SITEWIDE GROUNDWATER

INVESTIGATION

FINAL REPORT

FOR

PLUM BROOK ORDNANCE WORKS

PLUM BROOK STATION/NASA

SANDUSKY, OHIO

Prepared for:

U.S. Army Corps of Engineers

Nashville District/Huntington District

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EXECUTIVE SUMMARY

The former Plum Brook Ordnance Works (PBOW), an approximately 9,000 acre site located in Sandusky, Ohio, was used as an explosives manufacturing facility during World War II. The site is now owned by the National Aeronautics and Space Administration (NASA) and is operated as the NASA Lewis Research Center, Plum Brook Station (PBS). Under provisions of the Department of Defense (DoD) Defense Environmental Restoration Program - Formerly Used Defense Sites, the U.S. Army Corps of Engineers (USACE), Nashville District (CEORN) conducted a Sitewide Groundwater Investigation of the overburden and bedrock hydrostratigraphic units at the former PBOW.

The objectives of the Sitewide Groundwater Investigation were to evaluate groundwater occurrence and flow conditions in the overburden and bedrock aquifers; to assess the groundwater quality in the overburden aquifer at the former Red Water Ponds and TNT manufacturing areas with respect to the primary chemicals of concern from the former manufacturing operations - nitroaromatics and metals; to investigate on a sitewide basis the baseline groundwater quality of the bedrock aquifer; and to evaluate whether additional investigation of the groundwater in either or both aquifers is warranted.

Groundwater Flow

Groundwater at the site occurs in two hydrostratigraphic units: the unconsolidated overburden materials and the consolidated bedrock. The overburden is composed of glacial outwash materials, and varies in thickness from a few feet to over 40 feet. The bedrock consist of both limestone and shale.

Contouring of water level measurements made in the site wells indicates that, generally, groundwater flow in both hydrostratigraphic units is to the north, eventually toward Lake Erie, as would be expected for this site. On the western side of the site, the groundwater contours for the overburden indicate that flow is to the northwest. In the bedrock, contours indicate that flow in the western portion of the site is to the

northeast, from the area of TNT Area C and the West Area Red Water Ponds toward the Pentolite Road Red Water Ponds and the Reactor Area.

In the overburden it is likely that the vertical component of groundwater flow is much more significant than the horizontal flow characterized by the contours. Because of the shallow bedrock and the thin veneer of overlying glacial materials, the dominant direction of groundwater flow in the overburden over most of the site is probably not horizontal but is vertically downward from the overburden into the bedrock. This flow pattern, if accurate, would facilitate migration of contaminants from the overburden soils and groundwater into the bedrock aquifer.

The presence of groundwater in the overburden hydrostratigraphic unit at the site is apparently very seasonal. During the early winter when groundwater samples were collected for this investigation, several of the overburden monitoring wells were dry. However, in the early spring after abundant winter precipitation, groundwater was present in all of the previously dry wells.

Groundwater Quality

The results of the groundwater quality investigation indicate that significant levels of explosives residues are present in the groundwater in the overburden aquifer in the immediate vicinity of both former Red Water Ponds areas. With increasing distance from the ponds, even in the downgradient direction of horizontal flow, levels of explosives residues decrease in the overburden aquifer.

At the Pentolite Road Red Water Ponds, significant levels of explosives residues were detected in three overburden wells located within or adjacent to the perimeter of the former ponds. The most elevated concentrations were detected for 1,3,5-trinitrobenzene (TNB), 1,3-dinitrobenzene (DNB), and 2,4-dinitrotoluene (DNT).

Explosives residues were not detected in overburden well IT-MW5 which is located a short distance downgradient of the ponds. Thus, the chemical data for this investigation supports the conclusion of the groundwater flow investigation with

regard to the predominance of vertical flow in the overburden hydrostratigraphic unit. Even after 50 years, nitroaromatics at concentrations comparable to those present in the wells within the ponds have not migrated horizontally the short distance to well IT-MW5.

At the West Area Red Water Ponds, explosives residues were also detected in two of the overburden wells but at concentrations considerably lower than were detected in the overburden wells installed within the pond perimeter at the Pentolite Road Red Water Ponds. However, the concentrations of explosives residues detected in a sample of reddish-tinted groundwater from a test pit excavated on the north bank of the west pond were significantly higher than concentrations detected at the Pentolite Road Red Water Ponds. Again, the presence of red water and high explosives residues concentrations in the immediate vicinity of the pond supports the conclusion of the groundwater flow assessment that the dominant direction of groundwater flow in the overburden is apparently vertically downward.

Low levels of explosives residues were detected in one of the five overburden wells in TNT Area A and in one of the two overburden wells at TNT Area B. No nitroaromatics were detected in the two overburden wells sampled at TNT Area C.

Nitroaromatics were also detected at low levels in several of the bedrock wells: one well at the Pentolite Road Red Water Ponds, two wells at the West Area Red Water Ponds, one well at TNT Area C, the well installed at the central toluene tanks, and the background well.

