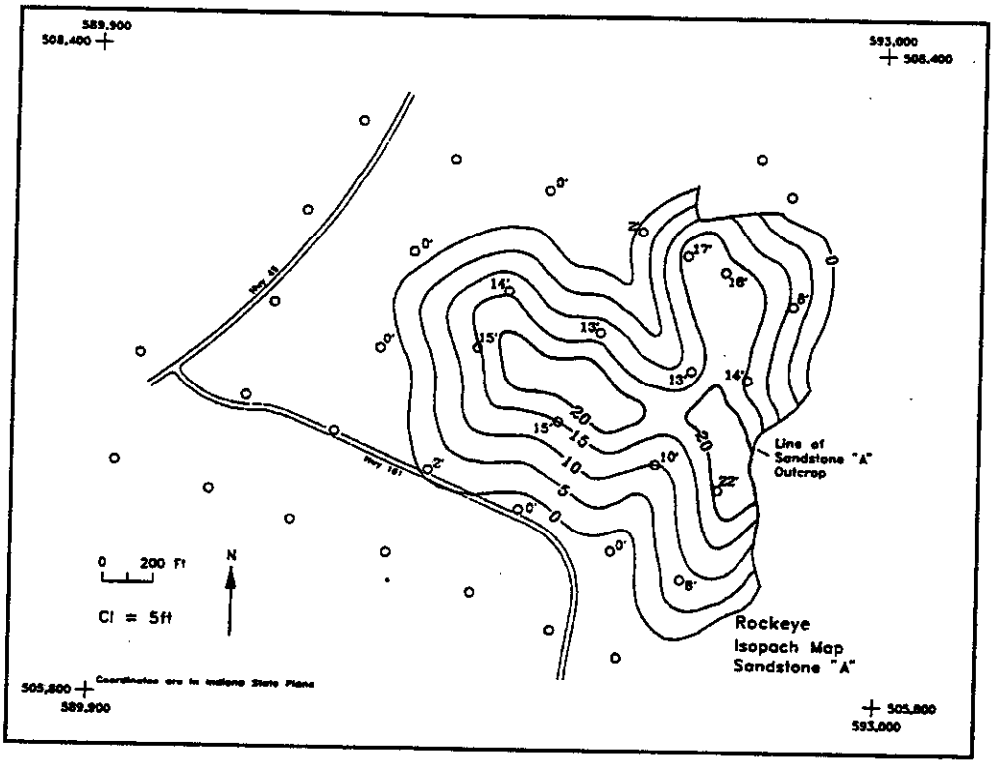


Figure 19. Isochore of sandstone "A", Rockeye Facility (Barnhill, 1992).

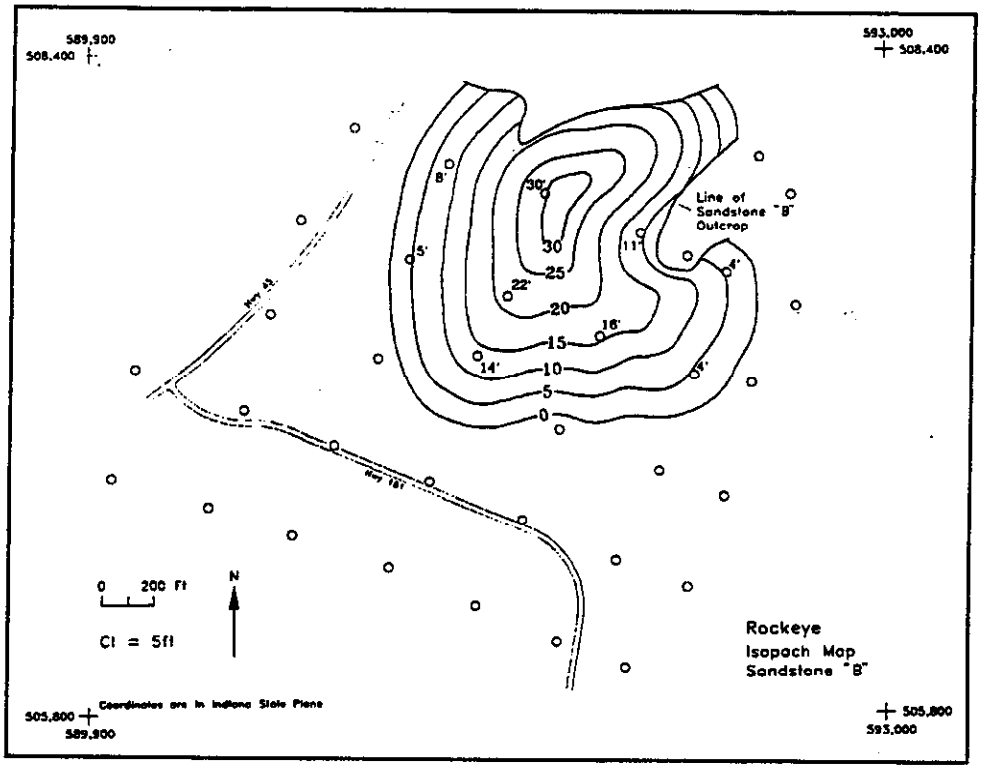


Figure 20. Isochore of sandstone "B", Rockeye Facility (Barnhill, 1992).

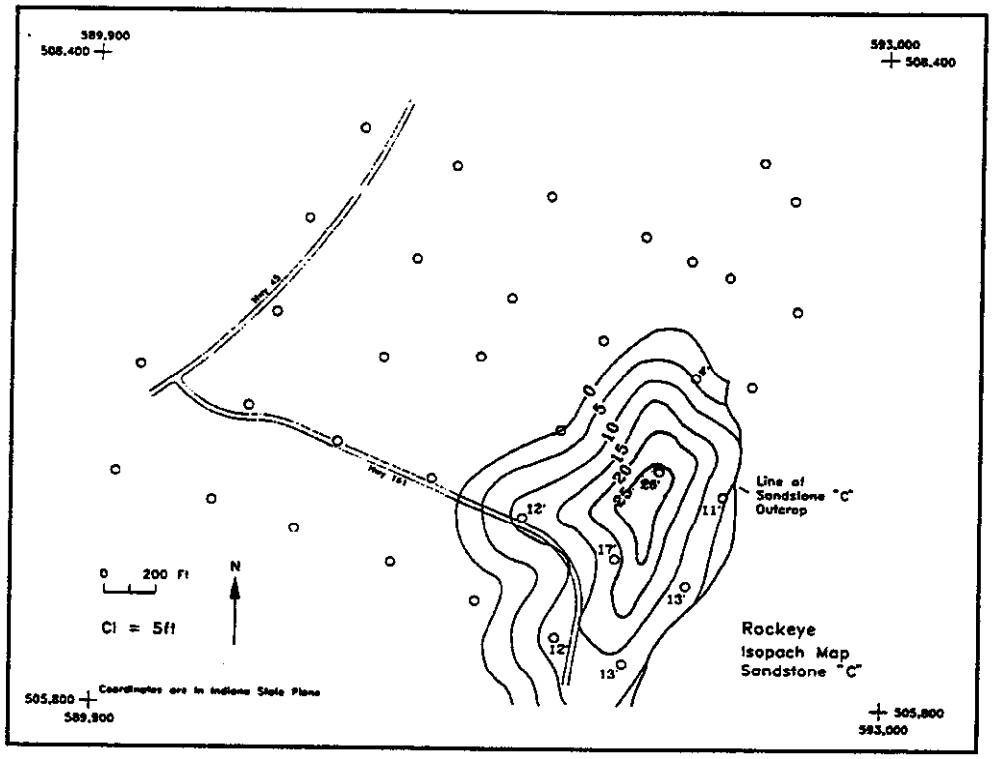
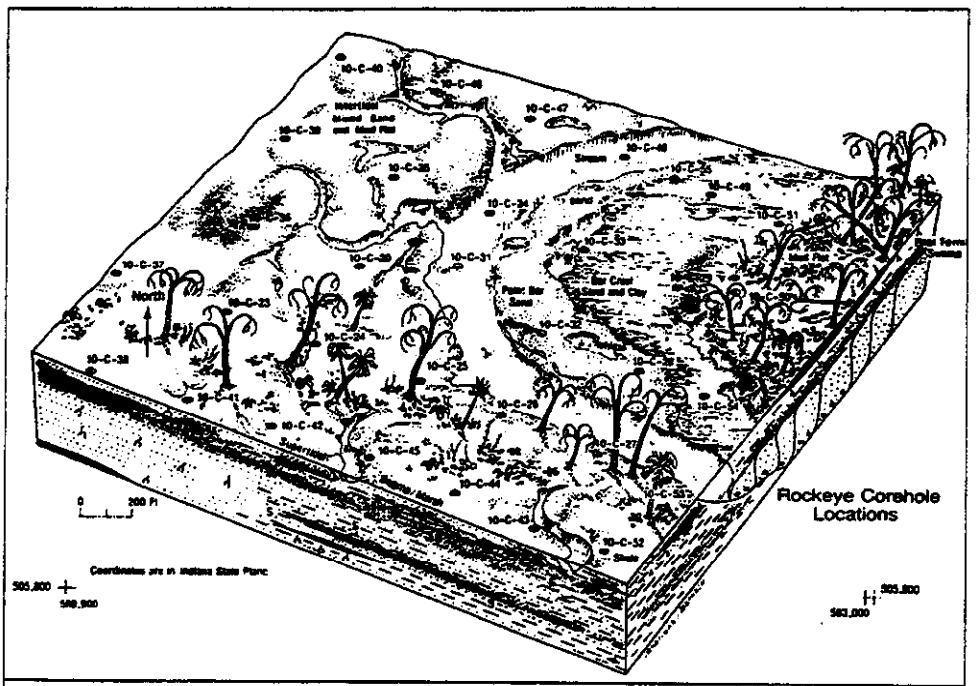
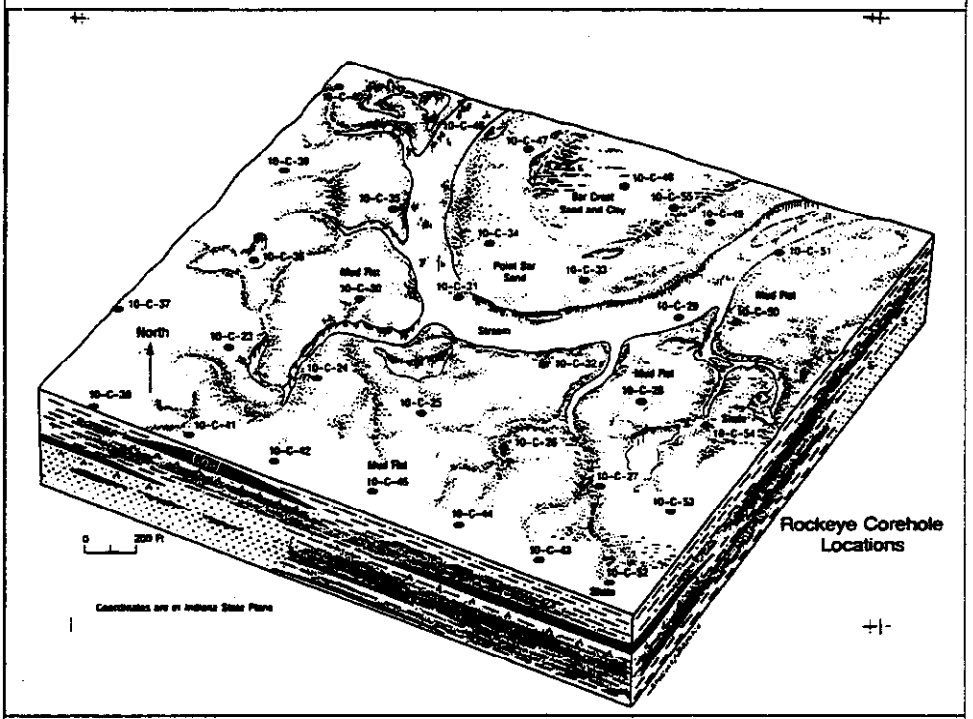


Figure 21. Isochore of sandstone "C", Rockeye Facility (Barnhill, 1992).



Block diagram showing paleogeographic/depositional model during maximum lateral accretion of sandstone "A".



Block diagram showing paleogeographic/depositional model during maximum lateral accretion of sandstone "B".

Figure 22. Depositional environments of sandstones "A" (top) and "B" (Barnhill, 1992).

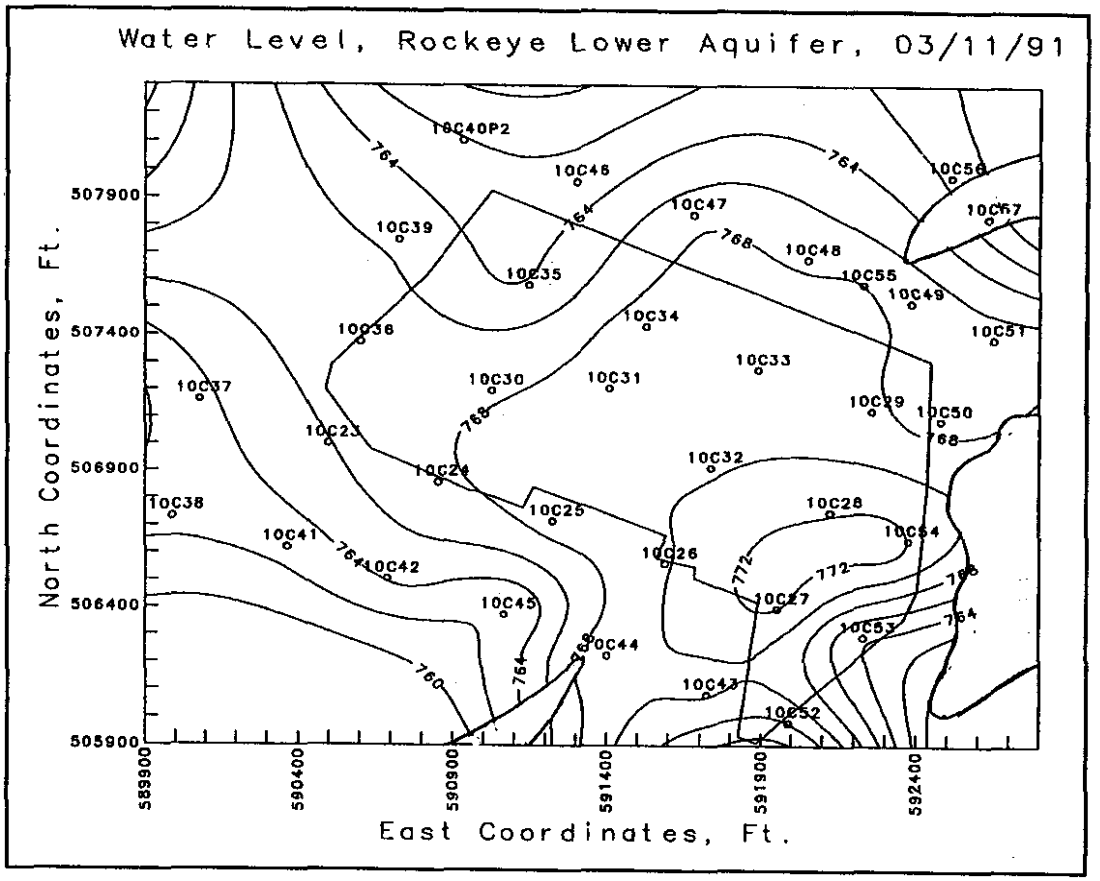


Figure 23. Contours on lower aquifer piezometric surface, Rockeye. Contours are elevations in ft. Contour interval 2 ft.

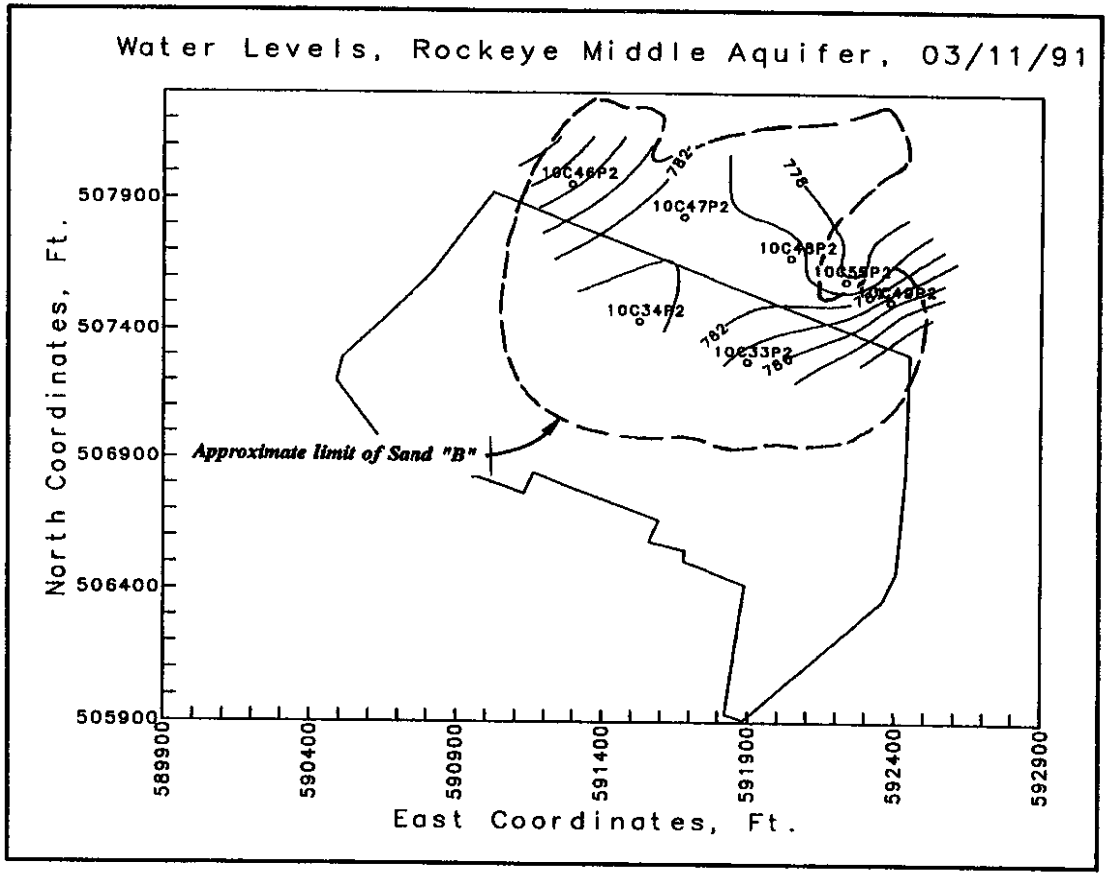


Figure 24. Contours on middle aquifer piezometric surface, Rockeye. Contours are elevations in ft. Contour interval 2 ft. Dashed line is limit of middle aquifer.

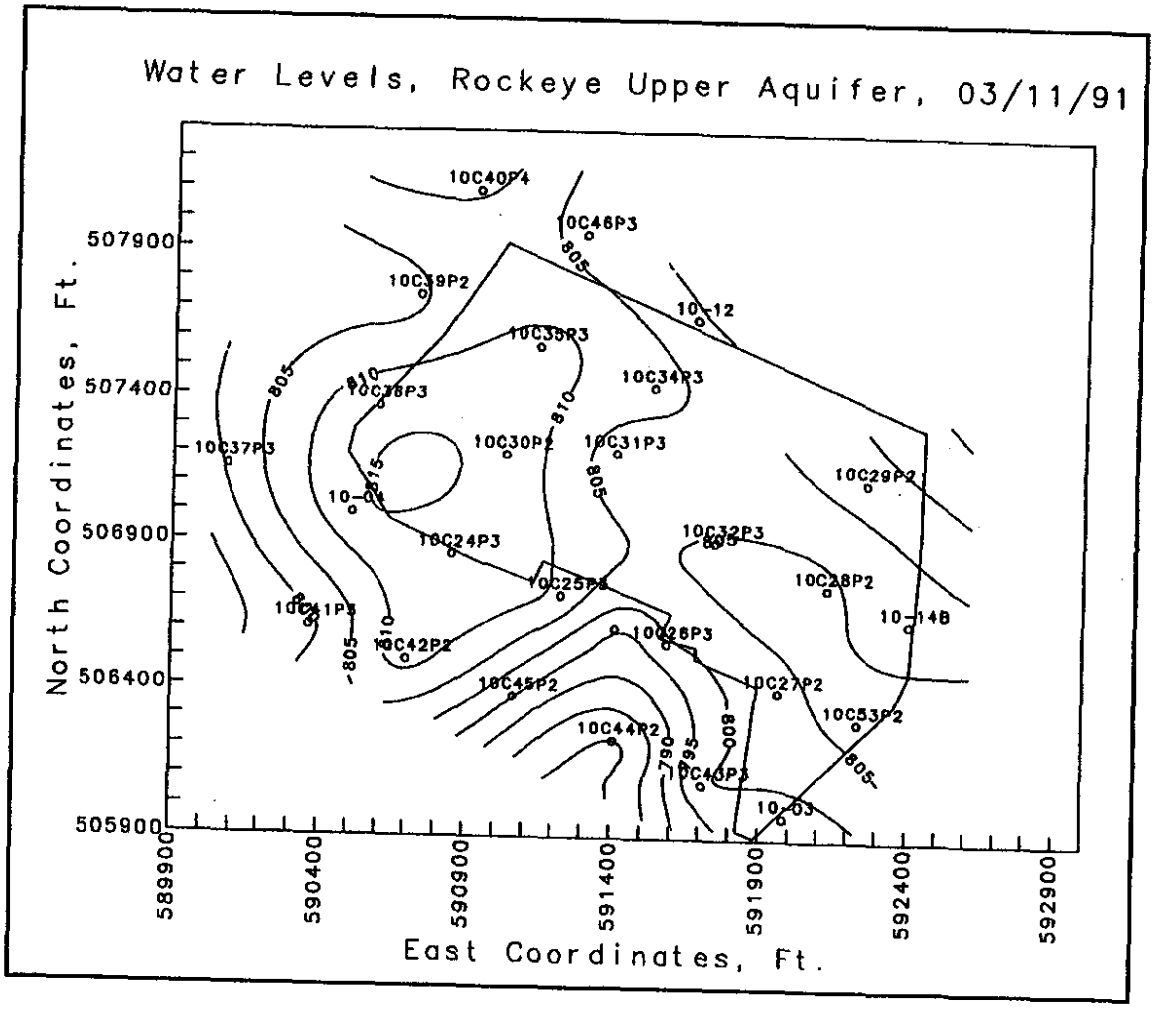


Figure 25. Contours on upper aquifer piezometric surface, Rockeye. Contours are elevations in ft. Contour interval 5 ft.

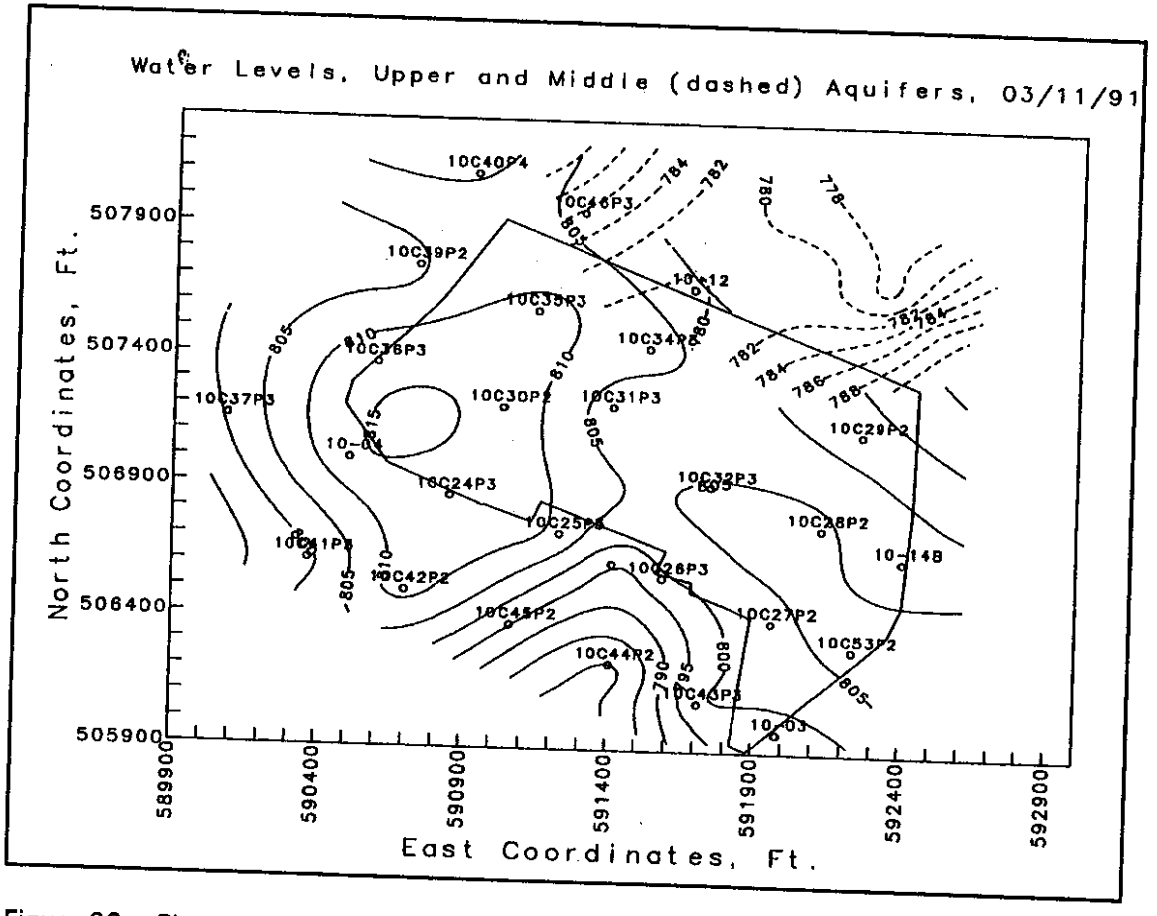


Figure 26. Piezometric surfaces of upper and middle aquifers superimposed. Contour interval of upper aquifer (solid) is 5 ft. Contour interval of middle aquifer (dashed) is 2 ft.

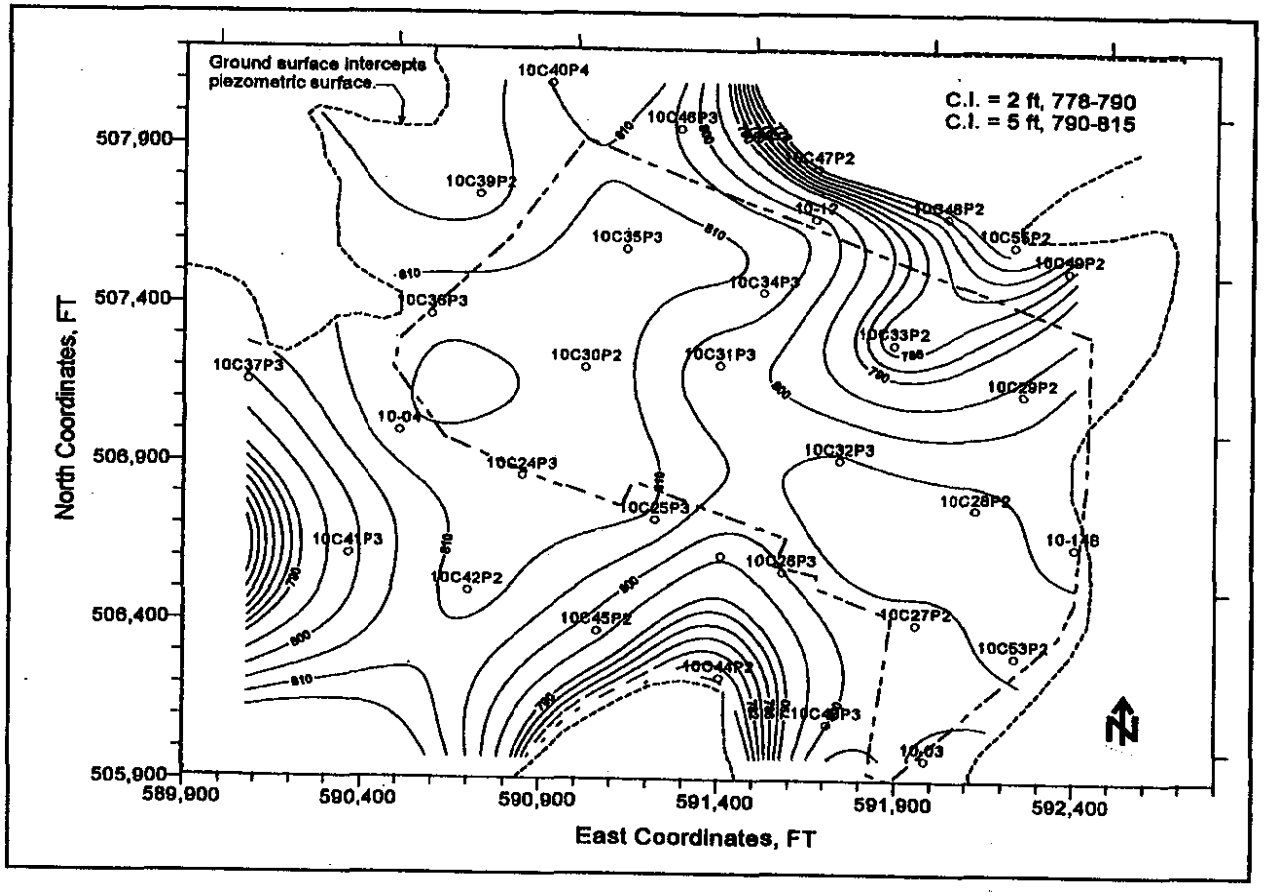


Figure 27. Contours of piezometric surfaces of combined upper and middle aquifers. Contour interval is 5 ft above elevation 790, 2 ft below 790

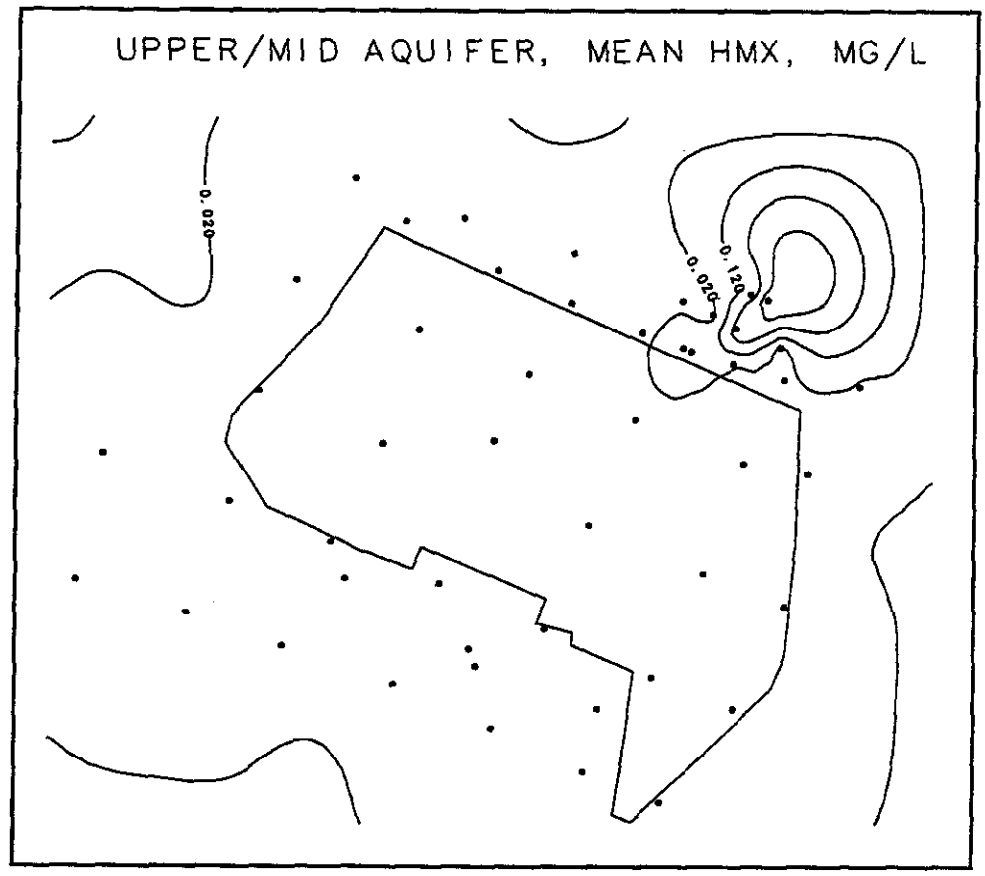


Figure 28. Contours of mean concentrations of HMX, uppermost aquifer, Rockeye. Contour interval is 0.10 mg/l.

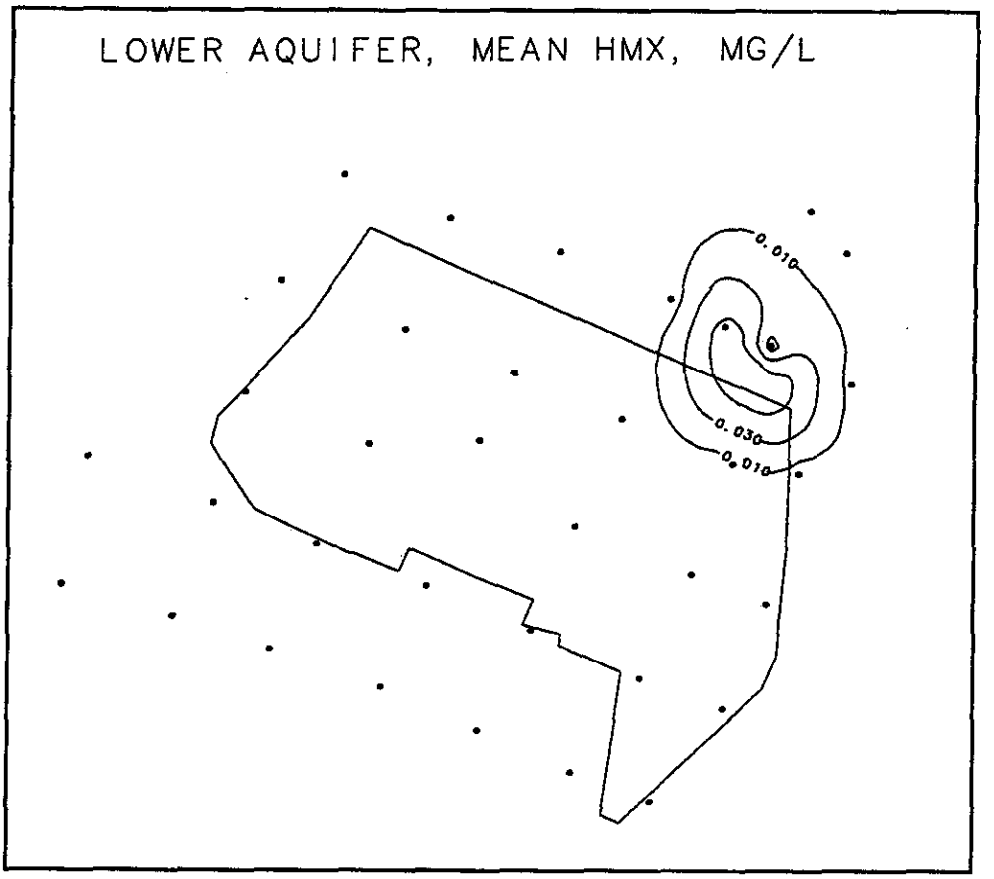


Figure 29. Contours of mean concentrations of HMX, lower aquifer, Rockeye. Contour interval is 0.02 mg/l.

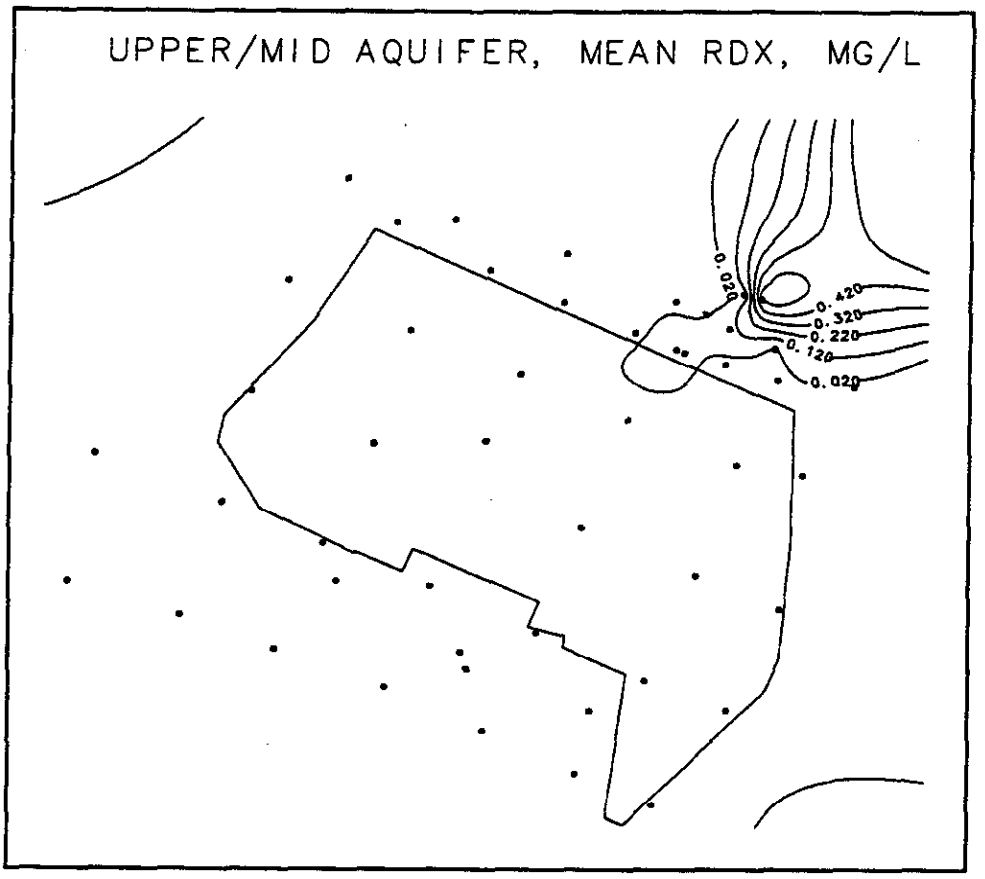


Figure 30. Contours of mean concentrations of RDX, uppermost aquifer, Rockeye. Contour interval is 0.10 mg/l.

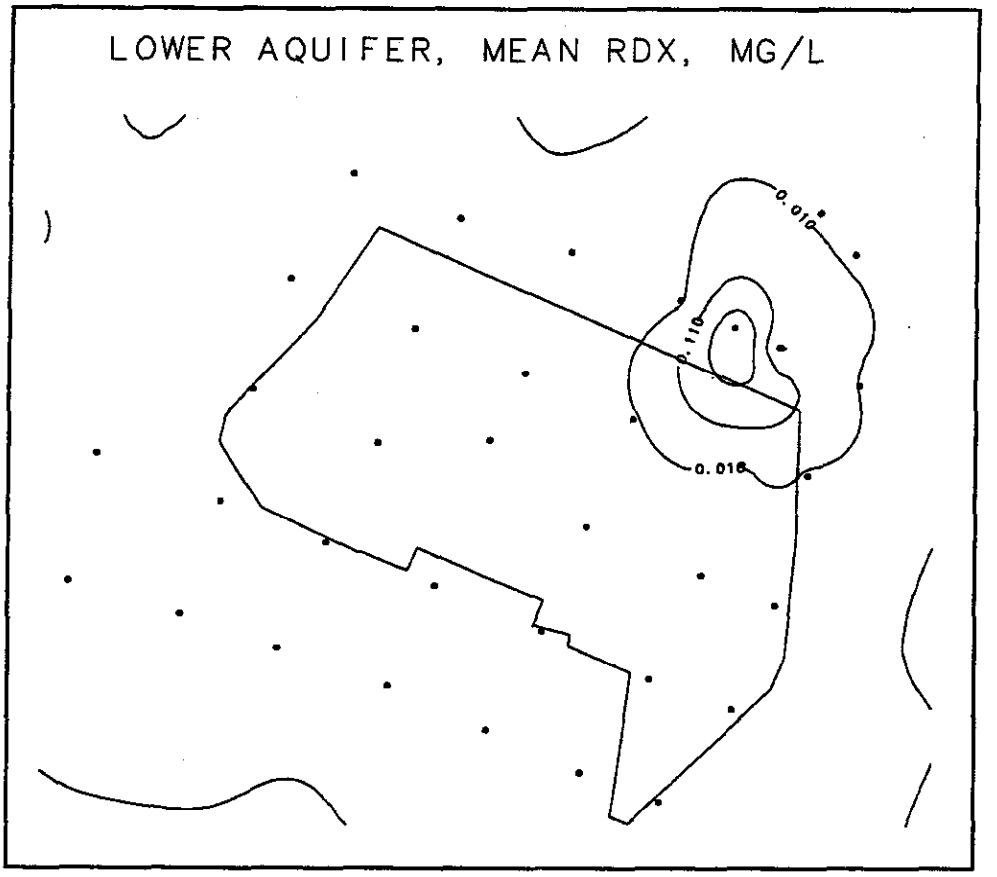


Figure 31. Contours of mean concentrations of RDX, lower aquifer, Rockeye. Contour interval is 0.10 mg/l.

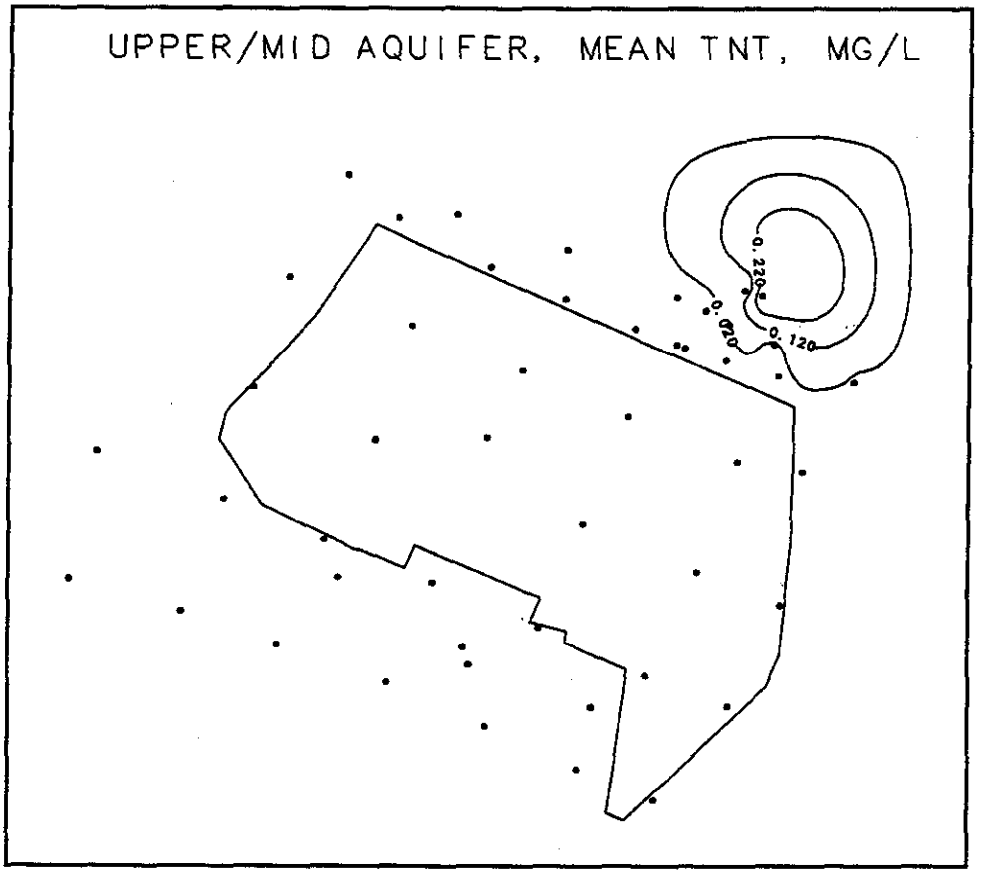


Figure 32. Contours of mean concentrations of TNT, uppermost aquifer, Rockeye. Contour interval is 0.10 mg/l.

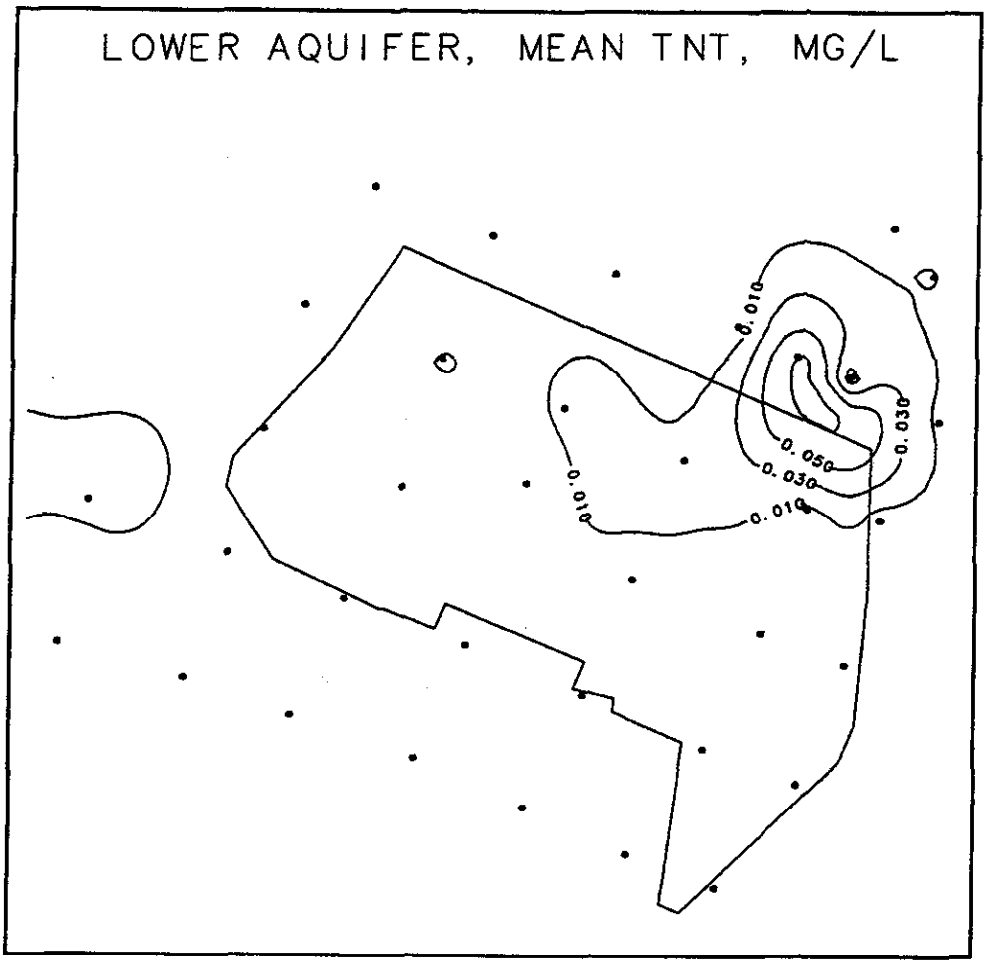


Figure 33. Contours of mean concentrations of TNT, lower aquifer, Rockeye. Contour interval is 0.02 mg/l.

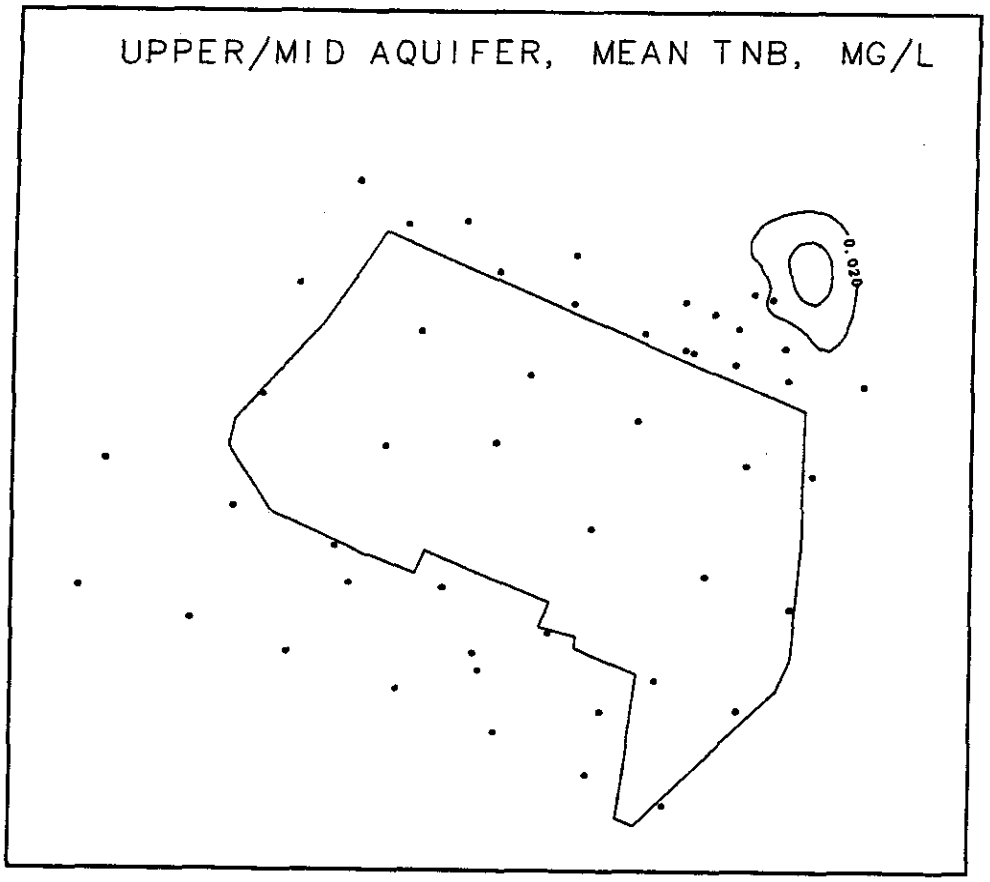


Figure 34. Contours of mean concentrations of TNB, uppermost aquifer, Rockeye. Contour interval is 0.01 mg/l.

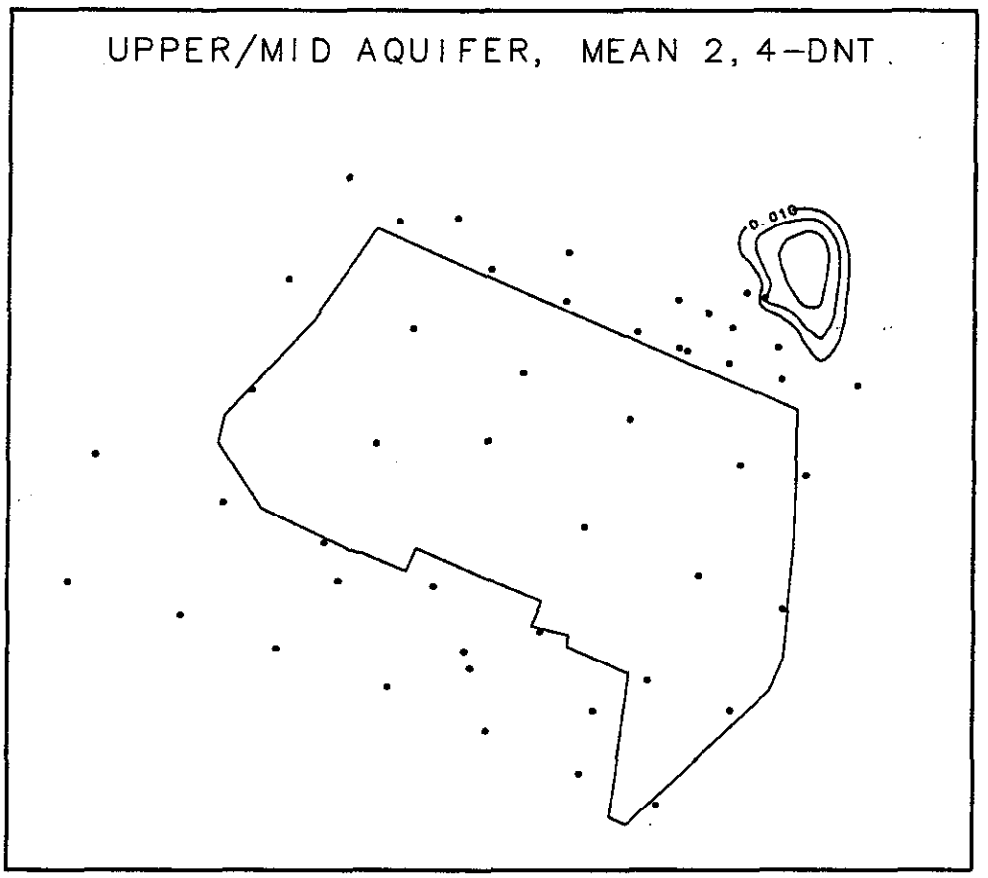


Figure 35. Contours of mean concentrations of 2,4-DNT, uppermost aquifer, Rockeye. Contour interval is 0.002 mg/l.

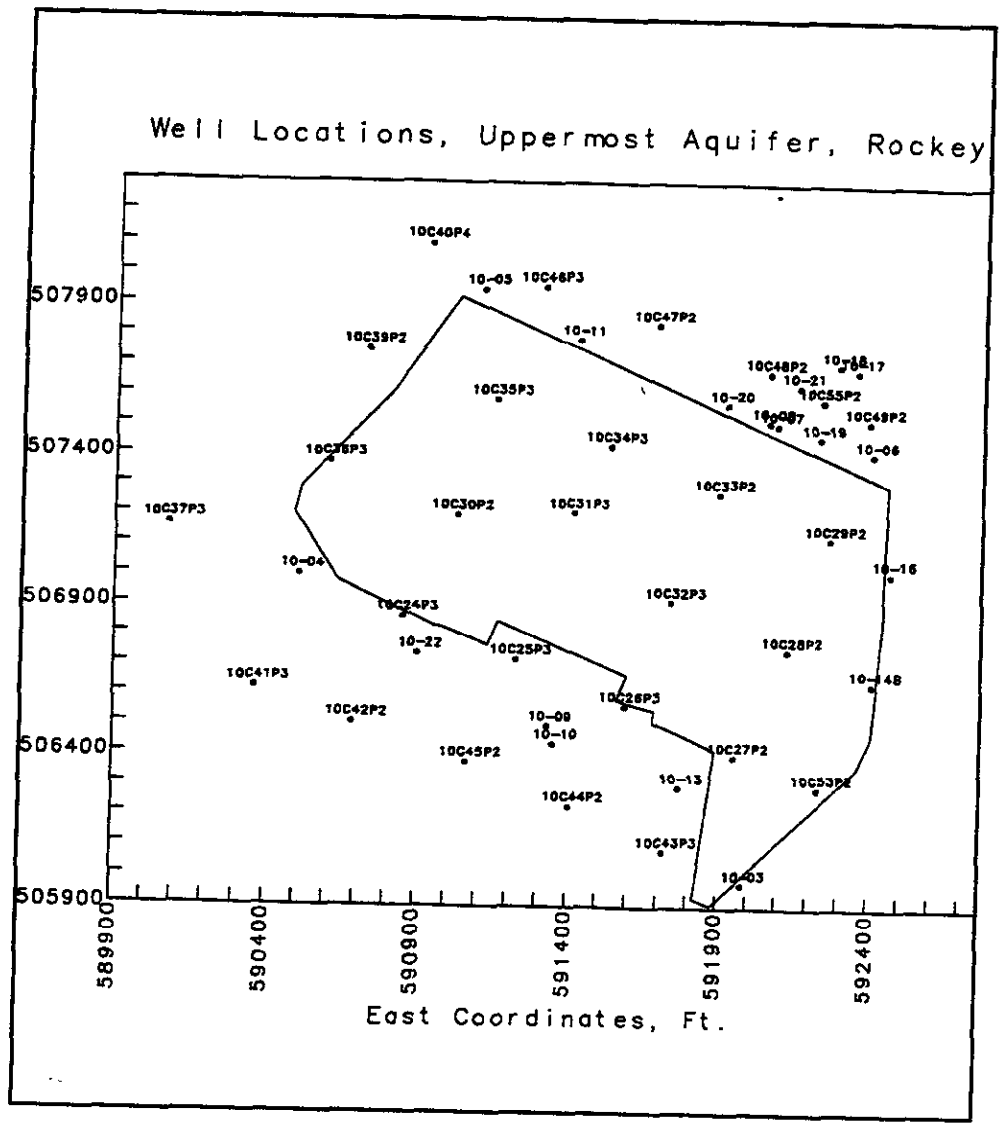


Figure 36. Wells of the uppermost aquifer, Rockeye.

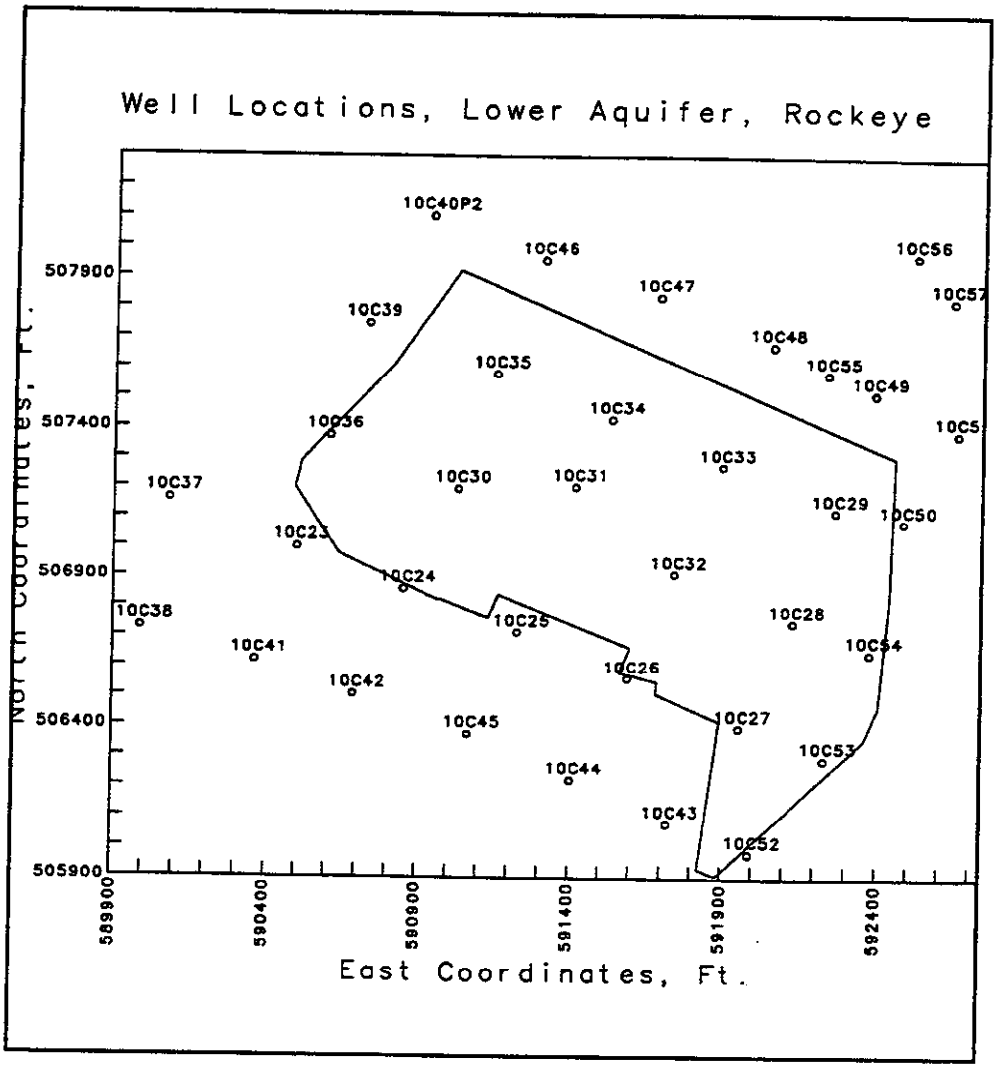


Figure 37. Wells of the lower aquifer, Rockeye.

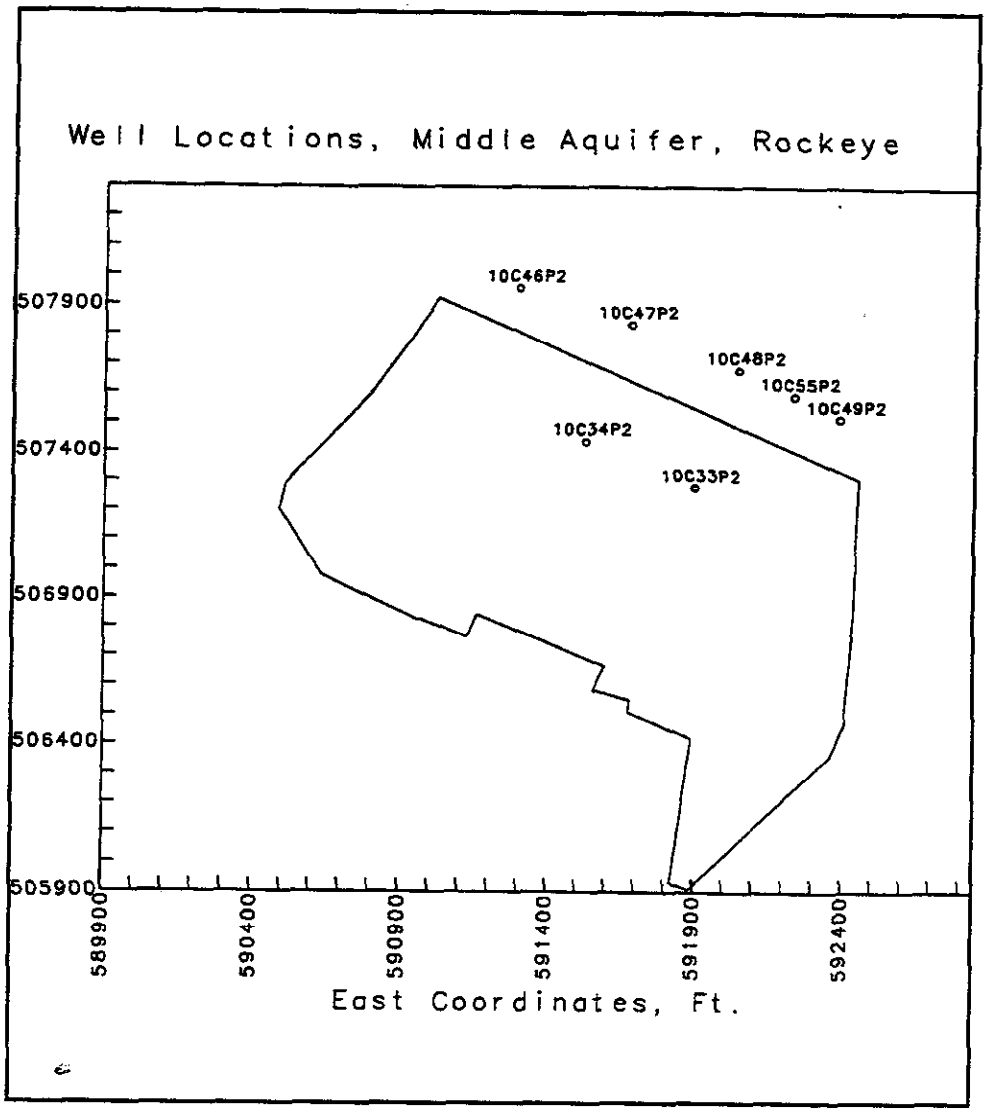


Figure 38. Wells of the middle aquifer, Rockeye.

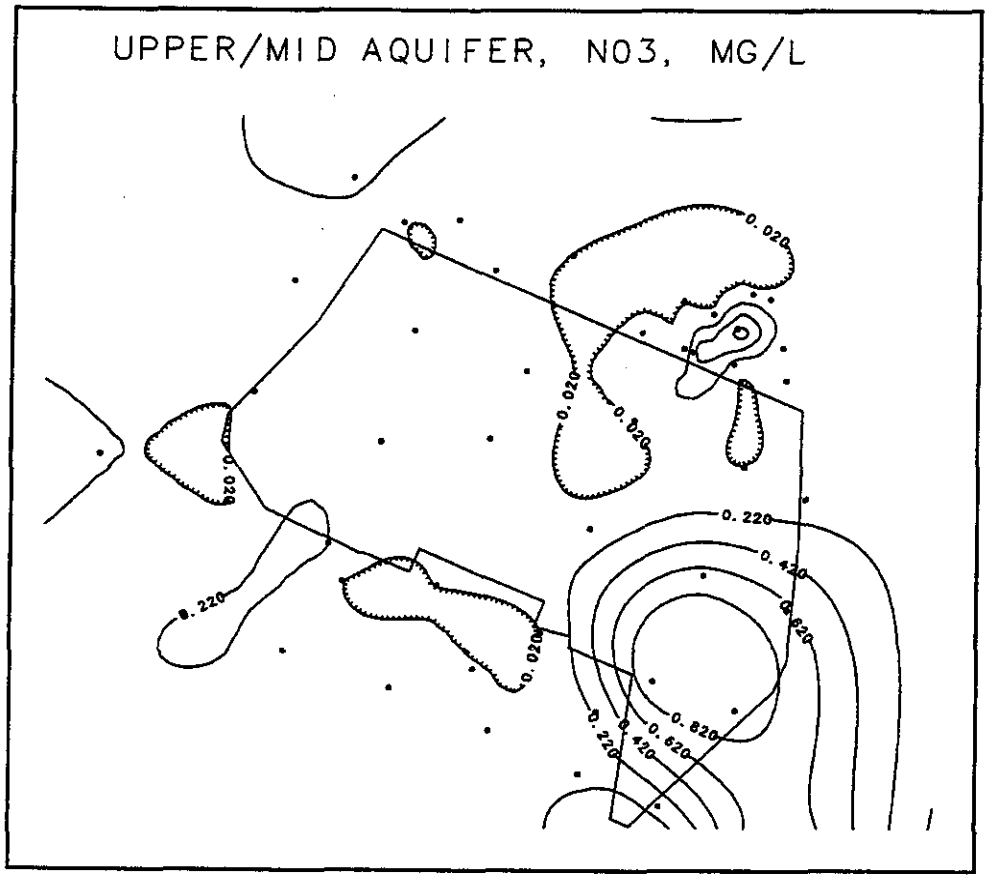


Figure 39. Contours of nitrate (NO3) concentrations, uppermost aquifer. Contour interval is 0.2 mg/l.

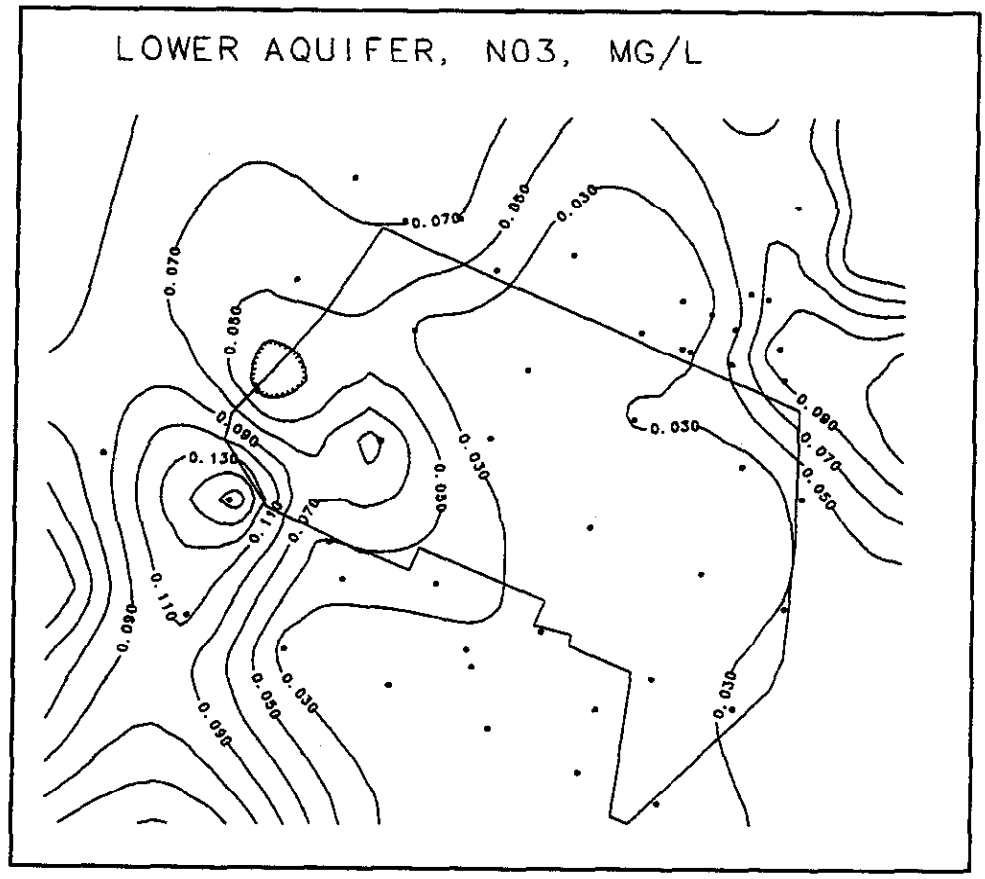


Figure 40. Contours of nitrate (NO3) concentrations, lower aquifer. Contour interval is 0.02 mg/l.

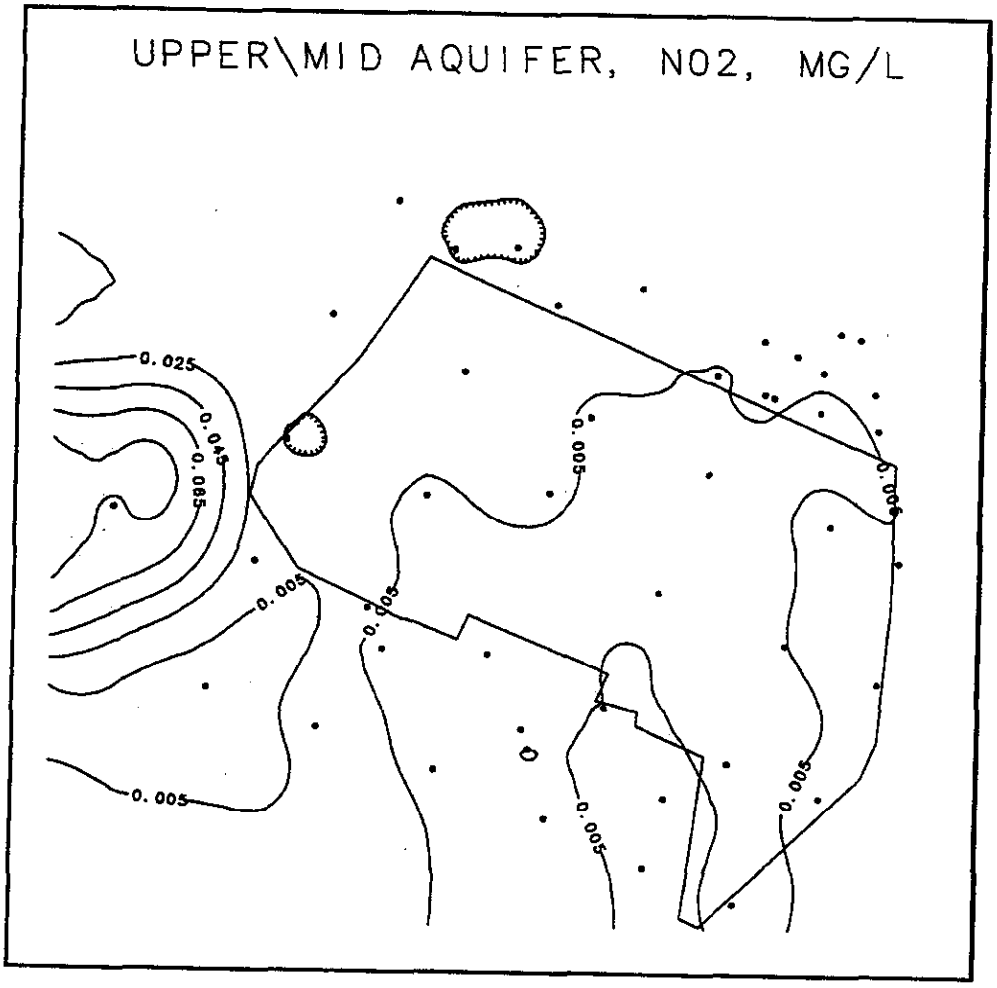


Figure 41. Contours of nitrite (NO2) concentrations, uppermost aquifer. Contour interval is 0.02 mg/l.

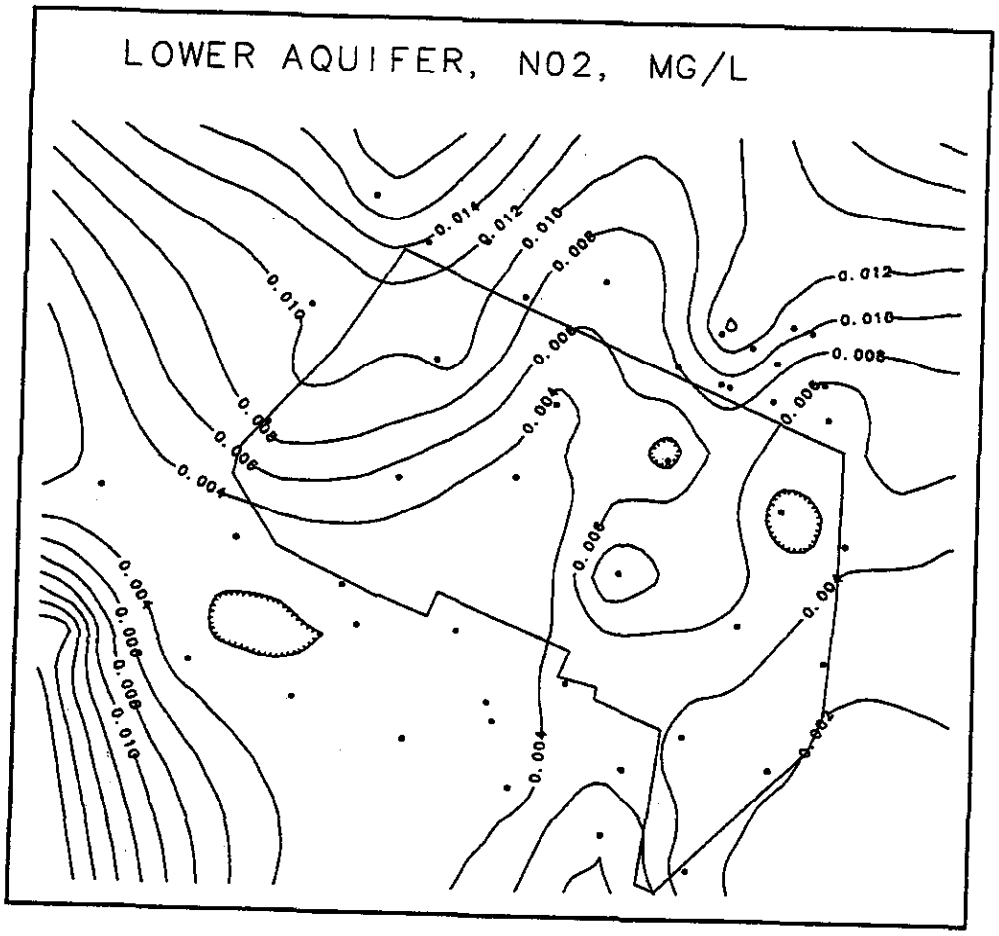


Figure 42. Contours of nitrite (NO2) concentrations, lower aquifer. Contour interval is 0.002 mg/l.

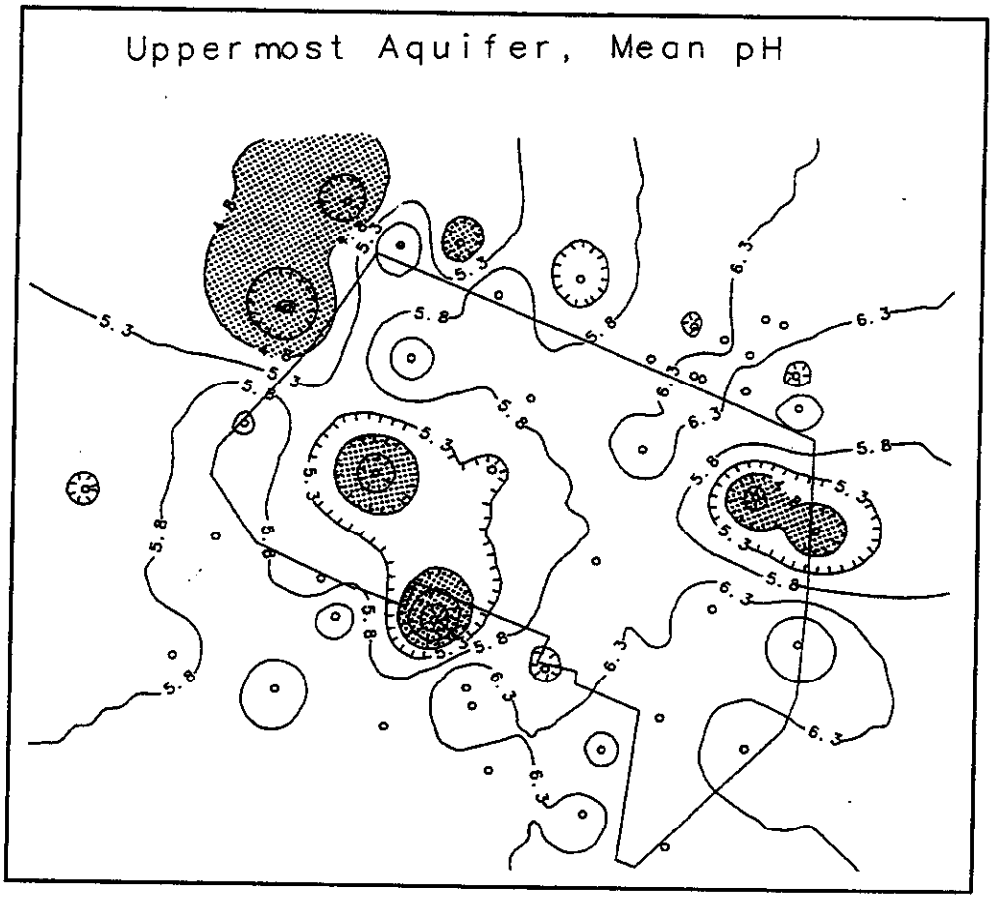


Figure 43. Contours of mean pH in wells of the uppermost aquifer. Areas of pH readings below 4.8 are shaded. Contour interval is 0.5.

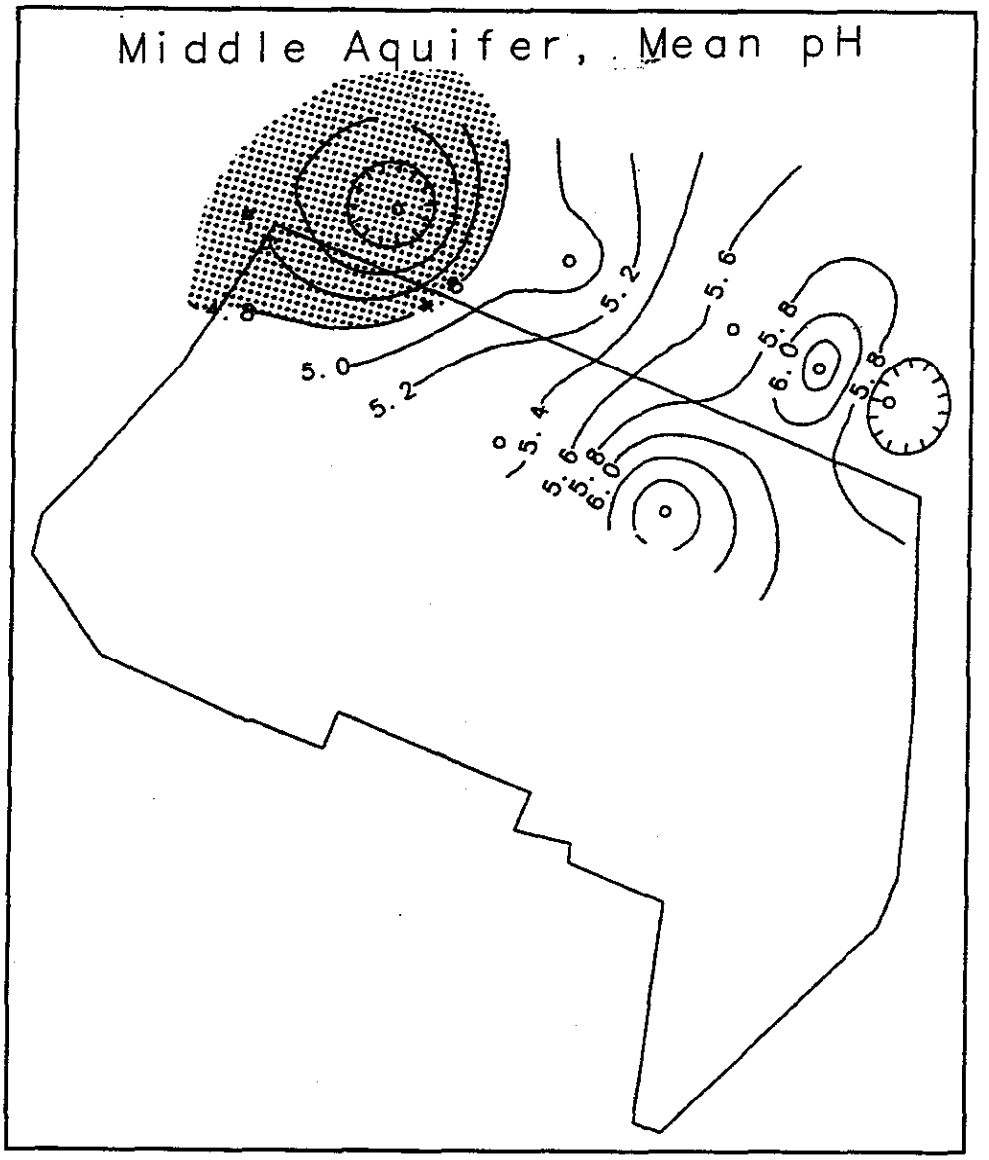


Figure 44. Contours of mean pH in wells of the middle aquifer. Areas of pH readings below 4.8 are shaded. Contour interval is 2.

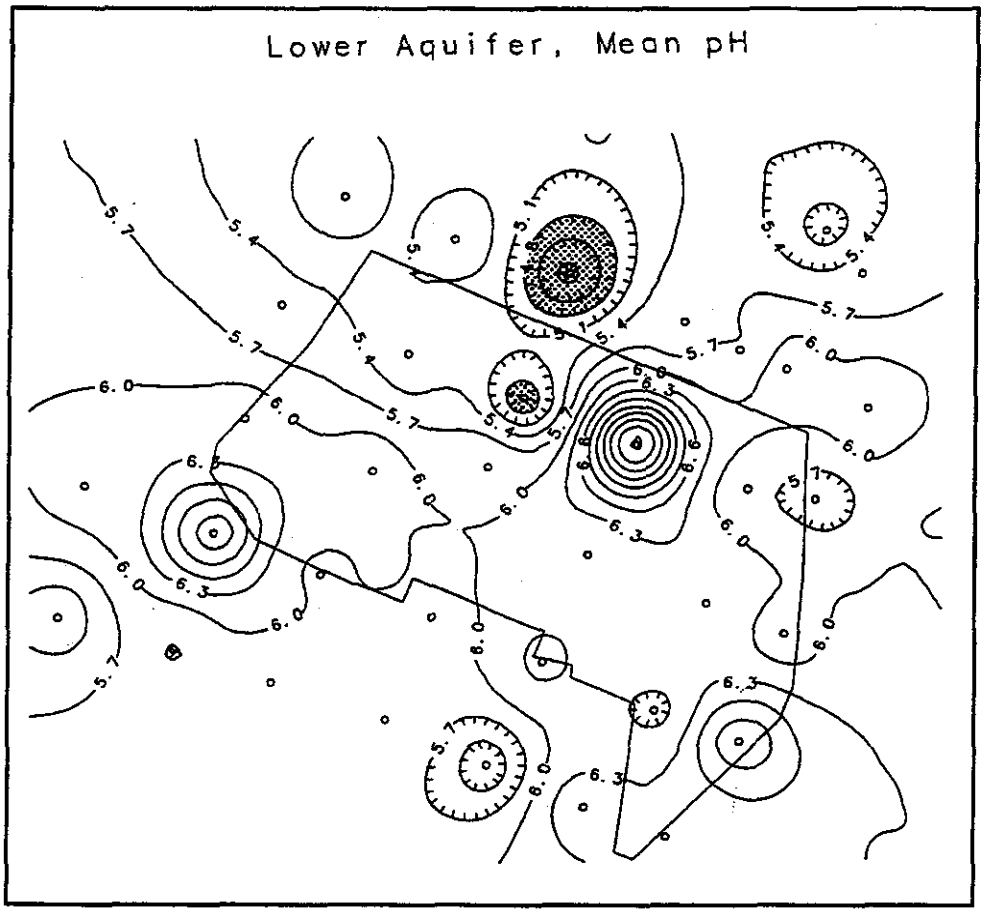


Figure 45. Contours of mean pH in wells of the lower aquifer. Areas of pH readings below 4.8 are shaded. Contour interval is 0.3.

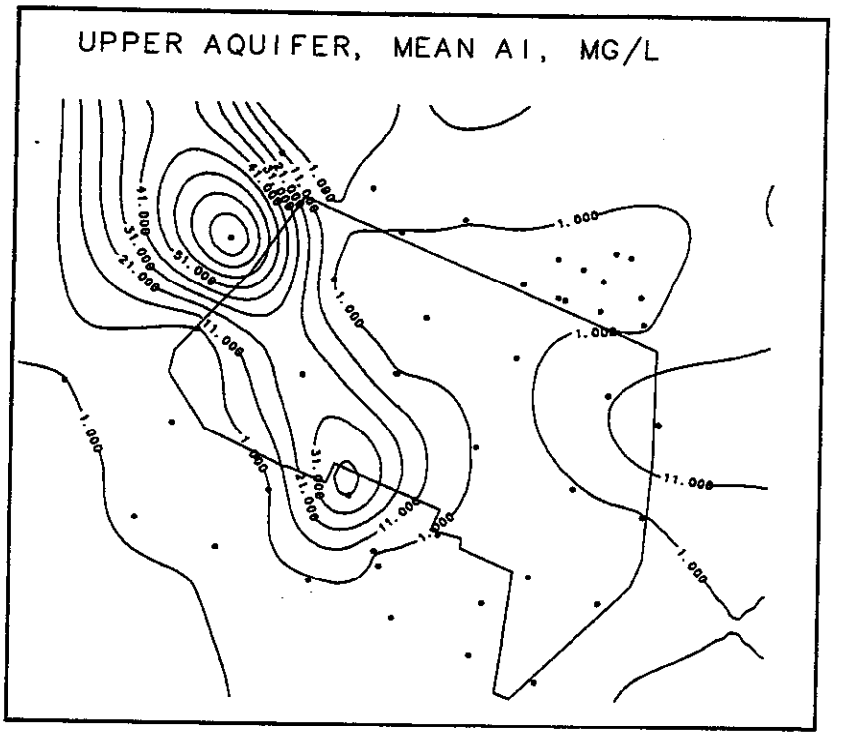


Figure 46. Contours of mean aluminum concentrations, uppermost aquifer. Contour interval is 10 mg/l.

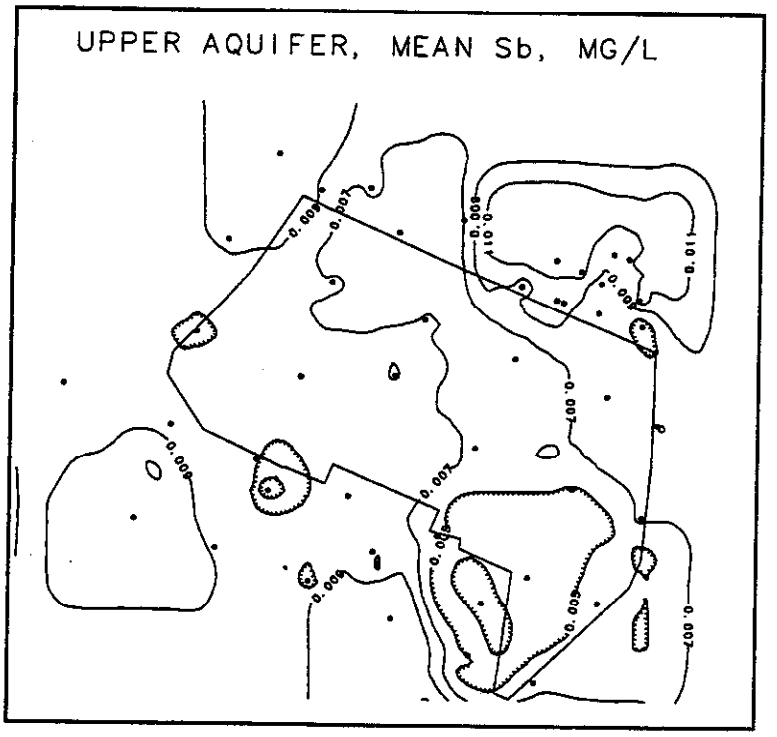


Figure 47. Contours of mean antimony concentrations, uppermost aquifer. Contour interval is 0.002 mg/l.

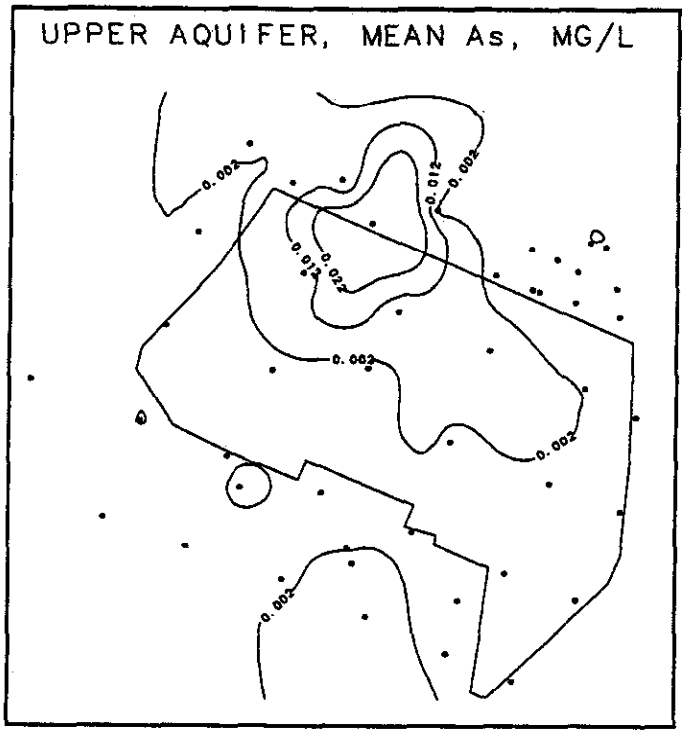


Figure 48. Contours of mean arsenic concentration, uppermost aquifer. Contour interval is 0.01 mg/l.

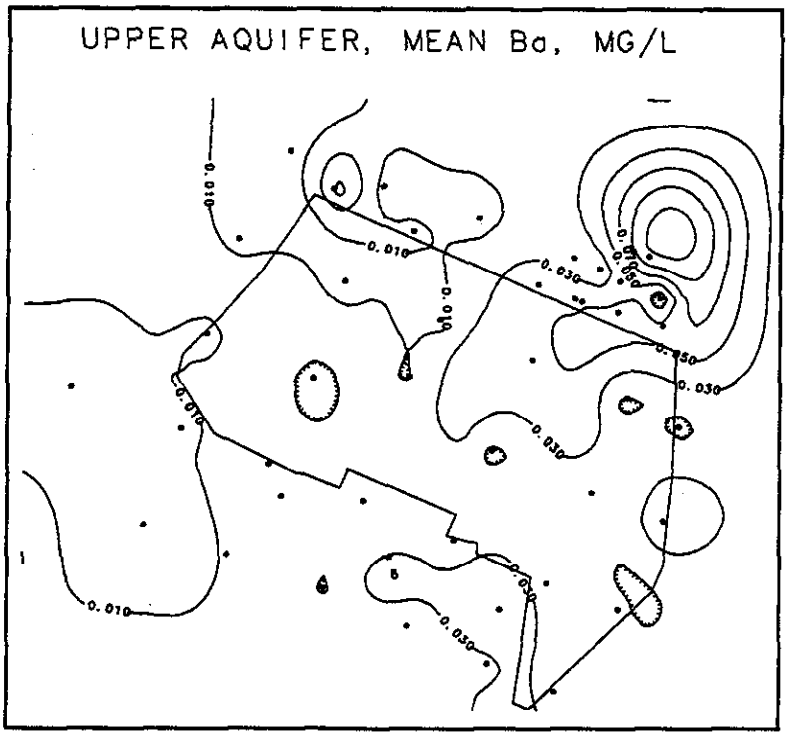


Figure 49. Contours of mean barium concentration, uppermost aquifer. Contour interval is 0.02 mg/l.

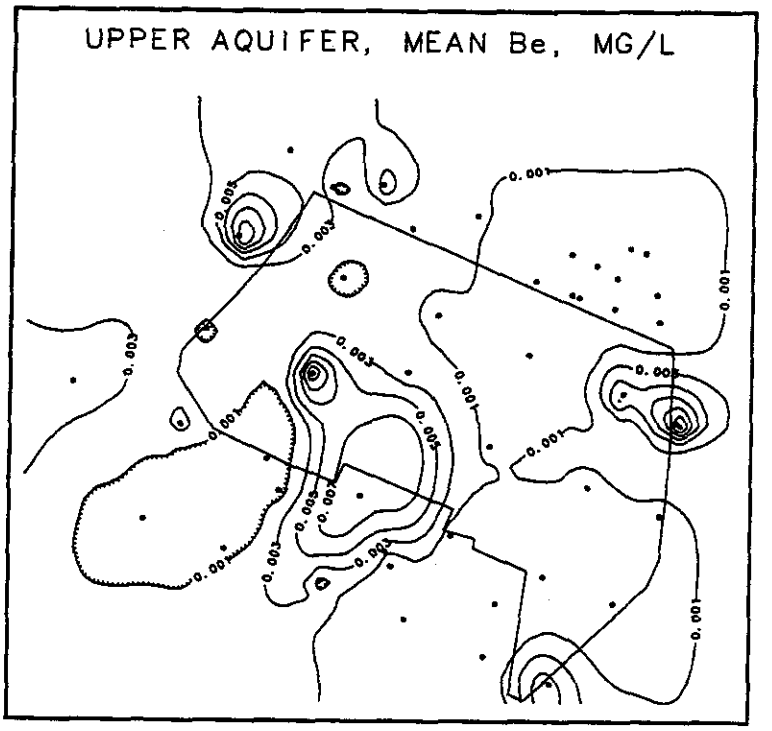


Figure 50. Contours of mean beryllium concentration, uppermost aquifer. Contour interval is 0.002 mg/l.

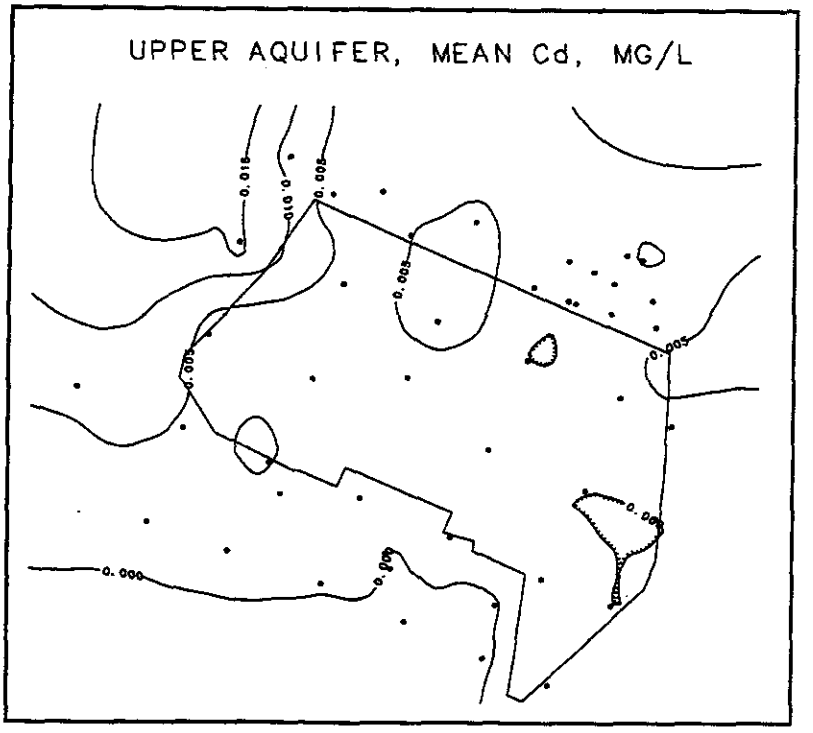


Figure 51. Contours of mean cadmium concentration, uppermost aquifer. Contour interval is 0.005 mg/l.

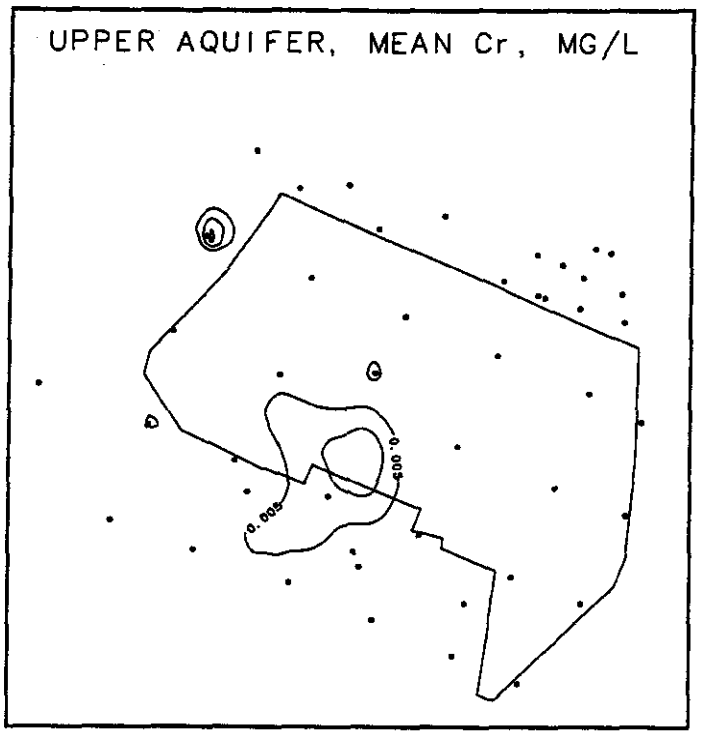


Figure 52. Contours of mean chromium concentration, uppermost aquifer. Contour interval is 0.002 mg/l.

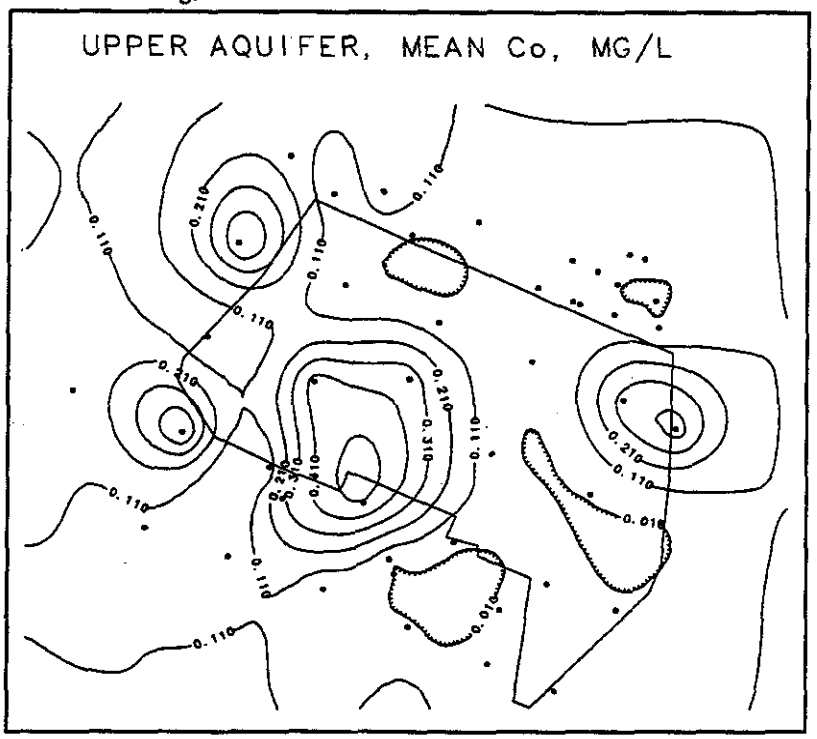


Figure 53. Contours of mean cobalt concentration, uppermost aquifer. Contour interval is 0.1 mg/l.

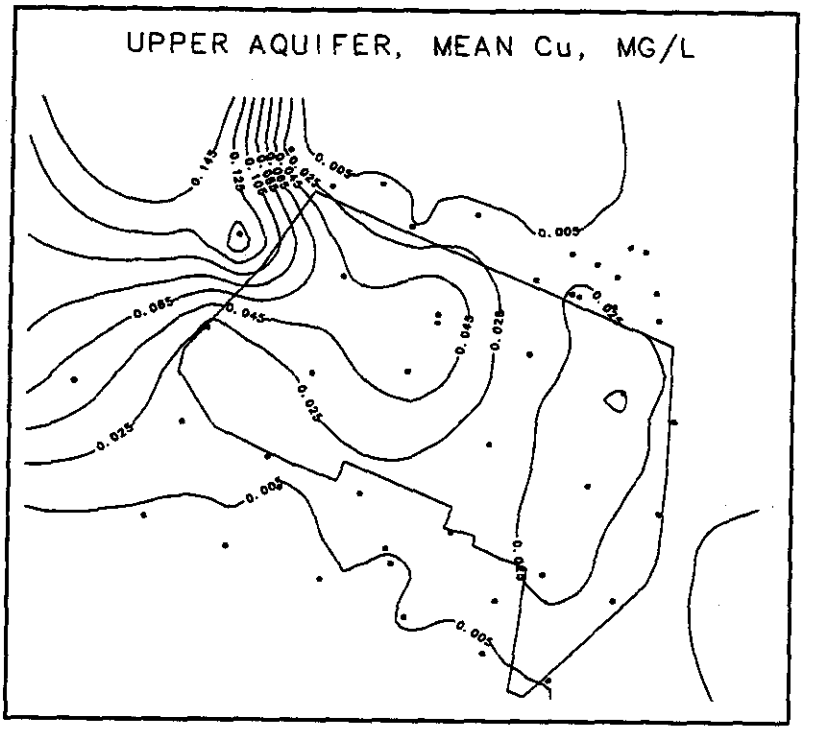


Figure 54. Contours of mean copper concentration, uppermost aquifer. Contour interval is 0.02 mg/l.

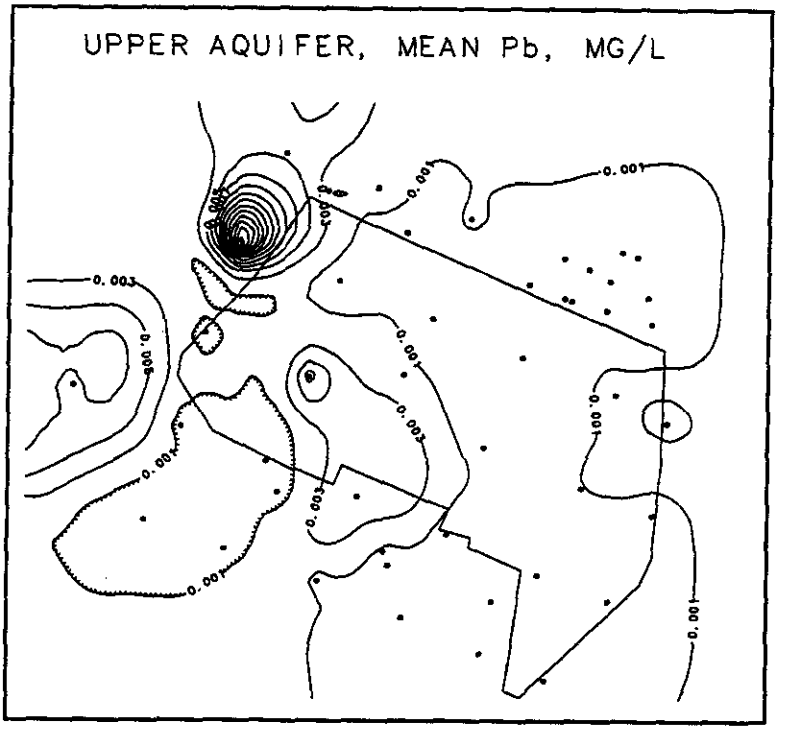


Figure 55. Contours of mean lead concentration, uppermost aquifer. Contour interval is 0.002 mg/l.

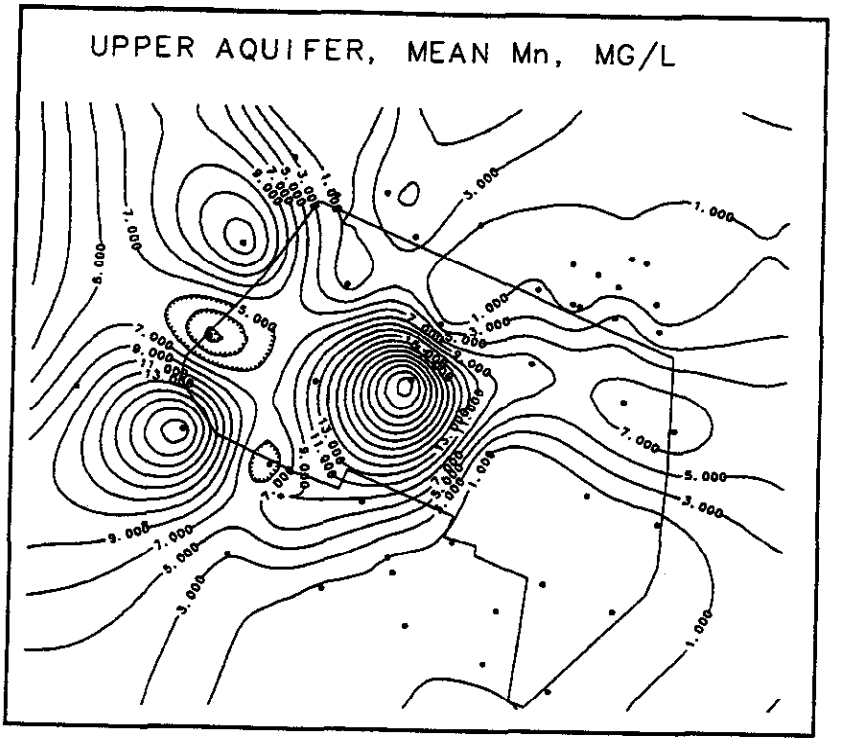


Figure 56. Contours of mean manganese concentration, uppermost aquifer. Contour interval is 2 mg/l.

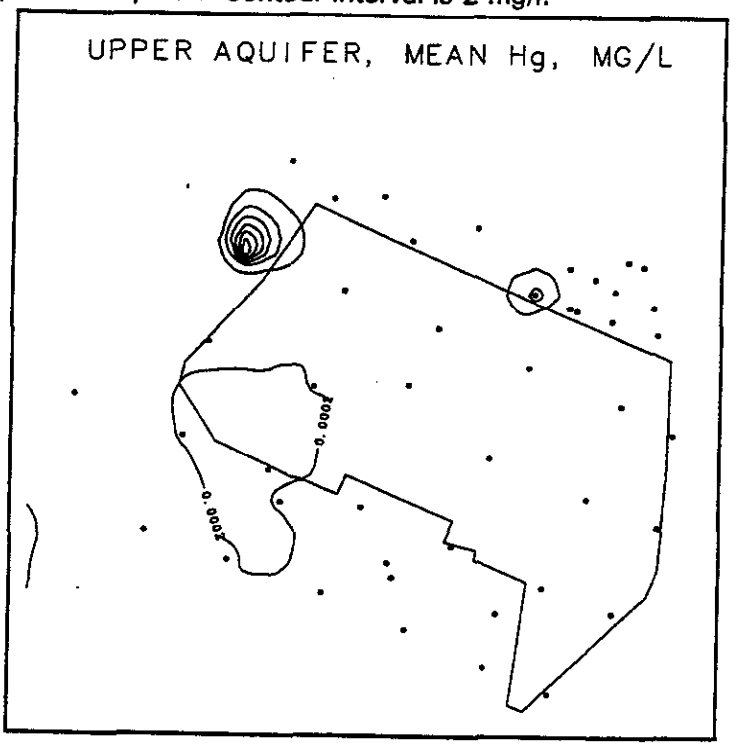


Figure 57. Contours of mean mercury concentration, uppermost aquifer. Contour interval is 0.0005 mg/l.

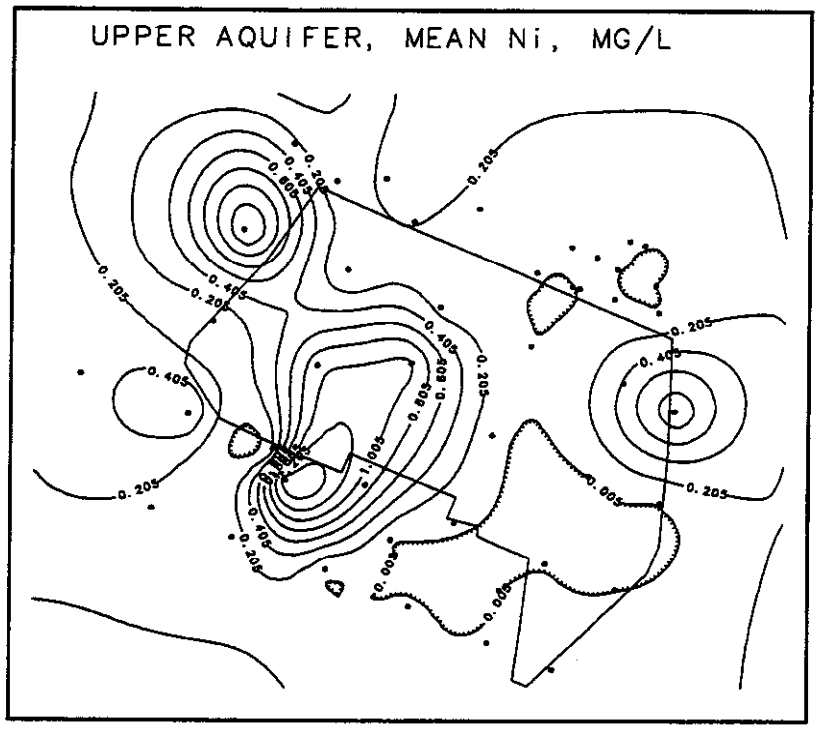


Figure 58 Contours of mean nickel concentration, uppermost aquifer. Contour interval is 0.2 mg/l.

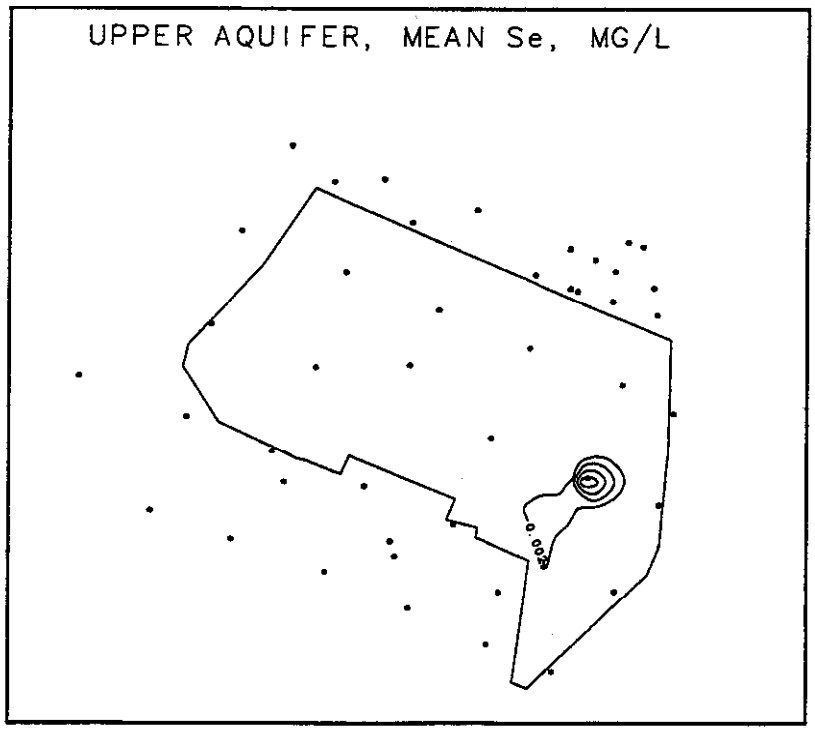


Figure 59. Contours of mean selenium concentration, uppermost aquifer. Contour interval is 0.001 mg/l.

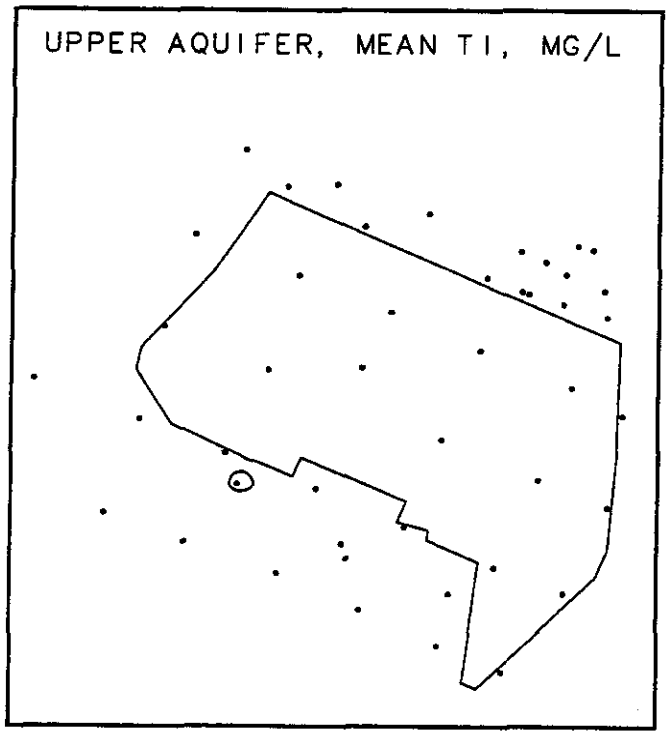


Figure 60. Contours of mean thallium concentration, uppermost aquifer. Contour interval is 0.001 mg/l.

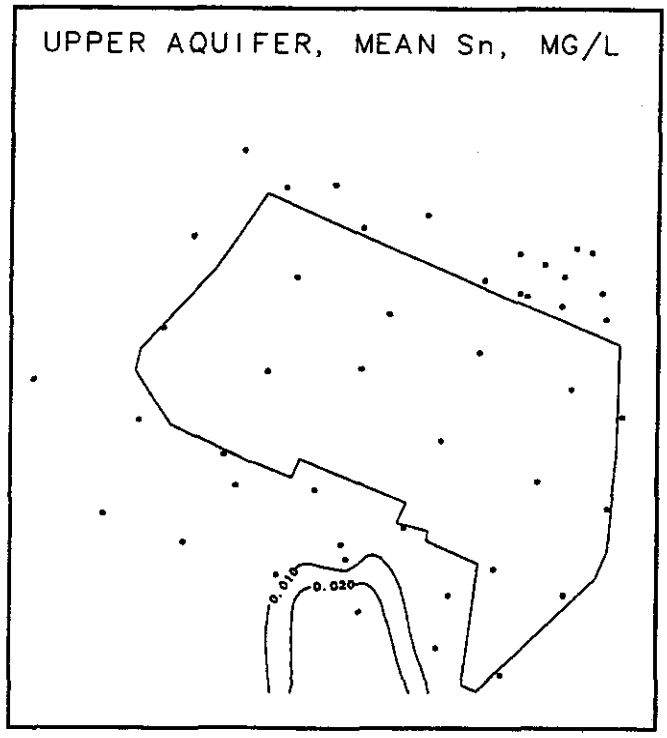


Figure 61. Contours of mean tin concentration, uppermost aquifer. Contour interval is 0.01 mg/l.

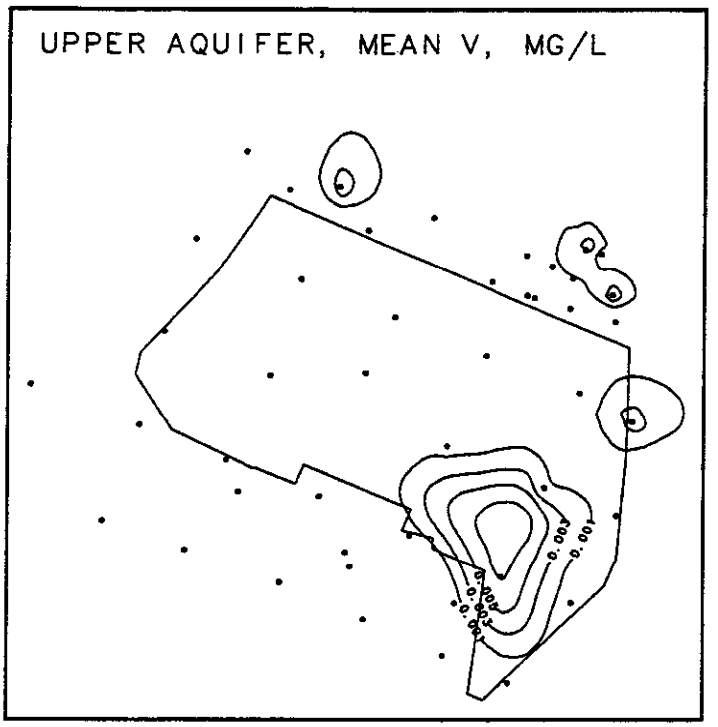


Figure 62. Contours of mean vanadium concentration, uppermost aquifer. Contour interval is 0.002 mg/l.

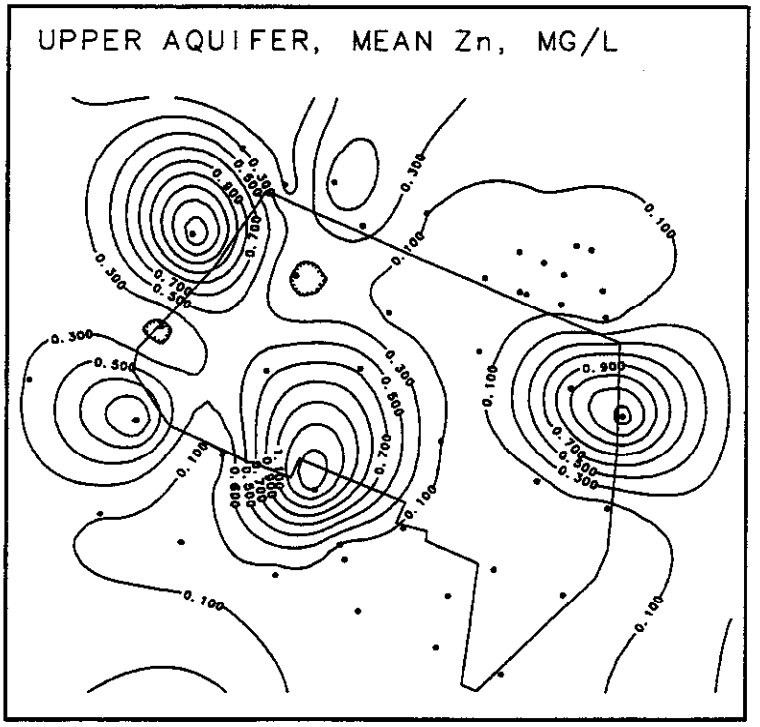


Figure 63. Contours of mean zinc concentration, uppermost aquifer. Contour interval is 0.2 mg/l.

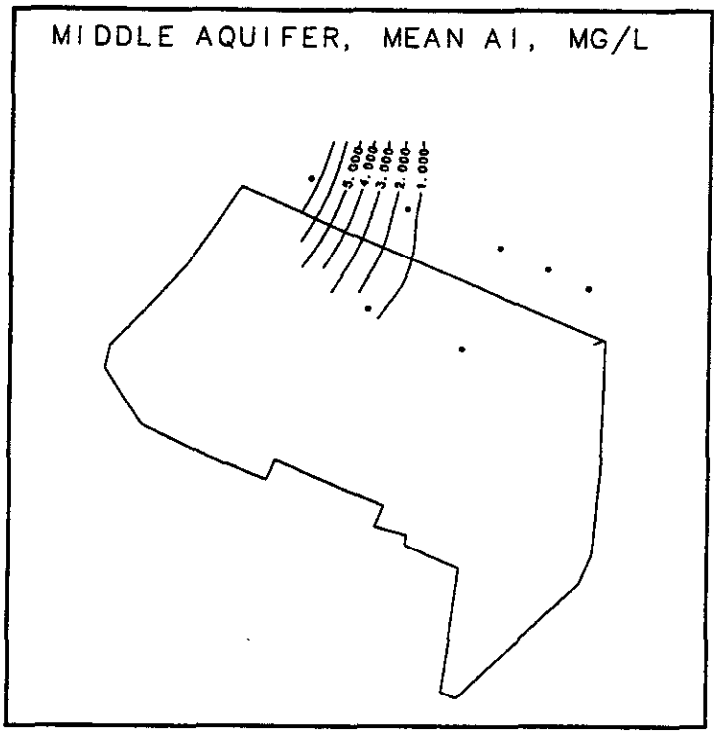


Figure 64. Contours of mean aluminum concentration, middle aquifer. Contour interval is 1 mg/l.

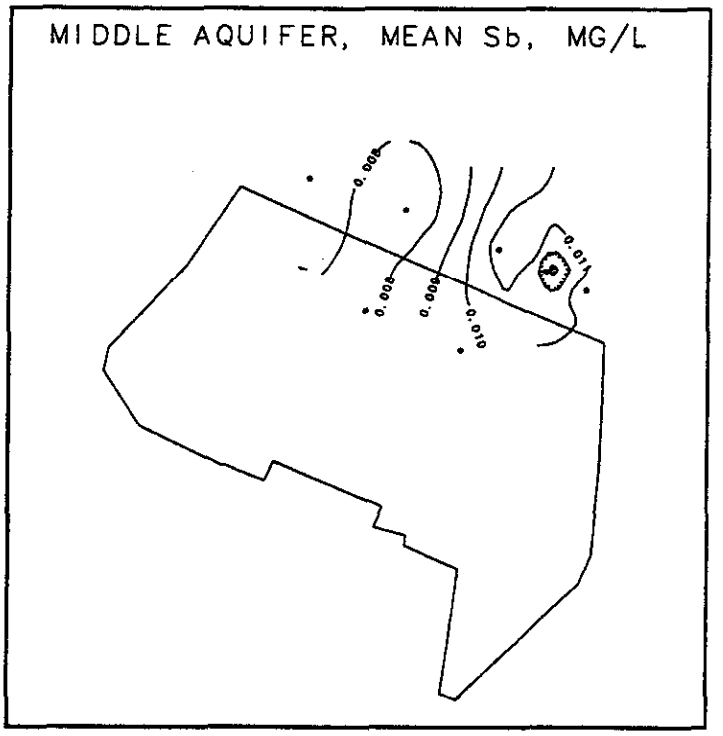


Figure 65. Contours of mean antimony concentration, middle aquifer. Contour interval is 0.001 mg/l.

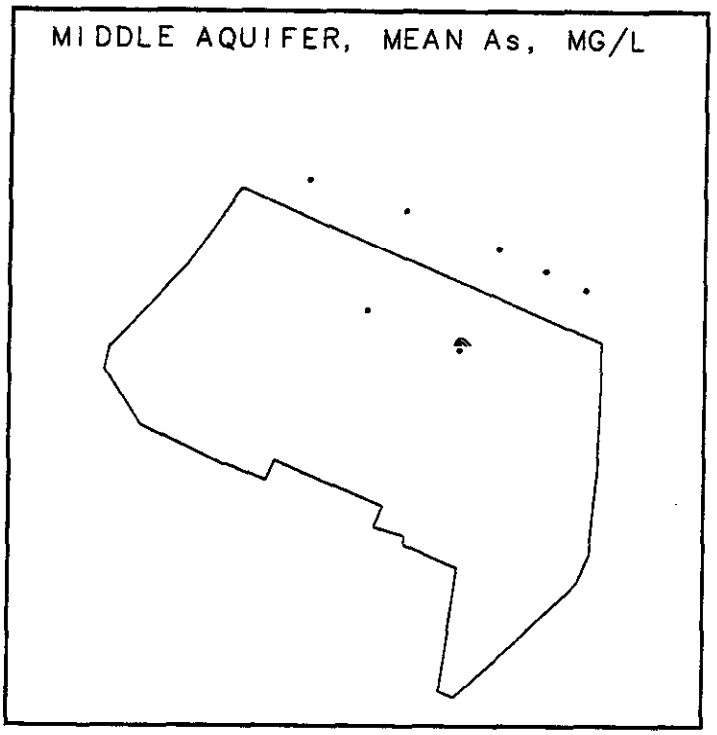


Figure 66. Contours of mean arsenic concentration, middle aquifer. Contour interval is 0.0001 mg/l.

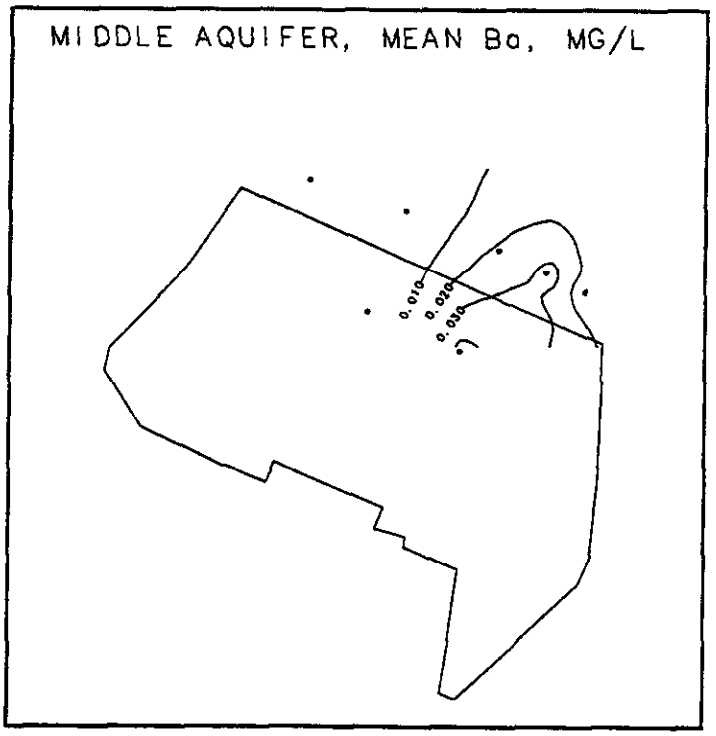


Figure 67. Contours of mean barium concentration, middle aquifer. Contour interval is 0.01 mg/l.

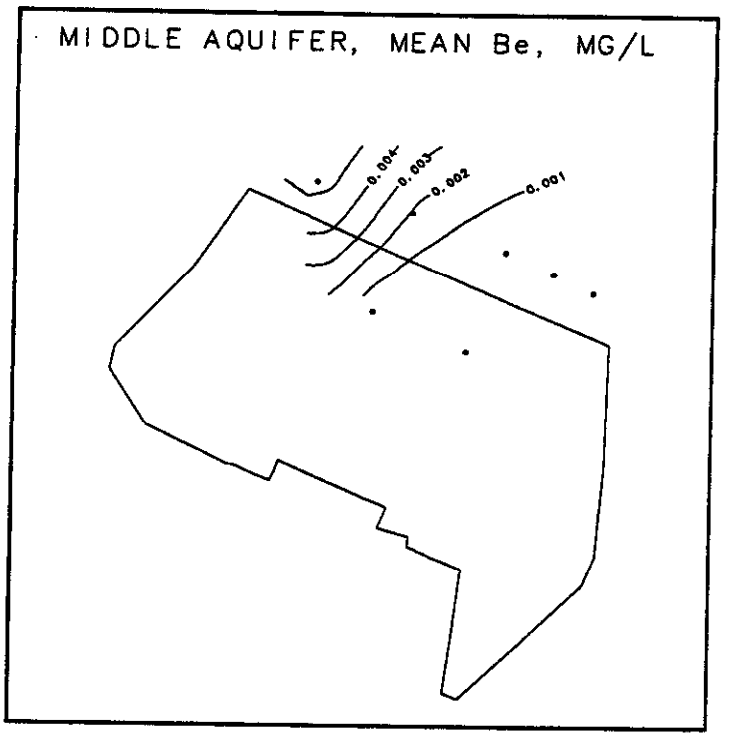


Figure 68. Contours of mean beryllium concentration, middle aquifer. Contour interval is 0.001 mg/l.

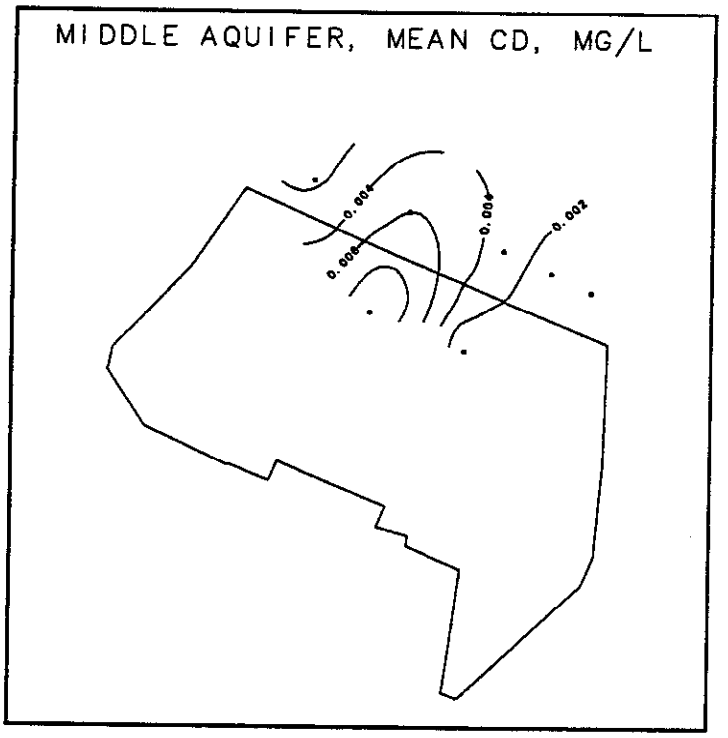


Figure 69. Contours of mean cadmium concentration, middle aquifer. Contour interval is 0.002 mg/l.

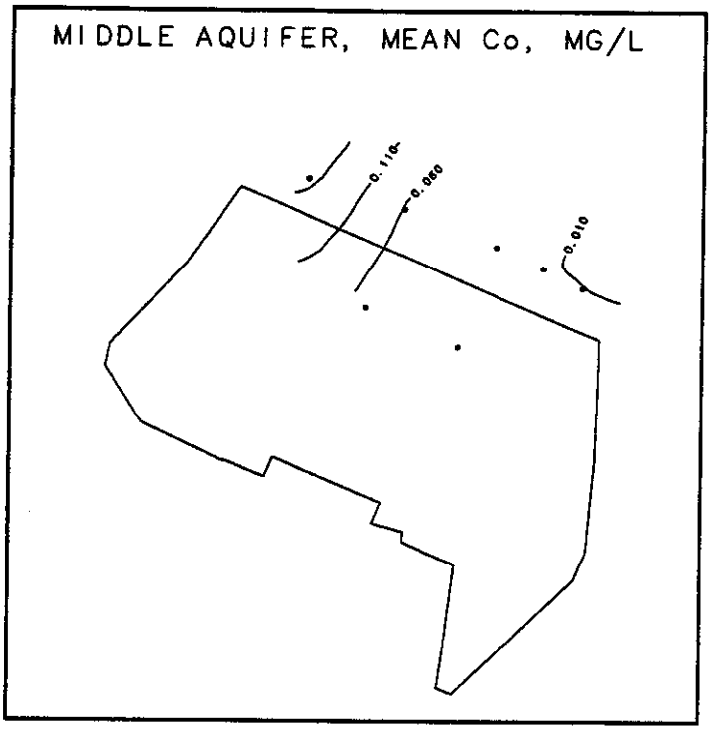


Figure 70. Contours of mean cobalt concentration, middle aquifer. Contour interval is 0.05 mg/l.

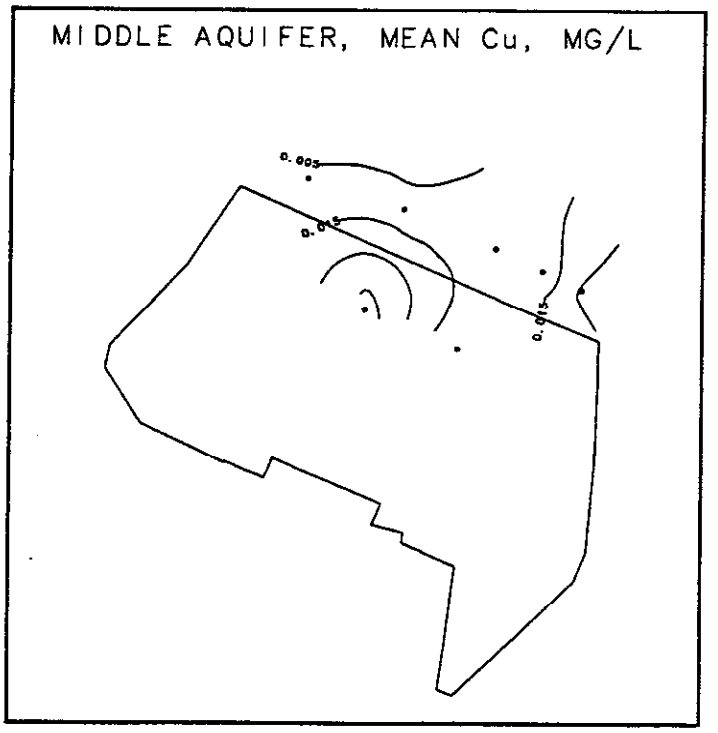


Figure 71. Contours of mean copper concentration, middle aquifer. Contour interval is 0.01 mg/l.

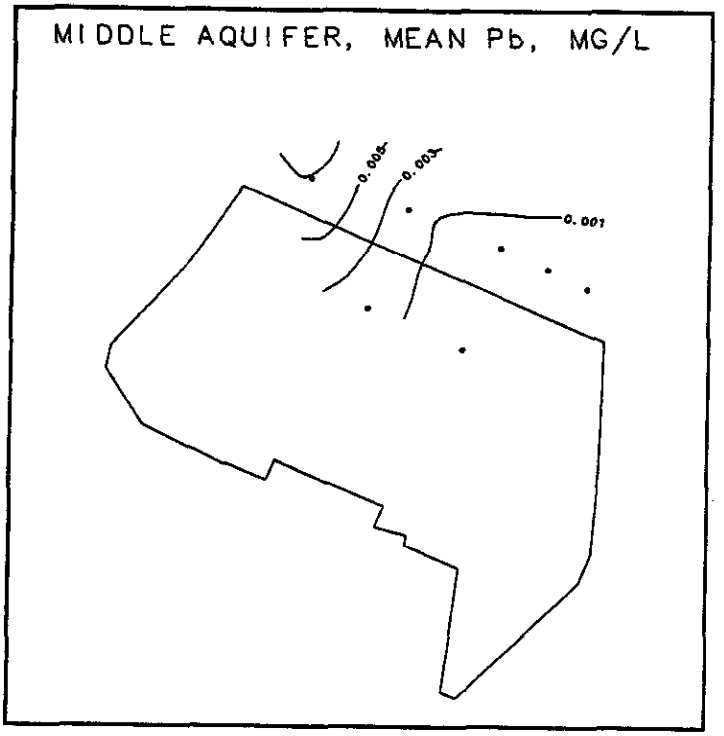


Figure 72. Contours of mean lead concentration, middle aquifer. Contour interval is 0.002 mg/l.

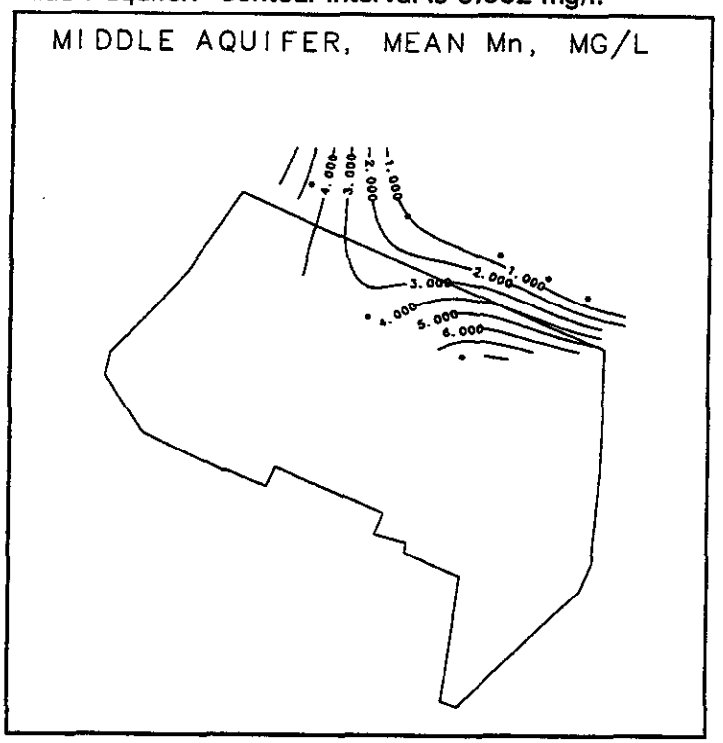


Figure 73. Contours of mean manganese concentration, middle aquifer. Contour interval is 1 mg/l.

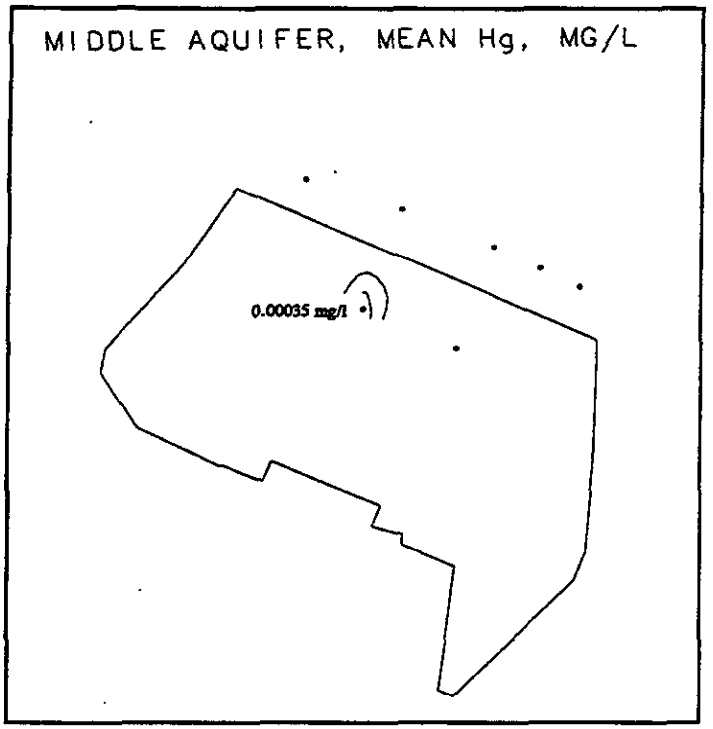


Figure 74. Contours of mean mercury concentration, middle aquifer. Contour interval is 0.00005 mg/l.

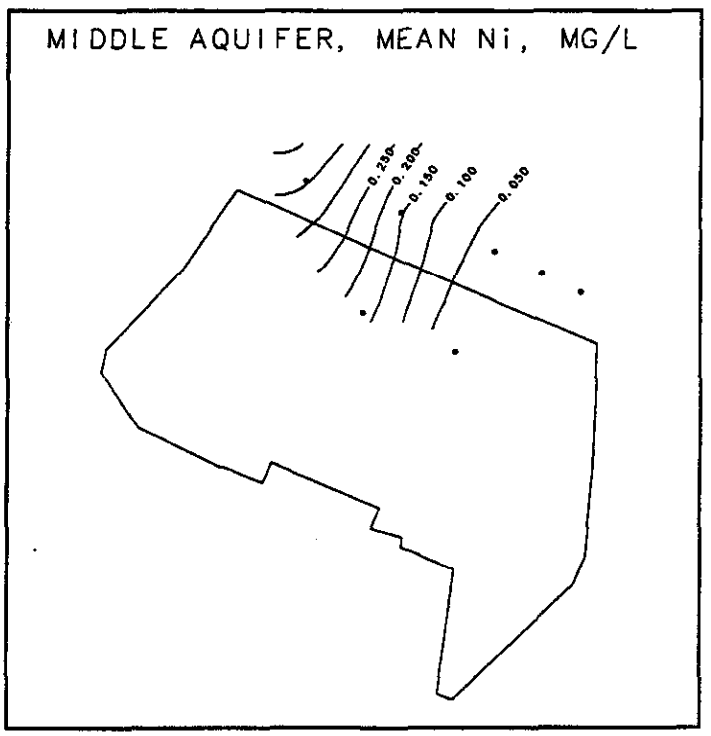


Figure 75. Contours of mean nickel concentration, middle aquifer. Contour interval is 0.05 mg/l.

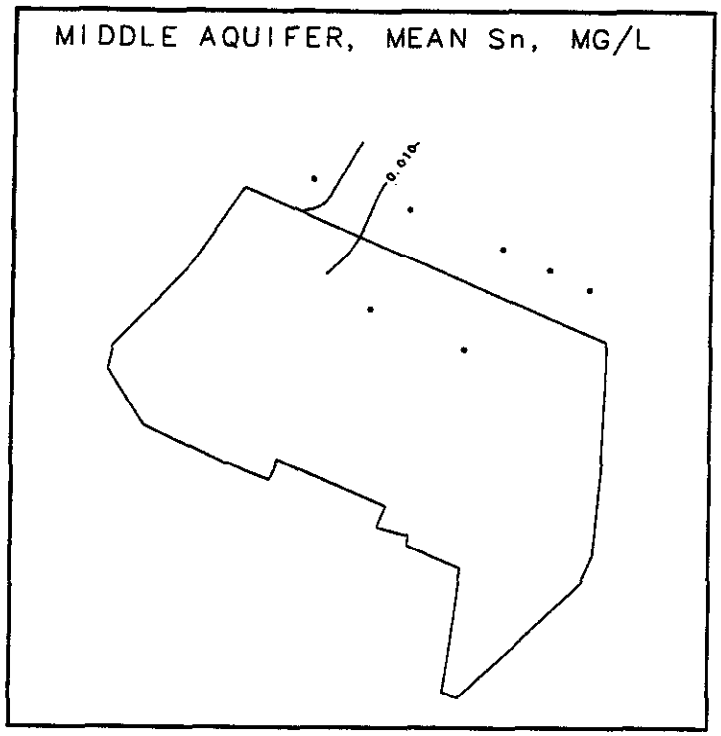


Figure 76. Contours of mean tin concentration, middle aquifer. Contour interval is 0.01 mg/l.

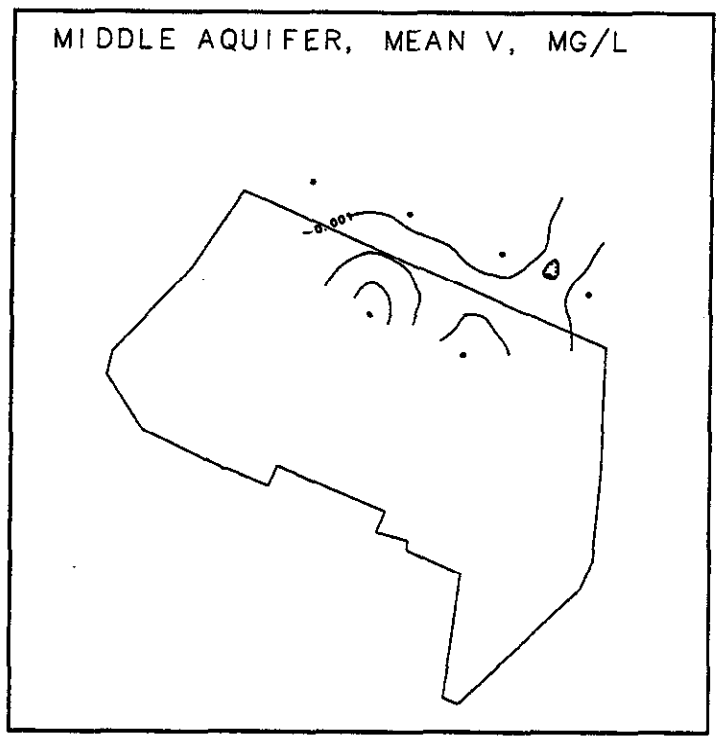


Figure 77. Contours of mean vanadium concentration, middle aquifer. Contour interval is 0.002 mg/l.

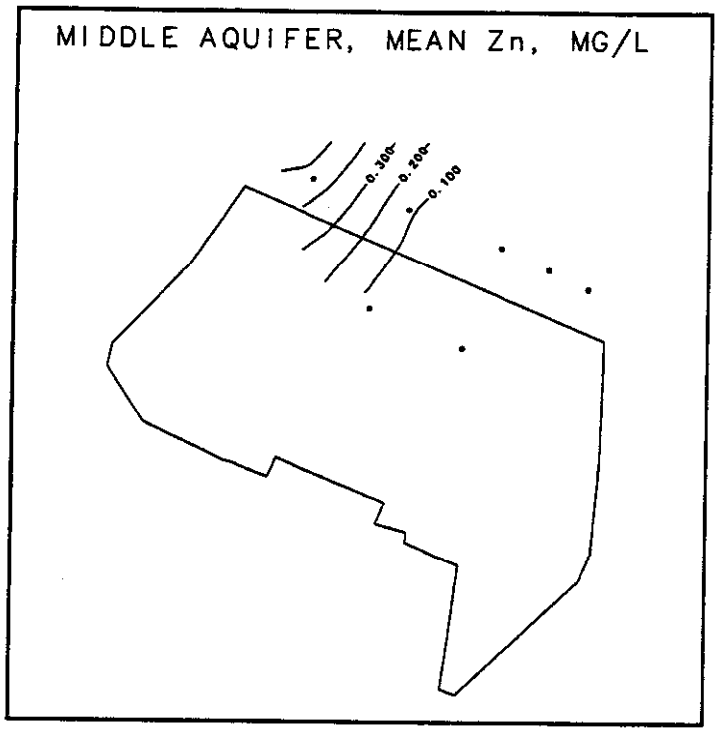


Figure 78. Contours of mean zinc concentration, middle aquifer. Contour interval is 0.1 mg/l.

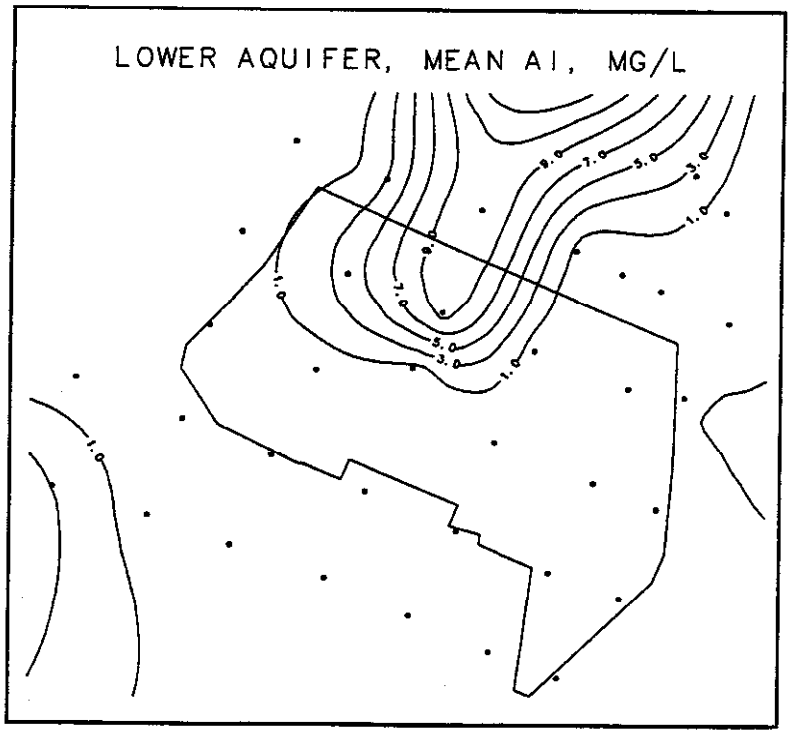


Figure 79. Contours of mean aluminum concentration, lower aquifer. Contour interval is 2 mg/l.

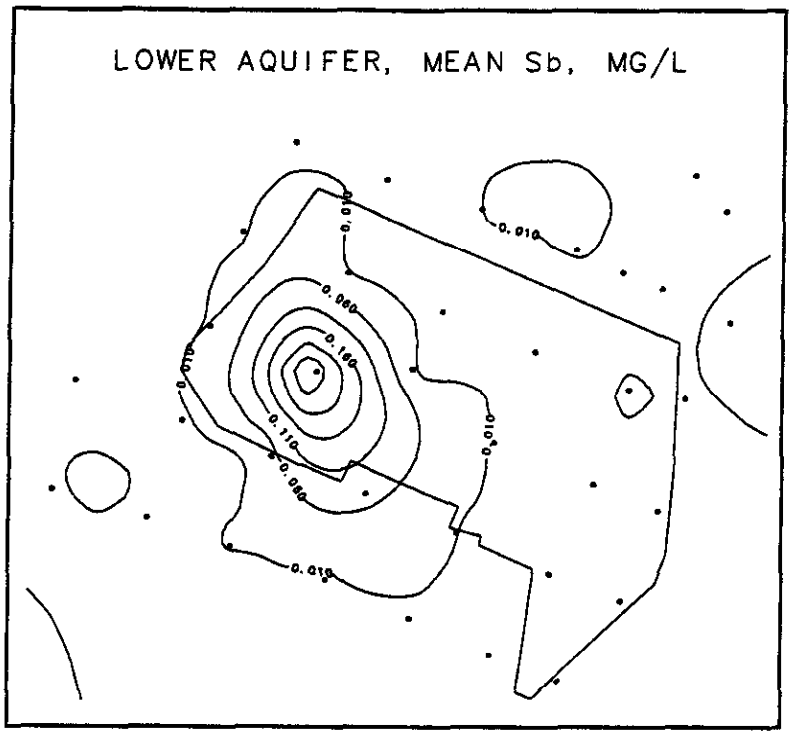


Figure 80. Contours of mean antimony concentration, lower aquifer. Contour interval is 0.05 mg/l.

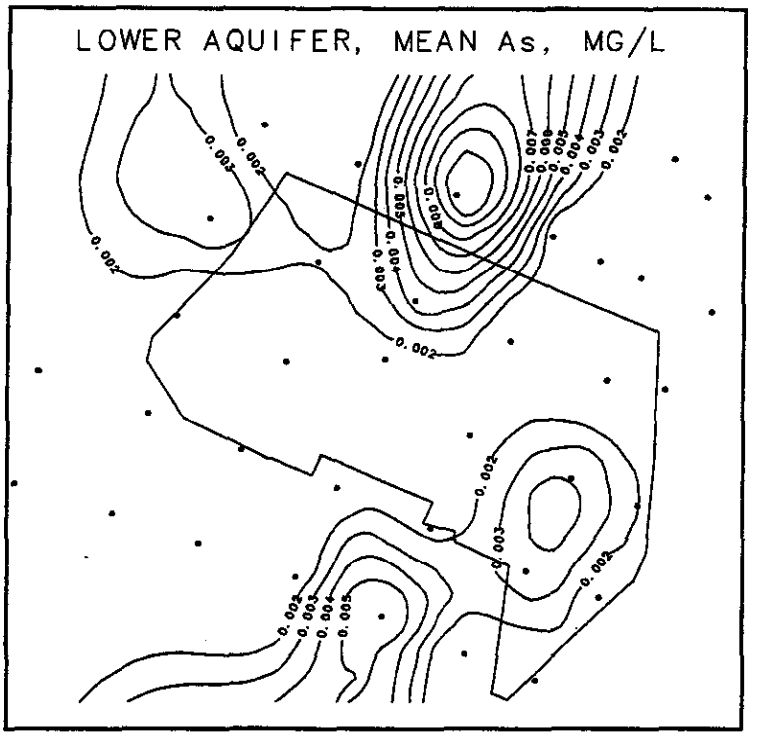


Figure 81. Contours of mean arsenic concentration, lower aquifer. Contour interval is 0.001 mg/l.

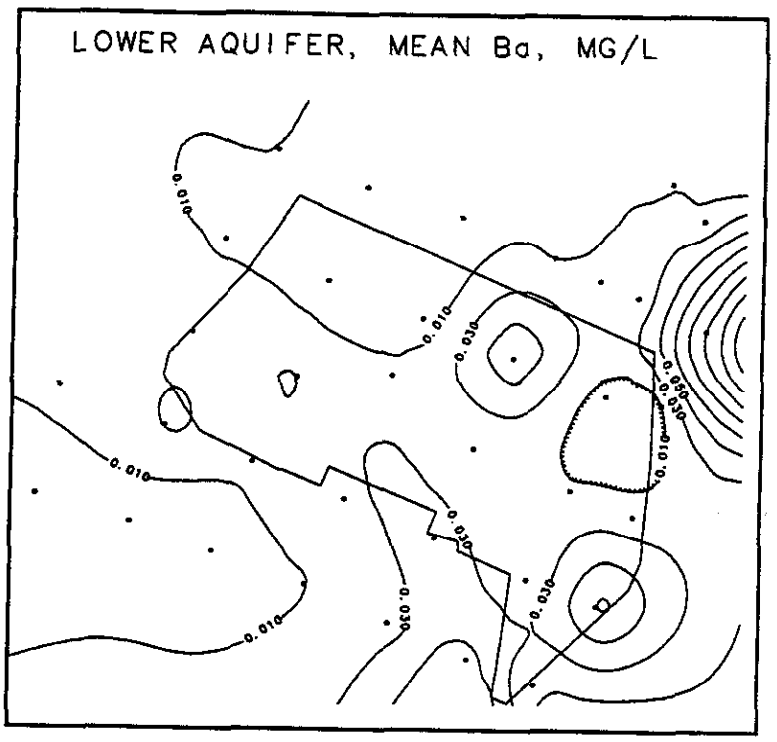


Figure 82. Contours of mean barium concentration, lower aquifer. Contour interval is 0.02 mg/l.

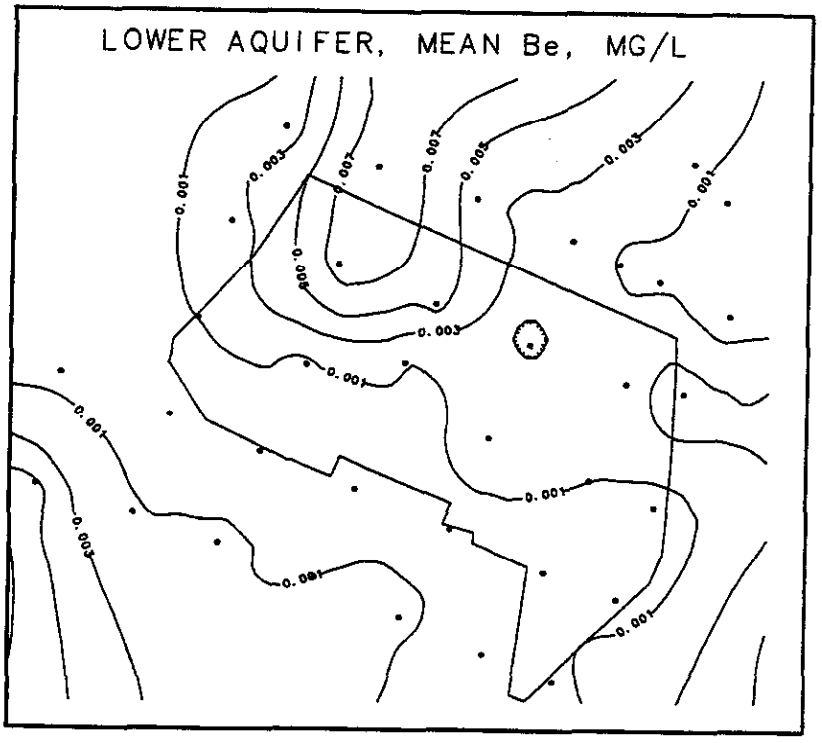


Figure 83. Contours of mean beryllium concentration, lower aquifer. Contour interval is 0.002 mg/l.

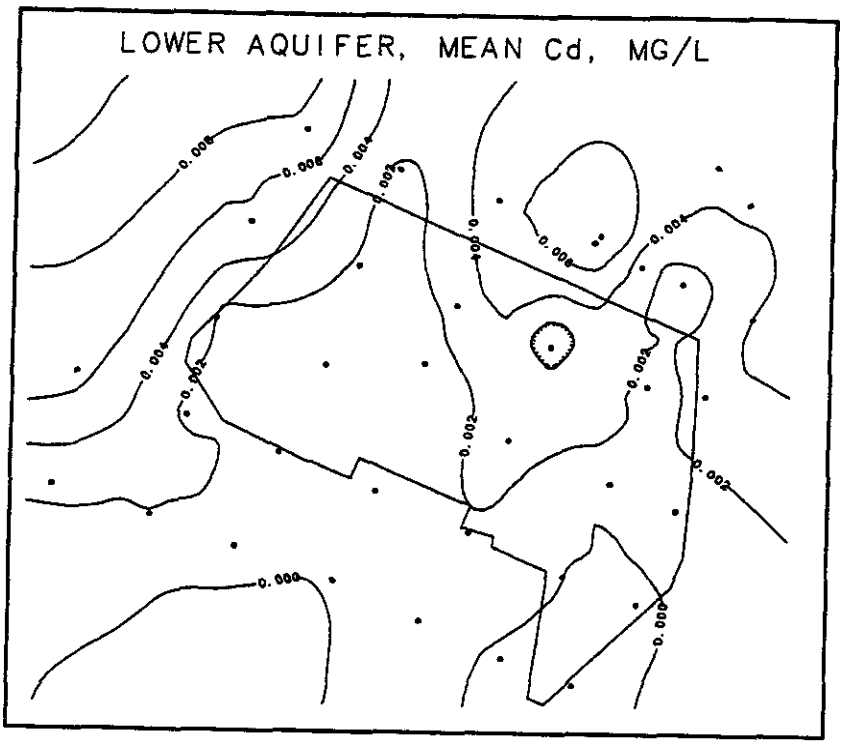


Figure 84. Contours of mean cadmium concentration, lower aquifer. Contour interval is 0.002 mg/l.

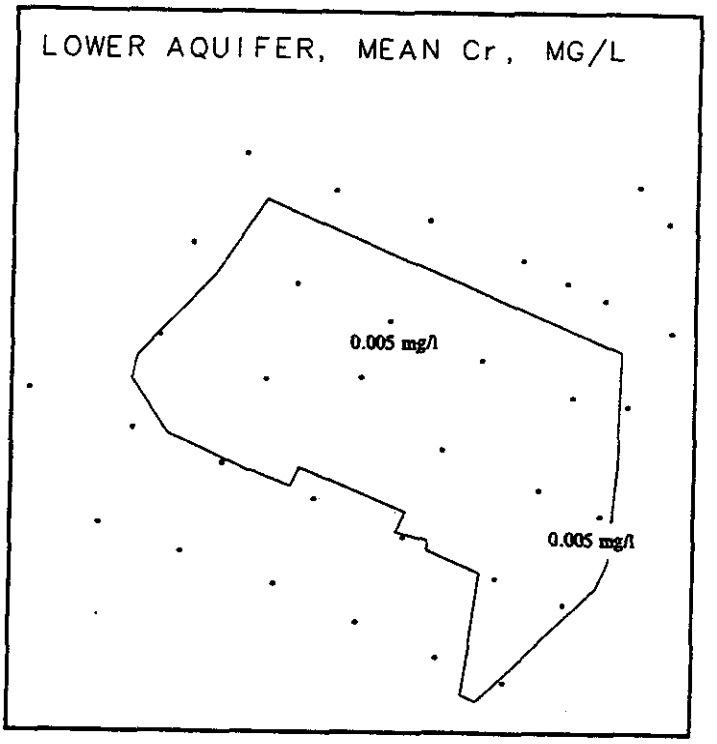


Figure 85. Levels of mean chromium concentration, lower aquifer. DL was 0.005 mg/l.

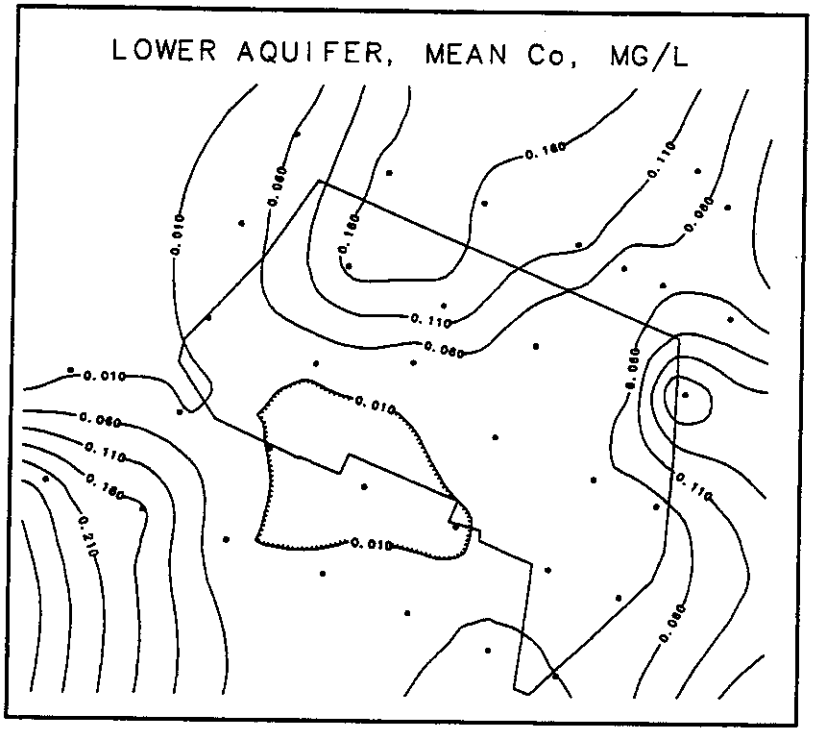


Figure 86. Contours of mean cobalt concentration, lower aquifer. Contour interval is 0.05 mg/l.

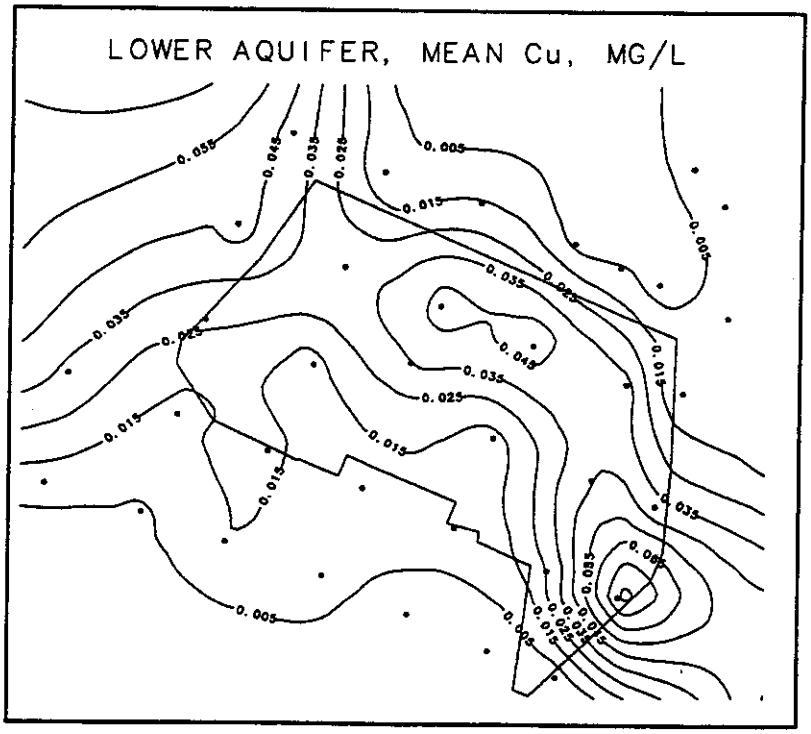


Figure 87. Contours of mean copper concentration, lower aquifer. Contour interval is 0.01 mg/l.

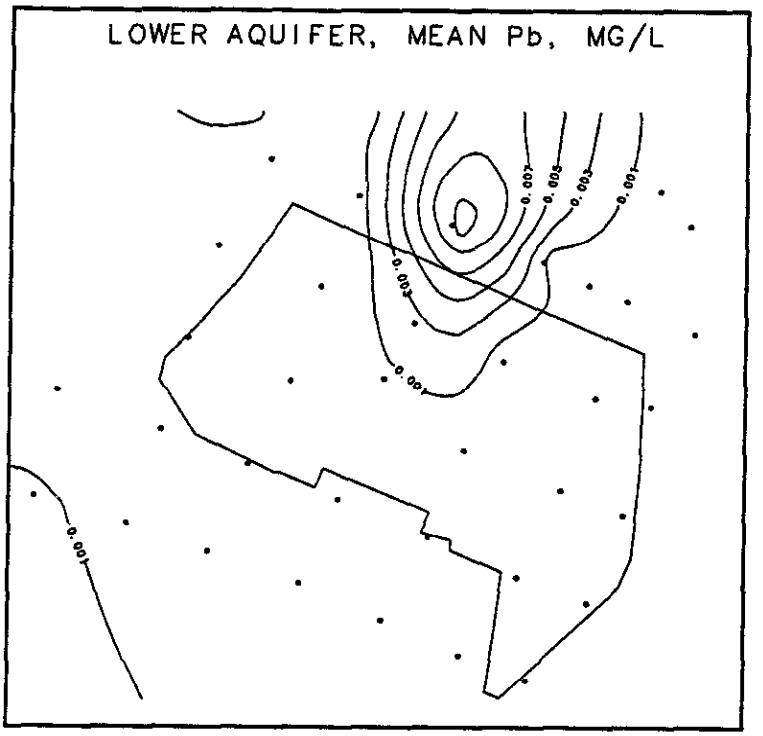


Figure 88. Contours of mean lead concentration, lower aquifer. Contour interval is 0.002 mg/l.

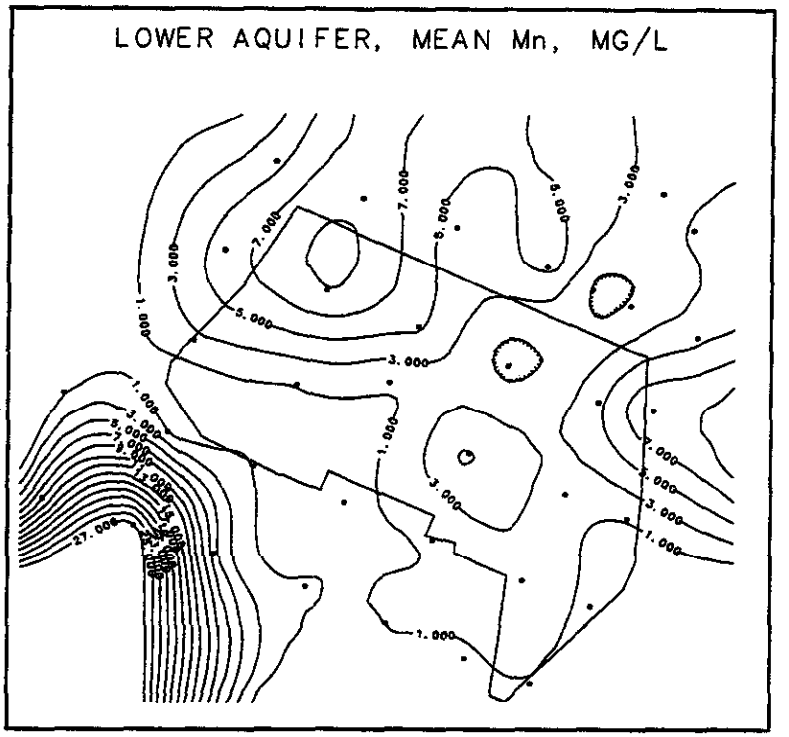


Figure 89. Contours of mean manganese concentration, lower aquifer. Contour interval is 2 mg/l.

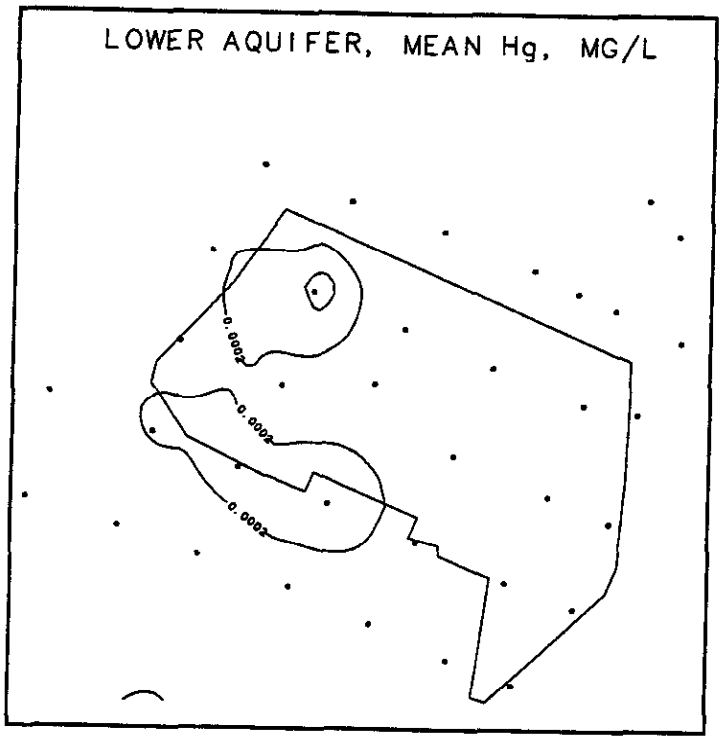


Figure 90. Contours of mean mercury concentration, lower aquifer. Contour interval is 0.0002 mg/l.

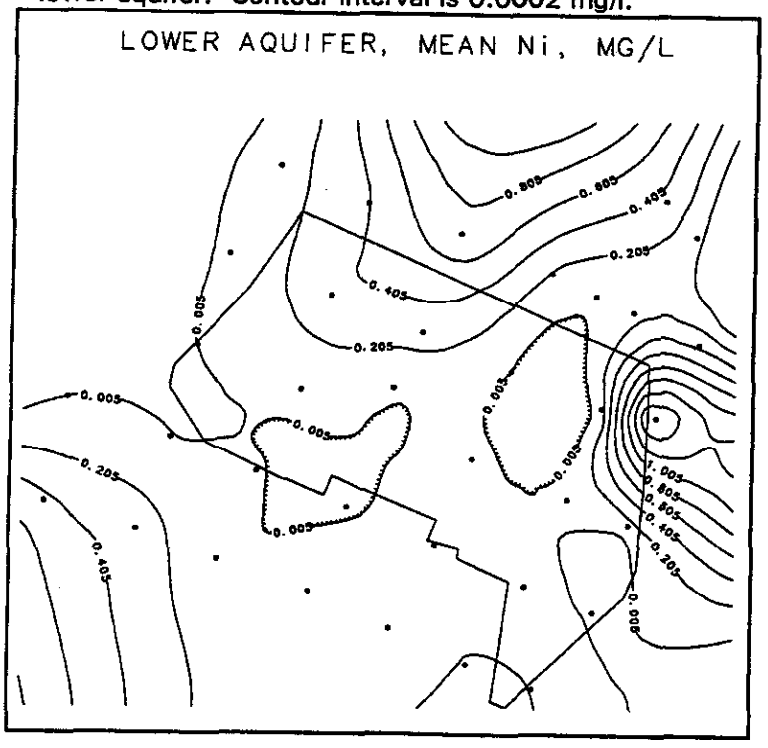


Figure 91. Contours of mean nickel concentration, lower aquifer. Contour interval is 0.2 mg/l.

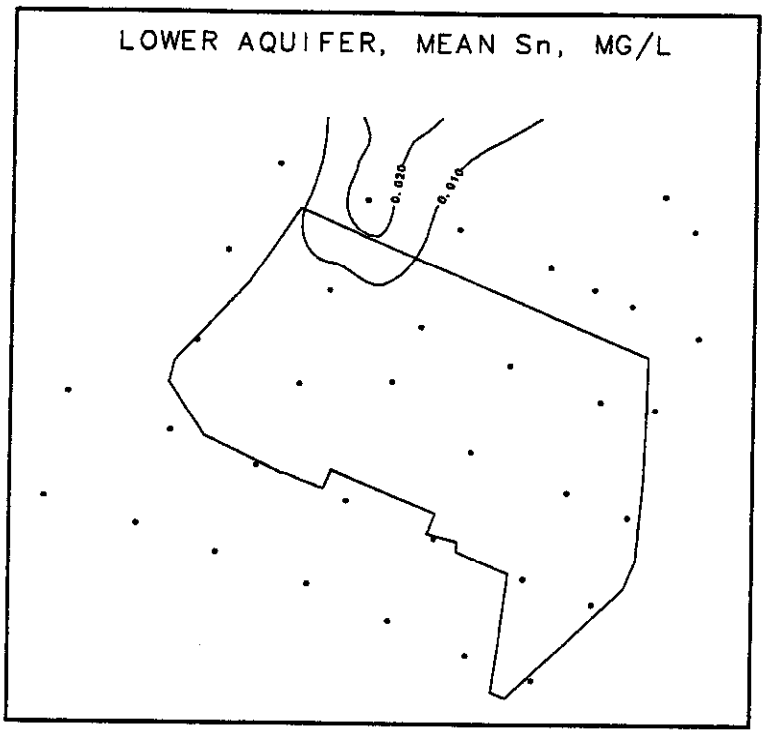


Figure 92. Contours of mean tin concentration, lower aquifer. Contour interval is 0.01 mg/l.

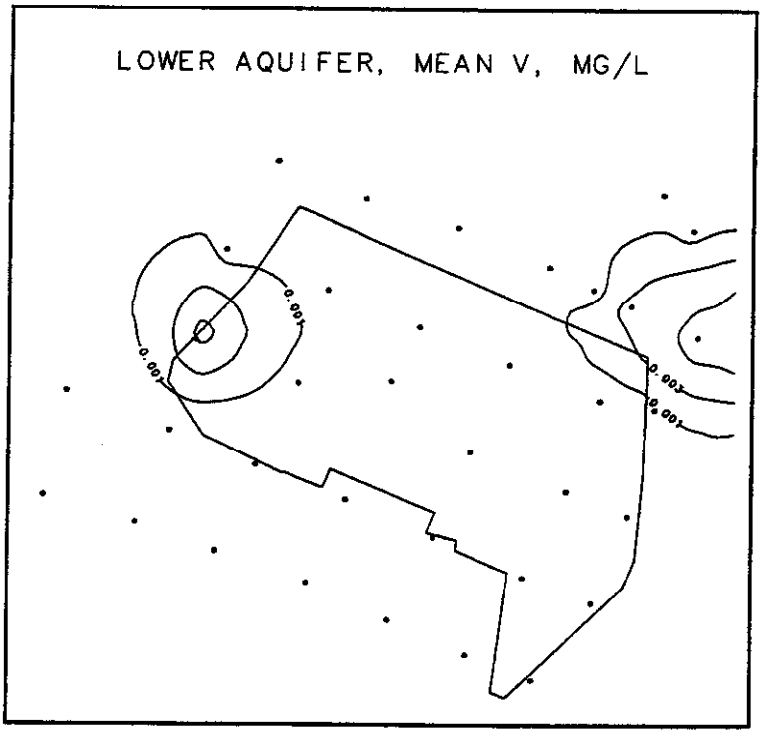


Figure 93. Contours of mean vanadium concentration, lower aquifer. Contour interval is 0.002 mg/l.

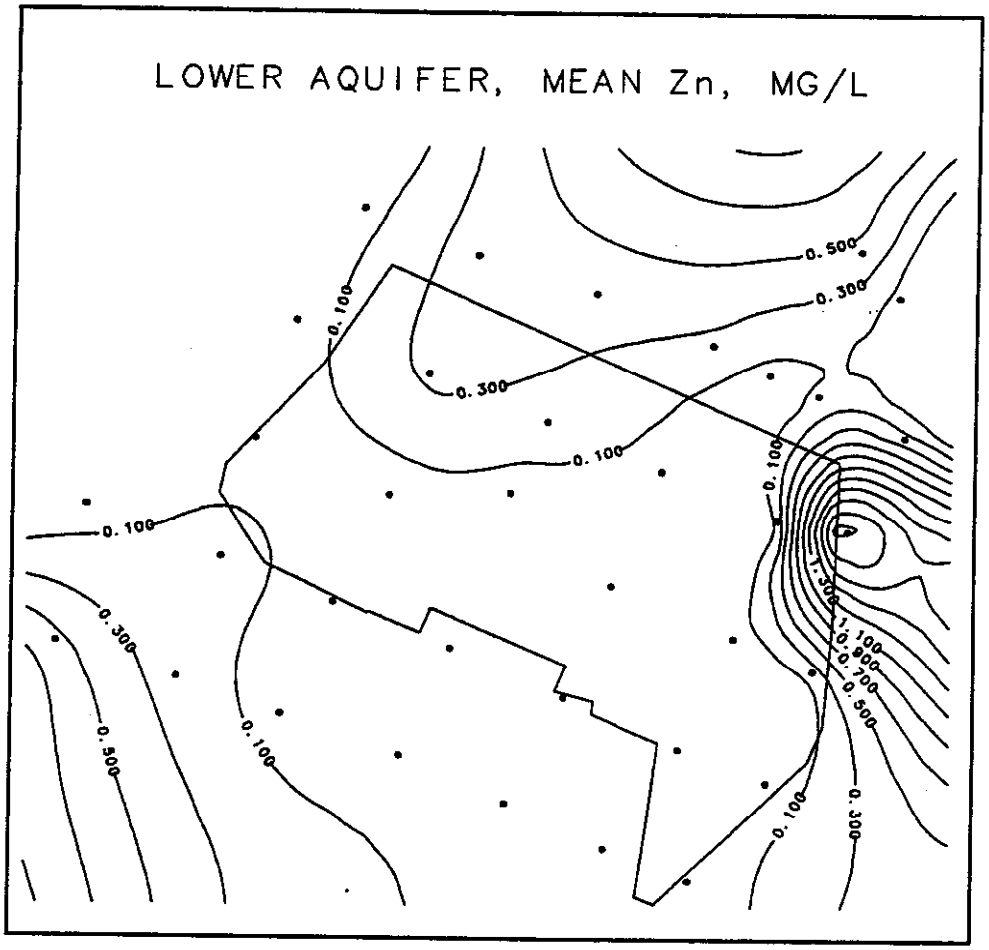
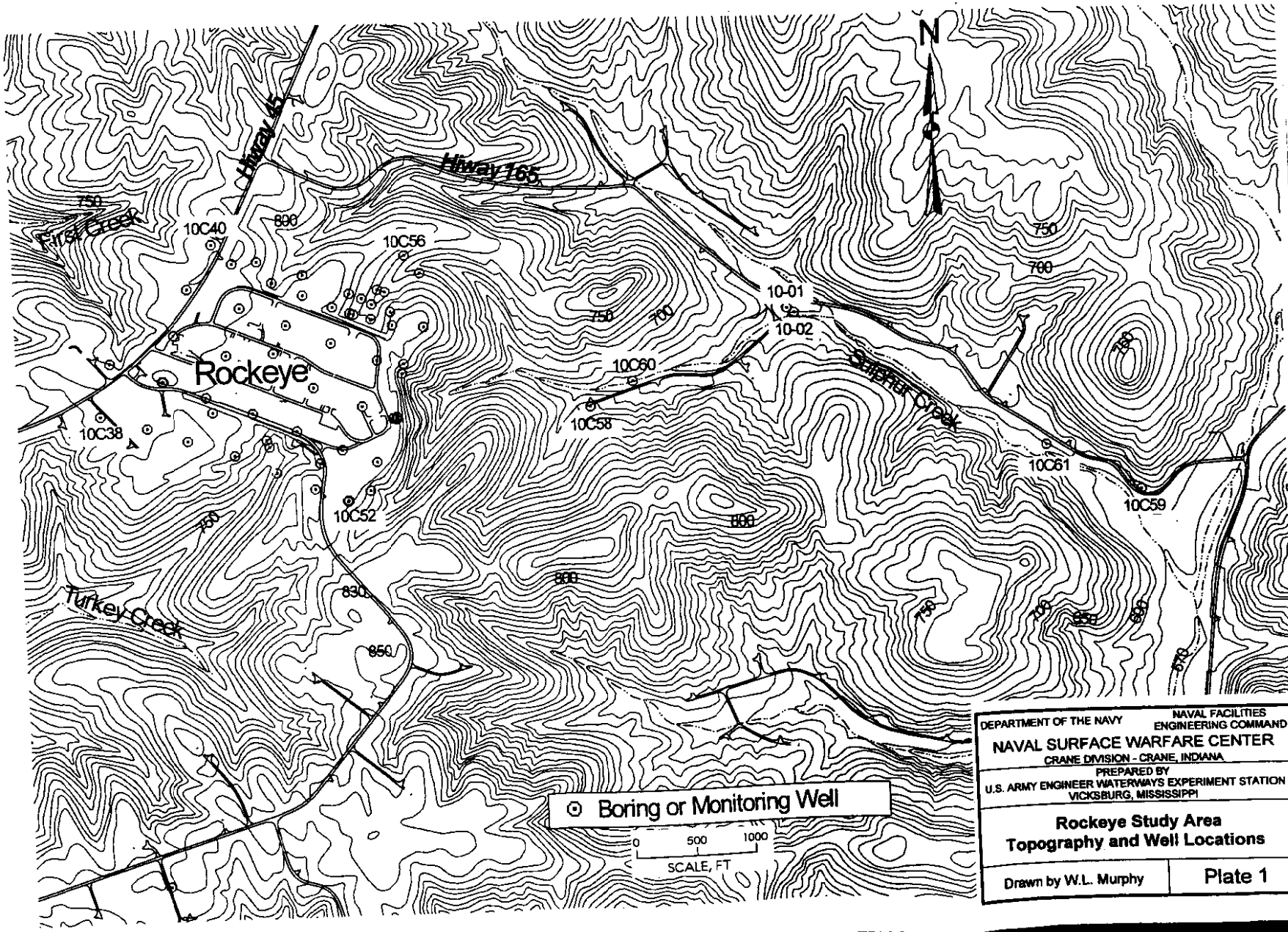


Figure 94. Contours of mean zinc concentration, lower aquifer. Contour interval is 0.2 mg/l.



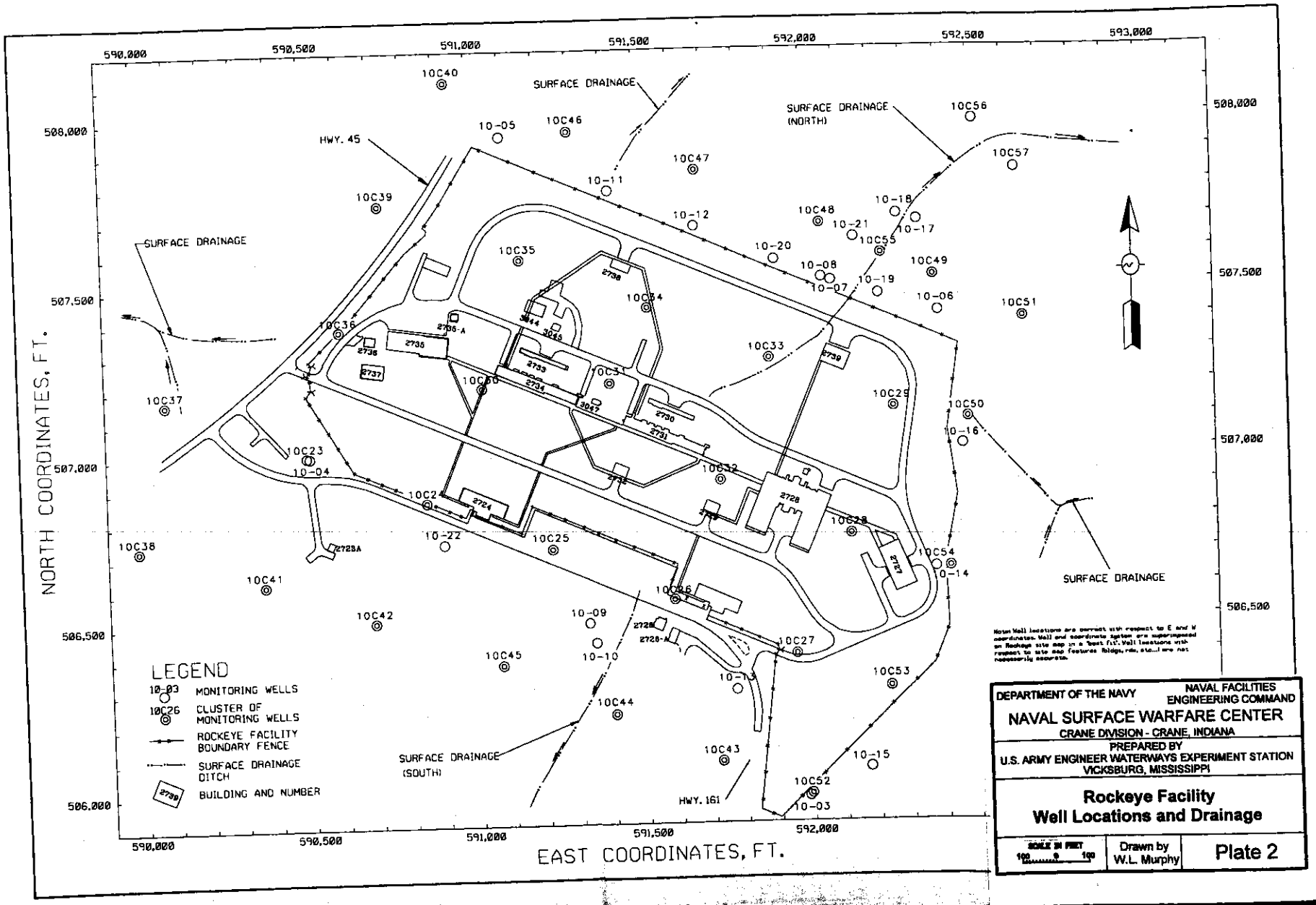
DEPARTMENT OF THE NAVY — NAVAL FACILITIES ENGINEERING COMMAND

NAVAL SURFACE WARFARE CENTER
CRANE DIVISION - CRANE, INDIANA

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

Rockeye Study Area
Topography and Well Locations

Drawn by W.L. Murphy | Plate 1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ROCKEYE FACILITY BOUNDARY FENCE
SURFACE DRAINAGE DITCH
BUILDING AND NUMBER
DEPARTMENT OF THE NAVY
NAVAL FACILITIES ENGINEERING COMMAND
NAVAL SURFACE WARFARE CENTER
CRANE DIVISION - CRANE, INDIANA
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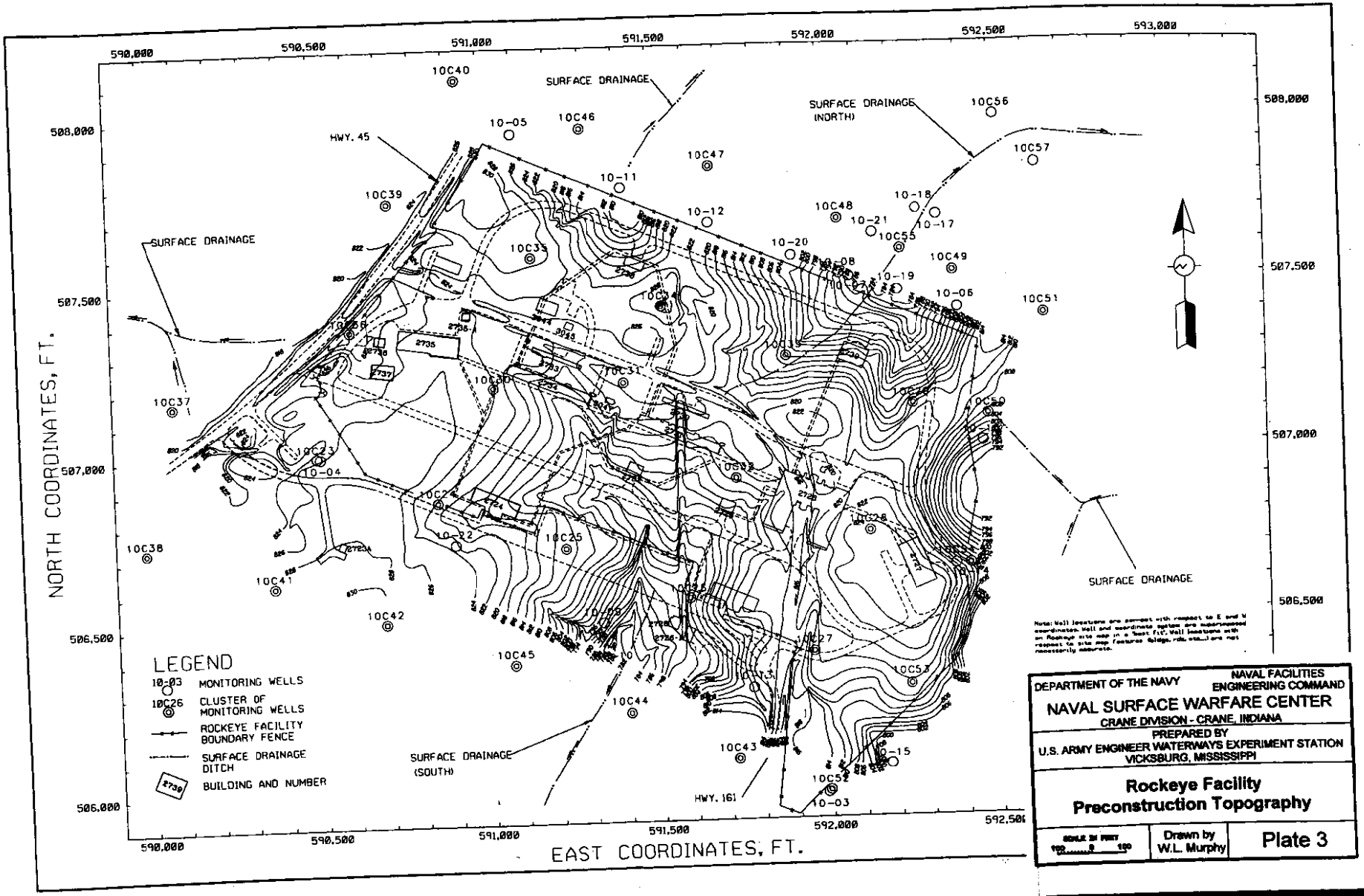
U.S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION
VICKSBURG, MISSISSIPPI
Rockeye Facility
Well Locations and Drainage
SCALE IN FEET
100 0 100
Drawn by
W.L. Murphy
Plate 2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LEGEND
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10C26 CLUSTER OF MONITORING WELLS
ROCKEYE FACILITY BOUNDARY FENCE
SURFACE DRAINAGE DITCH
2739 BUILDING AND NUMBER
DEPARTMENT OF THE NAVY
NAVAL FACILITIES ENGINEERING COMMAND
NAVAL SURFACE WARFARE CENTER
CRANE DIVISION - CRANE, INDIANA
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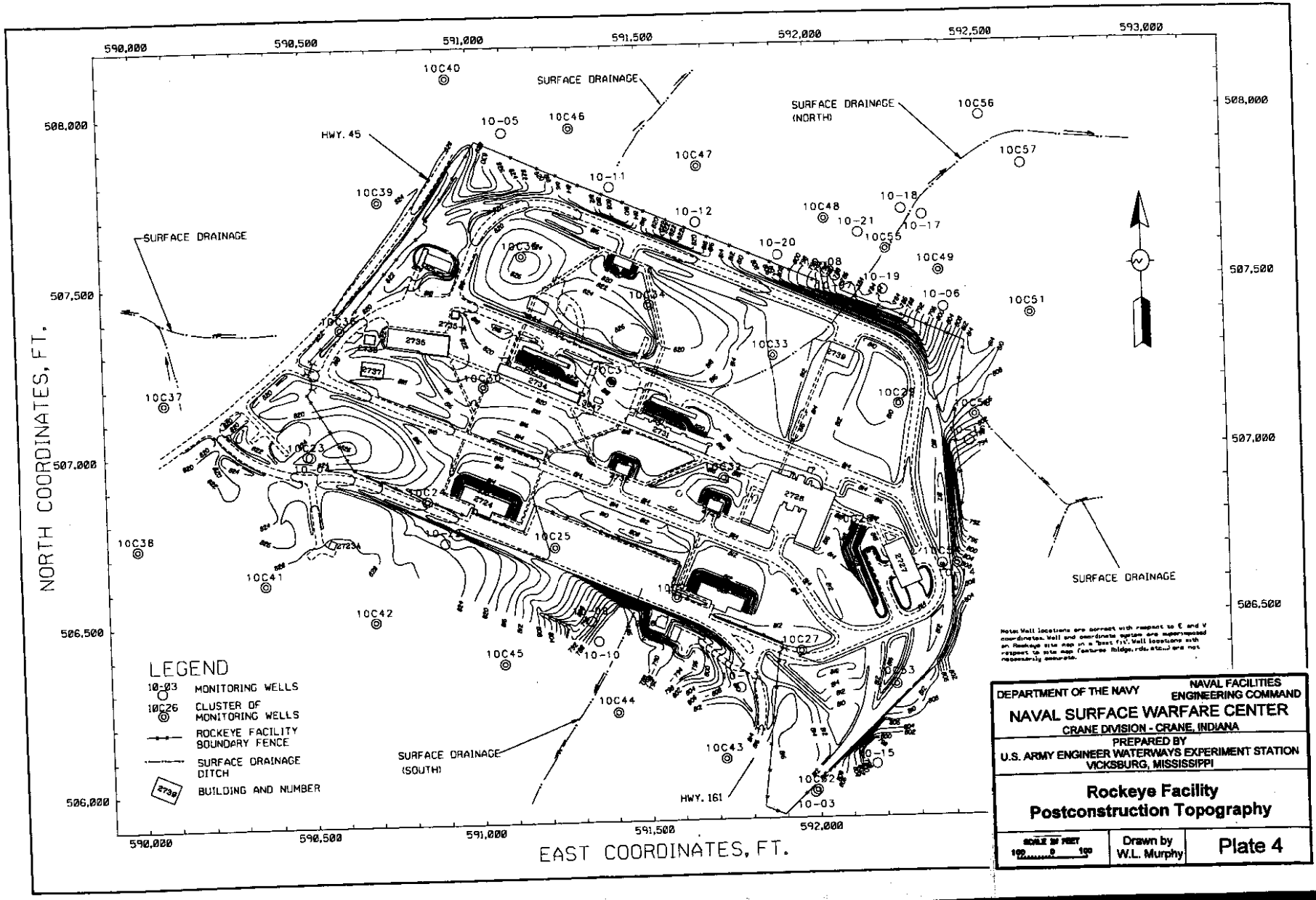
U.S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION
VICKSBURG, MISSISSIPPI
Rockeye Facility
Preconstruction Topography
SCALE IN FEET
Drawn by W.L. Murphy
Plate 3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SURFACE DRAINAGE (SOUTH)
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LEGEND
10-03 MONITORING WELLS
10C26 CLUSTER OF MONITORING WELLS
ROCKEYE FACILITY BOUNDARY FENCE
SURFACE DRAINAGE DITCH
2738 BUILDING AND NUMBER
Note: Well locations are correct with respect to E and N coordinates. Well and coordinate system are superimposed on Rockeye site map in a best fit. Well locations with respect to site map features (bldgs, rds, etc.) are not necessarily accurate.
DEPARTMENT OF THE NAVY
NAVAL FACILITIES ENGINEERING COMMAND
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CRANE DIVISION - CRANE, INDIANA
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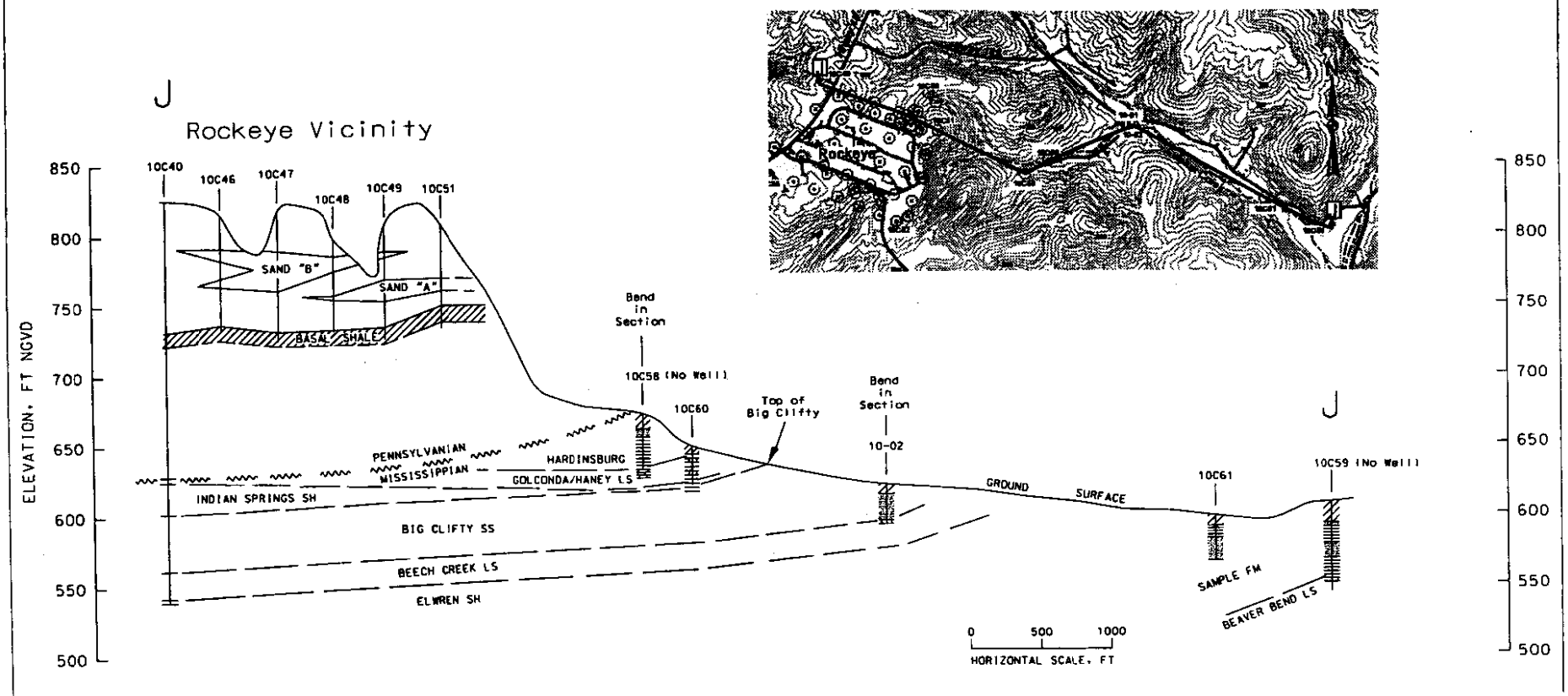
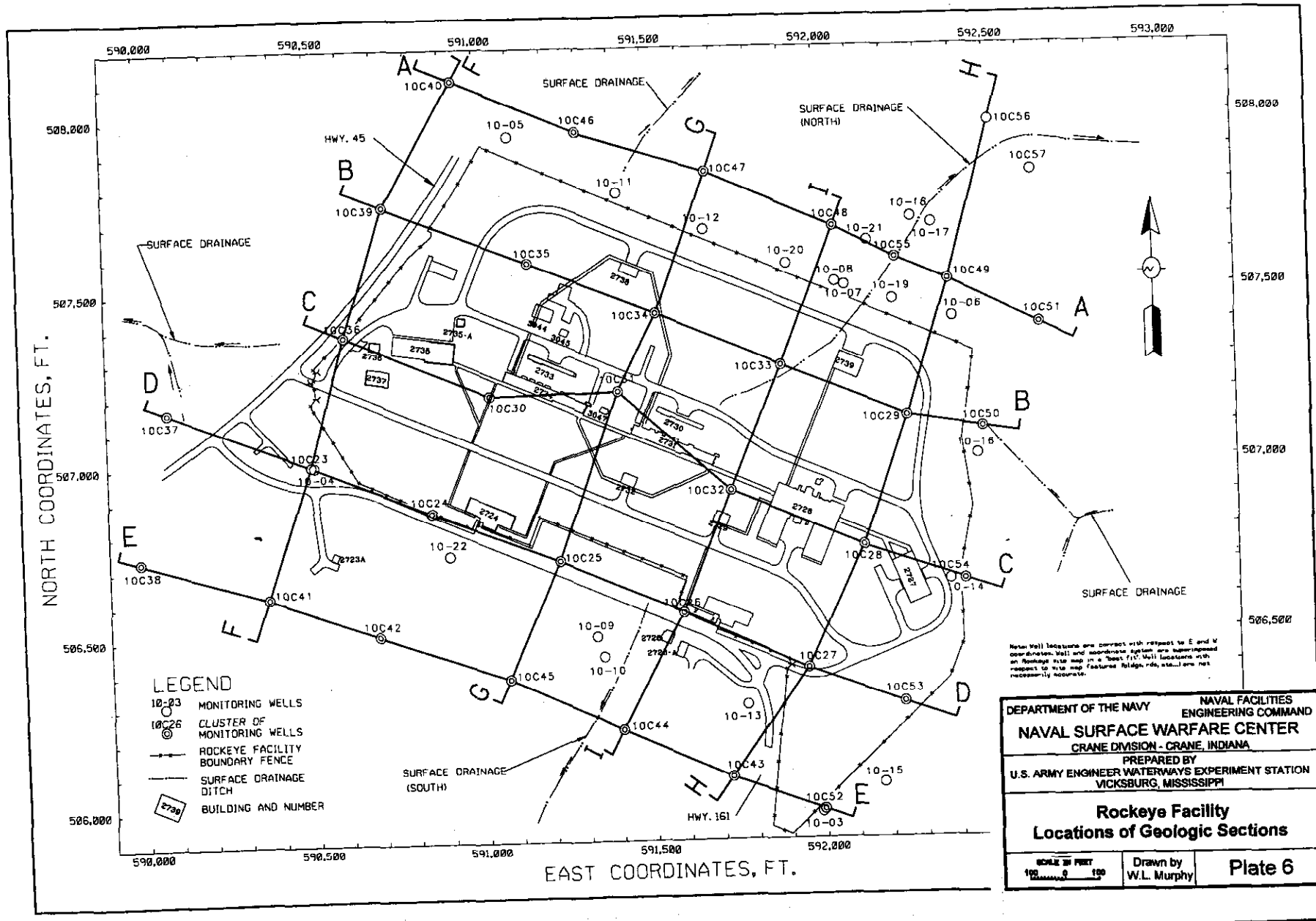
U.S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION
VICKSBURG, MISSISSIPPI
Rockeye Facility
Postconstruction Topography
SCALE IN FEET
100 0 100
Drawn by
W.L. Murphy
Plate 4



DEPARTMENT OF THE NAVY	NAVAL FACILITIES ENGINEERING COMMAND
NAVAL SURFACE WARFARE CENTER CRANE DIVISION - CRANE, INDIANA	
PREPARED BY U.S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG, MISSISSIPPI	
Rockeye Study Area Geologic Profile	
Drawn by W.L. Murphy	Plate 5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NORTH COORDINATES, FT.
EAST COORDINATES, FT.
A
B
C
D
E
F
G
H
I
SURFACE DRAINAGE
SURFACE DRAINAGE (NORTH)
SURFACE DRAINAGE (SOUTH)
HWY. 45
HWY. 161
10C40
10-05
10C46
10C47
10-11
10-12
10C39
10C35
10C34
10C33
10C48
10-21
10-16
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10C55
10-20
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10C49
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10C51
10C56
10C57
10C36
10C30
10C29
10C50
10-18
10C37
10C23
10-04
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10C32
10C25
10C28
10C54
10-14
10C38
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10C42
10-09
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10C27
10C53
10C45
10C44
10-13
10C43
10-15
10C52
10-03
2736
2735-A
2737
2733
2734
2730
2731
2739
2724
2723A
2726
2727
2728
2728-A
LEGEND
10-03 MONITORING WELLS
10C26 CLUSTER OF MONITORING WELLS
ROCKEYE FACILITY BOUNDARY FENCE
SURFACE DRAINAGE DITCH
2736 BUILDING AND NUMBER
Note: Well locations are correct with respect to E and N coordinates. Well and coordinate system are superimposed on Rockeye site map in a "best fit". Well locations with respect to site map features (bldgs, rds, etc.) are not necessarily accurate.
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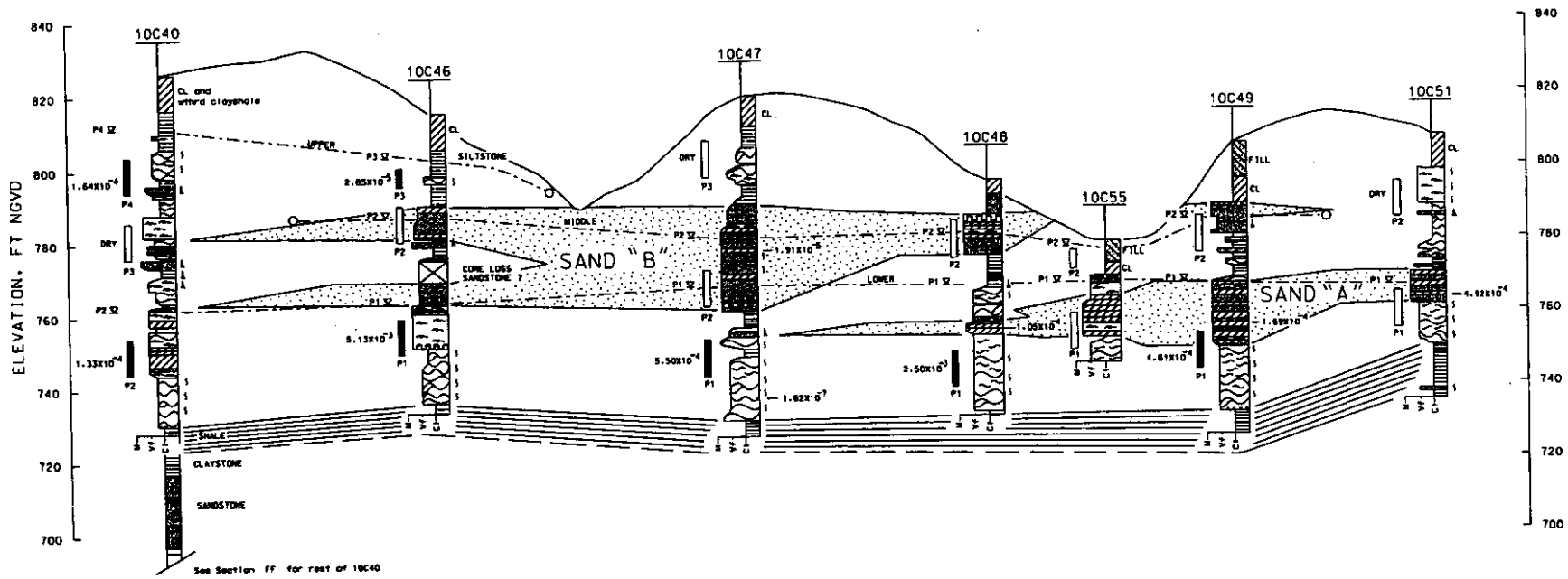
VICKSBURG, MISSISSIPPI
Rockeye Facility
Locations of Geologic Sections
SCALE IN FEET
100 0 100
Drawn by
W.L. Murphy
Plate 6



Dark Gray Shale Facies

Lenticular Bedded Shale Facies

Rooted Claystone, Siltstone & Sandstone Facies

Wavy Bedded Sandstone Facies

Ripple Bedded Sandstone Facies

Massive & Cross-bedded Sandstone Facies

Flaser Bedded Sandstone Facies

Rhythmic Bedded Siltstone Facies

Disrupted Bedded Sandstone & Shale Facies

Coal Facies

Bioturbated Mudstone, Siltstone & Sandstone

CLAY (CL)

FILL

SILT (ML)

SILTSTONE

SHALE

SANDSTONE & SHALE

SANDSTONE

COAL

LIMESTONE

P1 ▽ Water level for well P1

P2 Screen position for well P1

1.82 X 10^-7 Laboratory hydraulic conductivity in cm/sec

Piezometric surface, 03/91 (UPPER, MIDDLE, OR LOWER aquifer)

Piezometric surface terminus (approx. point at which aquifer terminates).

Confident geologic contact

Estimated geologic contact

5.13X10^-3 Hydraulic conductivity, cm/sec, from slug tests

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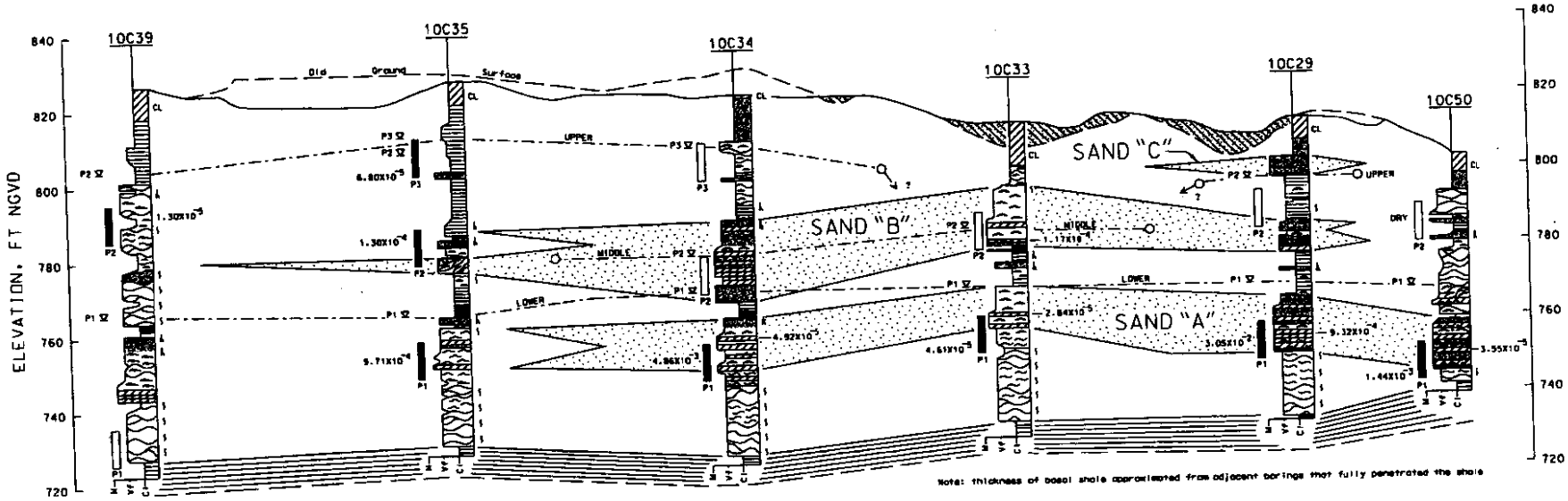
Geologic Section AA

APPROX HOR. SCALE 0 50 100 FT

Drawn by W.L. Murphy

Plate 7



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SANDSTONE & SHALE

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COAL

LIMESTONE

P1 ▽ Water level for well P1

Screen position for well P1

P2

1.82×10^{-7} Laboratory hydraulic conductivity in cm/sec

Piezometric surface, 03/91 (UPPER, MIDDLE, OR LOWER aquifer)

Piezometric surface terminus (approx. point at which aquifer terminates).

Confident geologic contact

Estimated geologic contact

5.13×10^{-3} Hydraulic conductivity, cm/sec, from slug tests

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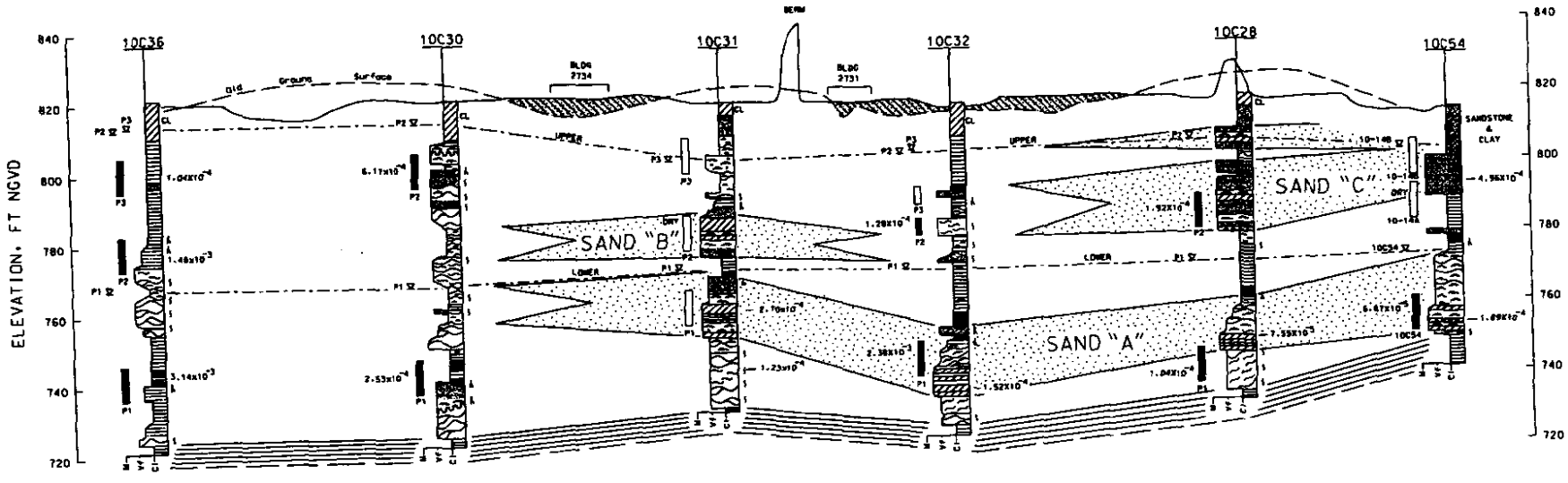
Geologic Section BB

APPROX HOR. SCALE 0 50 100 FT

Drawn by W.L. Murphy

Plate 8



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Bioturbated Mudstone, Siltstone & Sandstone

CLAY (CL)

FILL

SILT (ML)

SILTSTONE

SHALE

SANDSTONE & SHALE

SANDSTONE

COAL

LIMESTONE

P1 SZ — Water level for well P1

P2 — Screen position for well P1

1.82 X 10^-4 — Laboratory hydraulic conductivity in cm/sec

Piezometric surface, 03/91 (UPPER, MIDDLE, OR LOWER aquifer)

Piezometric surface terminus (approx. point at which aquifer terminates).

Confident geologic contact

Estimated geologic contact

5.13X10^-3 — Hydraulic conductivity, cm/sec, from slug tests

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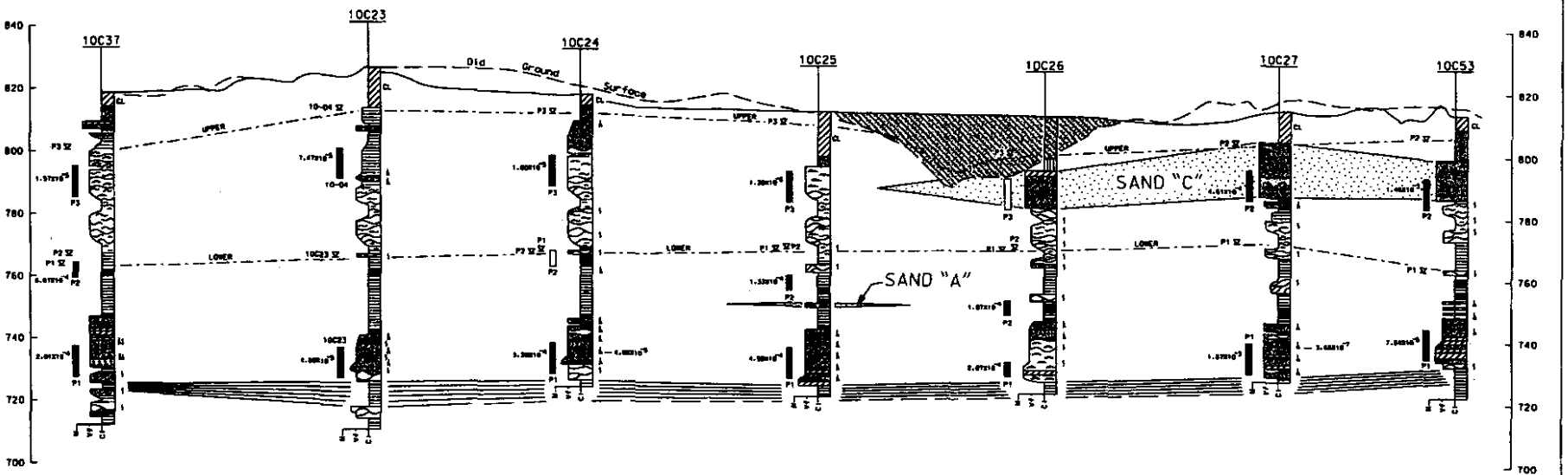
APPROX HOR. SCALE	Drawn by	
0 50 100 FT	W.L. Murphy	Plate 9



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SILTSTONE

SHALE

SANDSTONE & SHALE

SANDSTONE

COAL

LIMESTONE

P1 ▽ Water level for well P1

P2 Screen position for well P1

1.82×10^{-7} Laboratory hydraulic conductivity in cm/sec

Piezometric surface, 03/91 (UPPER, MIDDLE, OR LOWER aquifer)

Piezometric surface terminus (approx. point at which aquifer terminates).

Confident geologic contact

Estimated geologic contact

Hydraulic conductivity, cm/sec, from slug tests

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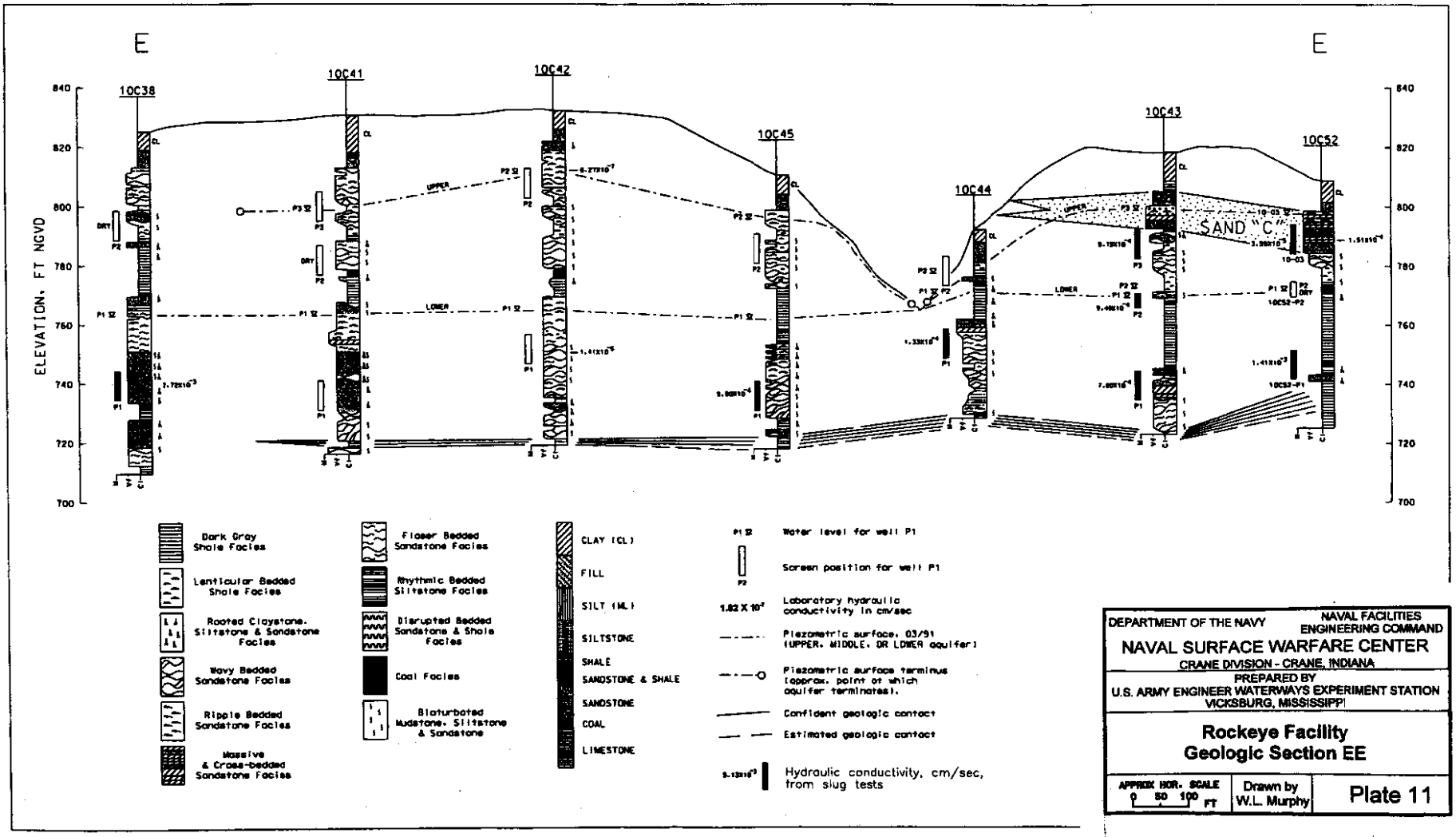
Rockeye Facility Geologic Section DD	
APPROX HOR. SCALE 0 50 100 FT	Drawn by W.L. Murphy	Plate 10



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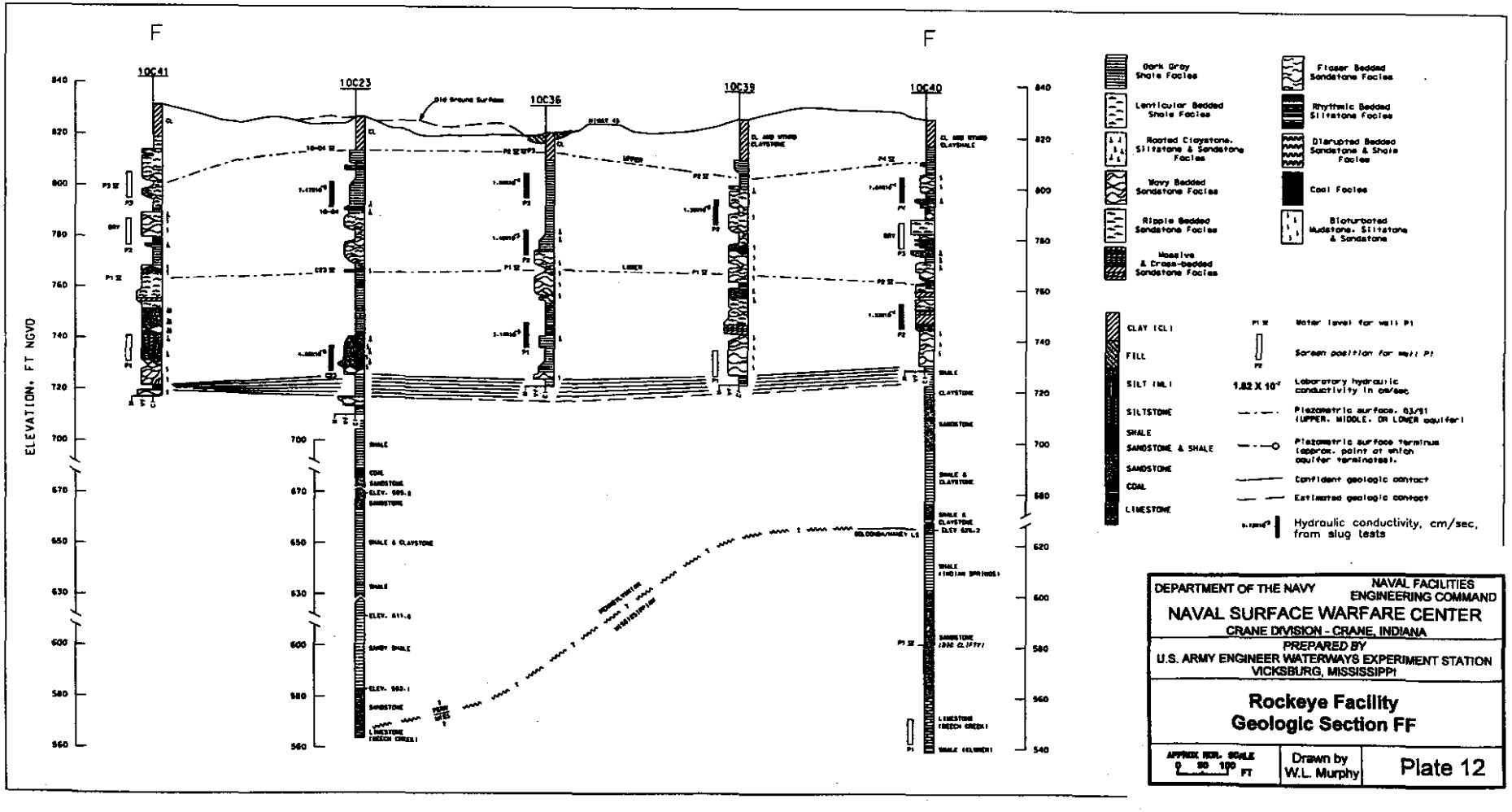
Geologic Section EE

APPROX HOR. SCALE 0 50 100 FT

Drawn by W.L. Murphy

Plate 11



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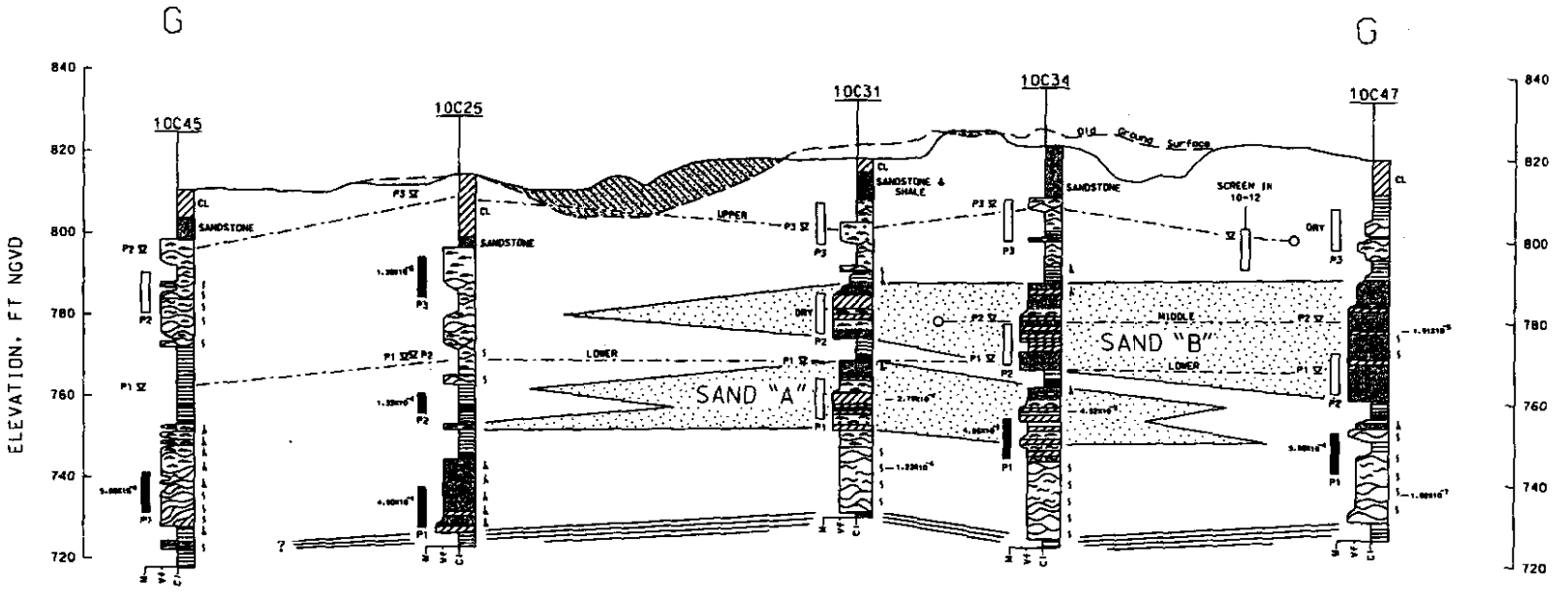
APPROX. HOR. SCALE 0 50 100 FT	Drawn by W.L. Murphy	Plate 12



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CLAY (CL)

FILL

SILT (ML)

SILTSTONE

SHALE

SANDSTONE & SHALE

SANDSTONE

COAL

LIMESTONE

P1 ▽ — Water level for well P1

P2 — Screen position for well P1

1.82×10^{-2} — Laboratory hydraulic conductivity in cm/sec

Piezometric surface, 03/91 (UPPER, MIDDLE, OR LOWER aquifer)

Piezometric surface terminus (approx. point at which aquifer terminates).

Confident geologic contact

Estimated geologic contact

Hydraulic conductivity, cm/sec, from slug tests

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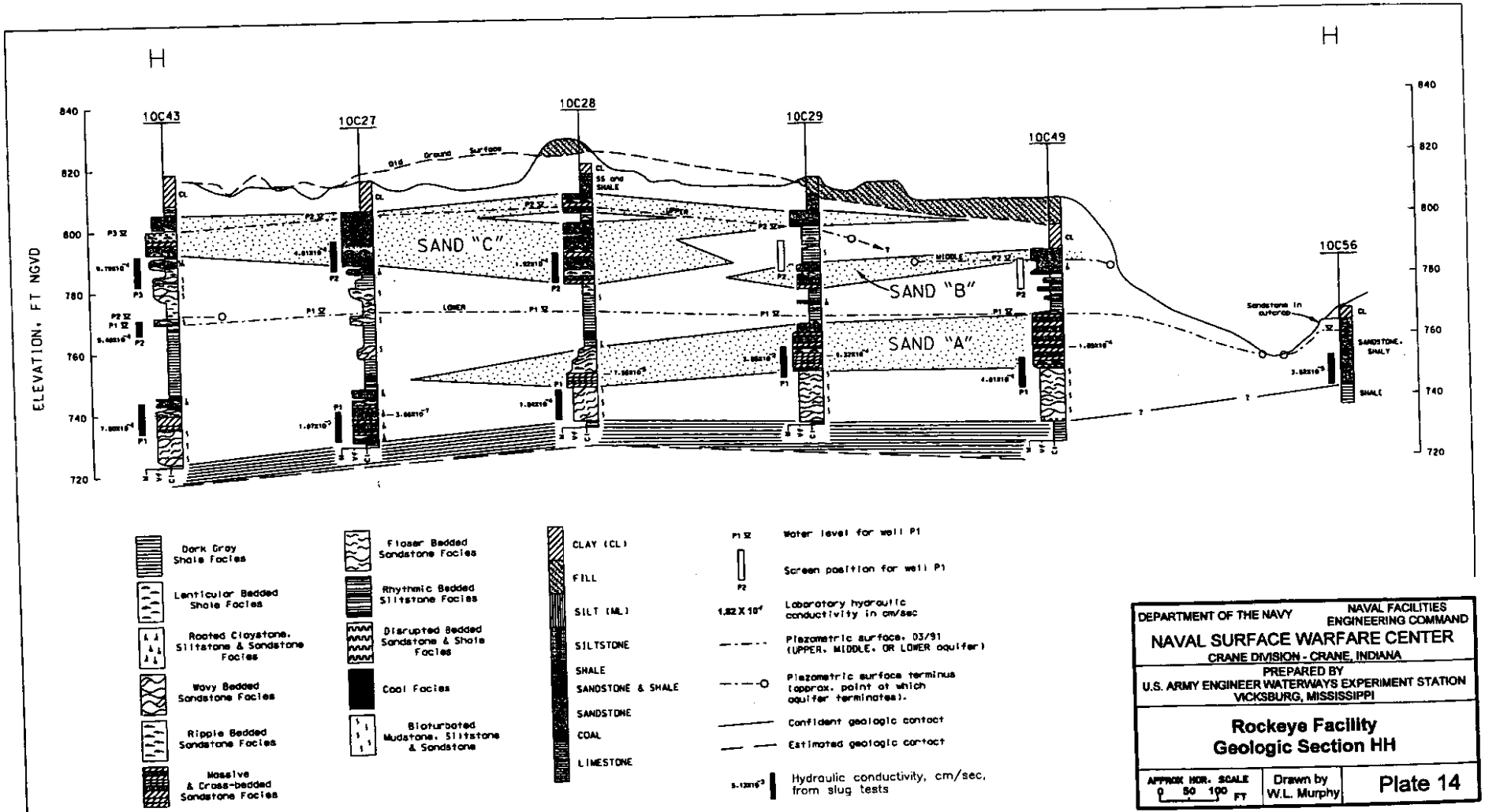
APPROX HOR. SCALE 0 50 100 FT

Drawn by W.L. Murphy

Plate 13



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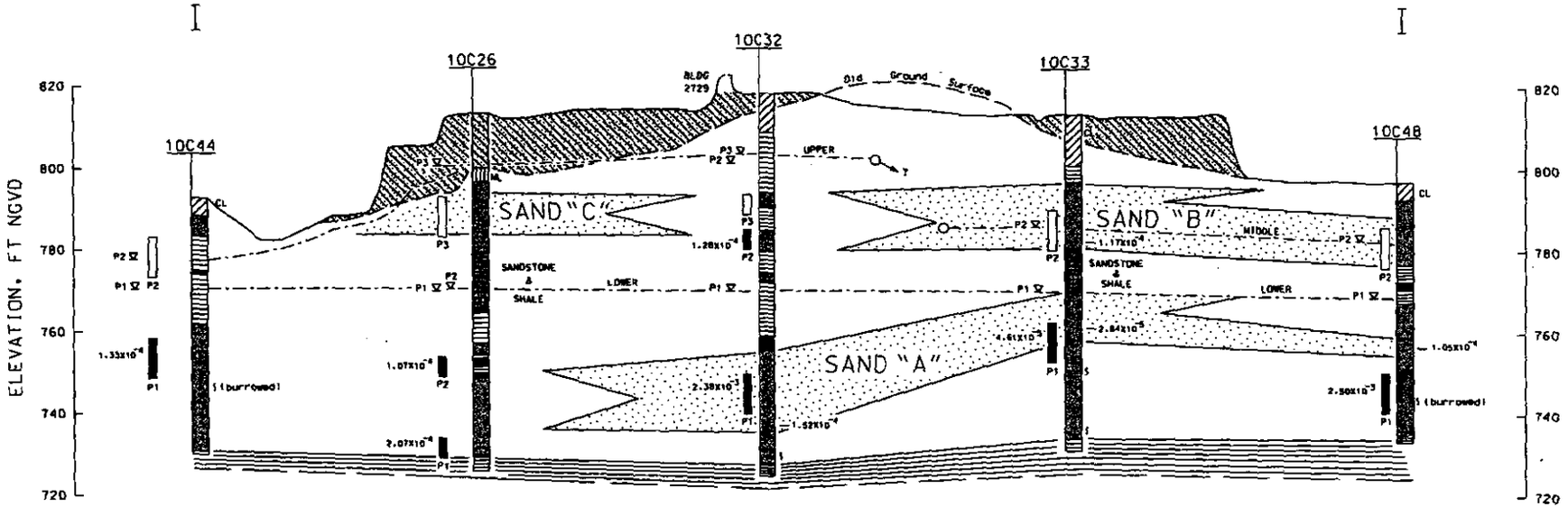
Geologic Section HH

APPROX HOR. SCALE 0 50 100 FT

Drawn by W.L. Murphy

Plate 14



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SANDSTONE & SHALE

SANDSTONE

COAL

LIMESTONE

P1 ▽ Water level for well P1

P2 Screen position for well P1

1.82 X 10^-7 Laboratory hydraulic conductivity in cm/sec

Piezometric surface, 03/91 (UPPER, MIDDLE, OR LOWER aquifer)

Piezometric surface terminus (approx. point at which aquifer terminates).

Confident geologic contact

Estimated geologic contact

5.13X10^-3 Hydraulic conductivity, cm/sec, from slug tests

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Geologic Section II

APPROX HOR. SCALE 0 50 100 FT

Drawn by W.L. Murphy

Plate 15

REPORT DOCUMENTATION PAGE

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6. AUTHOR(S)
William L. Murphy, Roy Wade, Mark Barnhill

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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Indiana Geological Survey
Bloomington, Indiana 29411-0068

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13. ABSTRACT *(Maximum 200 words)*

This report documents the Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI), Phase III Release Characterization for Groundwater, Solid Waste Management Unit (SWMU) 10/15 Rockeye Facility, at the Naval Surface Warfare Center Crane (NSWCC). The investigation was conducted in the period July 1988 to September 1993. The purpose of the RFI 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 Rockeye Facility.

The NSWCC provides material, 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. The Rockeye Facility occupies approximately 40 acres atop a ridge in the northeastern portion of the NSWCC. Past operations have discharged explosives-contaminated wastes to the ground surface and into drainageways flowing away from the facility.

Monitoring of the groundwater for chemical constituents at Rockeye began in November 1981 with the installation of monitoring wells. Twenty-four wells installed between 1981 and 1983 for a confirmation study, and an additional

(Continued)

14. SUBJECT TERMS

Explosives contamination	Groundwater monitoring
Geology in Indiana	Heavy metals
Groundwater	Military contaminants
Groundwater contamination	Naval Surface Warfare Center

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13. (Concluded).

eighty-three wells were installed beginning in 1988. Several aquifers were monitored in the Rockeye study area. The Beech Creek limestone and other Mississippian aquifers were monitored by five wells. Other wells screened strata of Pennsylvania age underlying the Rockeye Facility. Groundwater flow in the lower Pennsylvanian aquifer is radially away from a groundwater high in the southeast corner of the facility. The middle and upper aquifers merge in the northern half of the facility with flow primarily to the northeast. Surface flow away from the operations area is to the northeast and southeast.

Operations at Rockeye have contaminated the shallow aquifer beneath the facility and the surface drainageway to the northeast. Contaminants were primarily RDX, HMX, and TNT. Detected levels of explosives in the groundwater were below 1.0 mg/l. Metals were present in the groundwater but, with the possible exception of barium, are interpreted to be natural constituents of the rock. The concentrations of some metals were exacerbated by unusually low pH produced in the Pennsylvanian depositional environment. Some metals were detected at levels above the maximum contaminant limit for drinking water. Potential receptors of groundwater originating at the Rockeye Facility include Sulphur, Turkey, and First Creeks, as well as Lake Greenwood, which is fed by First Creek. Aquifers exposed in the valley of Sulphur Creek are potential receptors of contaminants. No explosives were detected beyond wells located about 3,500 ft downslope of the facility to the northeast.