Nitrate concentrations were elevated in the three wells in which high concentrations of nitroaromatics were detected at the Pentolite Road Red Water Ponds. Nitrates were also detected at elevated concentrations in both of the overburden wells in which explosives residues were detected at the West Area Red Water Ponds. However, concentrations were not as elevated as those at the Pentolite Road Red Water Ponds.

Several volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs) were detected in the bedrock aquifer, generally hydrocarbons and associated compounds. The highest concentrations were present in the two bedrock wells

installed in the north central portion of the site, well BED-MW16 which is located near the central set of toluene storage tanks, and well BED-MW15 which is downgradient from the Pentolite Road Red Water Ponds and the central toluene storage tanks. Benzene concentrations in seven of the nine bedrock wells equaled or exceeded the regulatory action level.

Eleven metals were detected in the groundwater samples: antimony, arsenic, beryllium, cadmium, chromium, copper, lead, manganese, nickel, thallium, and zinc.

The highest metals concentrations were reported at the Pentolite Road Red Water Ponds in the same three overburden wells that had the highest nitroaromatics concentrations. The metals detected at excessively high concentrations in these wells were copper, manganese, and nickel. These same three metals were also detected at high concentrations in the overburden wells that contained explosives residues at the West Area Red Water Ponds.

Zinc was detected in samples collected throughout the site. Most of the other seven metals, antimony, arsenic, beryllium, cadmium, chromium, lead, and thallium, were detected in a few limited areas. They were frequently detected only in the unfiltered samples indicating that the reported concentrations may be related to particulate matter in the samples.

Groundwater at the site is not used for potable water. However, for evaluation purposes, metals concentrations were compared to the applicable regulatory action levels. Copper, manganese, nickel, and thallium were detected in one or more wells at concentrations exceeding their respective regulatory action levels.

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LIST OF ACRONYMS

AL	Action Level
ASI	Analytical Services, Inc.
ATV	All terrain vehicle
BDL	below detection limit
BTEX	benzene, ethylbenzene, toluene, xylenes
CEORN	U.S. Army Corps of Engineers, Nashville District
COD	chemical oxygen demand
CRREL	Cold Regions Research and Engineering Laboratories
DNB	dinitrobenzene
DNT	dinitrotoluene
DoD	Department of Defense
EPA	U.S. Environmental Protection Agency
gpm	gallons per minute
HMX	cyclotetramethylene tetranitramine
ID	inside diameter
IT	IT Corporation
MCL	Maximum Contaminant Level
MDL	method detection limit
mg/Kg	milligrams per kilogram
mg/L	milligrams per liter
MRD	Missouri River Division
msl	mean sea level
NASA	National Aeronautics and Space Administration
NB	nitrobenzene
NPDES	National Pollutant Discharge Elimination System
NT	nitrotoluene

OD	outside diameter
OEPA	Ohio Environmental Protection Agency
ORD	Ohio River Division
PBOW	Plum Brook Ordnance Works
PBRF	Plum Brook Reactor Facility
PBS	Plum Brook Station
ppb	parts per billion
PPE	personal protective equipment
ppm	parts per million
PQL	practical quantitation limit
PVC	Polyvinyl Chloride
QC	Quality Control
RDX	cyclotrimethylene trinitramine
SAIC	Science Applications International Corporation
SCS	Soil Conservation Service
SMCL	Secondary Maximum Contaminant Level
SVOC	semivolatile organic compound
TNB	trinitrobenzene
TNT	trinitrotoluene
*u*g/L	micrograms per liter
*u*mhos/cm	microhoms per centimeter
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
V-J	Victory Over Japan
VOC	volatile organic compound

1.0 INTRODUCTION

The former Plum Brook Ordnance Works (PBOW), an approximately 9,000 acre site located in Sandusky, Ohio, was used as an explosives manufacturing facility during World War II. The site is now owned by the National Aeronautics and Space Administration (NASA) and is operated as the NASA Lewis Research Center, Plum Brook Station (PBS). The site location is illustrated on Figure 1-1. Under provisions of the Department of Defense (DoD) Defense Environmental Restoration Program - Formerly Used Defense Sites, the U.S. Army Corps of Engineers (USACE), Nashville District (CEORN) conducted a Sitewide Groundwater Investigation at the former PBOW.

1.1 SITE BACKGROUND

1.1.1 Site Location

The PBS is a 6,453.5-acre research facility located in Erie County, Ohio 4.7 miles south of Sandusky and 59 miles west of Cleveland. Although primarily in Perkins (T6N, R23W) and Oxford (T5N, R23W) Townships, the eastern edge of PBS extends into Huron and Milan Townships. The site is bounded on the north by Bogart Road, on the south by Mason Road, on the east by U.S. Highway 250, and on the west by County Road 43. State Route 4 is also located to the west. The PBS is served internally by a 62.5-mile paved road system and a currently unused 15.7-mile rail system.

The geographic coordinates for the extreme boundaries of PBS are:

Northern Boundary Latitude: 41° 23′ 39"
Southern Boundary Latitude: 41° 20′ 04"
Eastern Boundary Longitude: 82° 38′ 39"
Western Boundary Longitude: 82° 43′ 12"

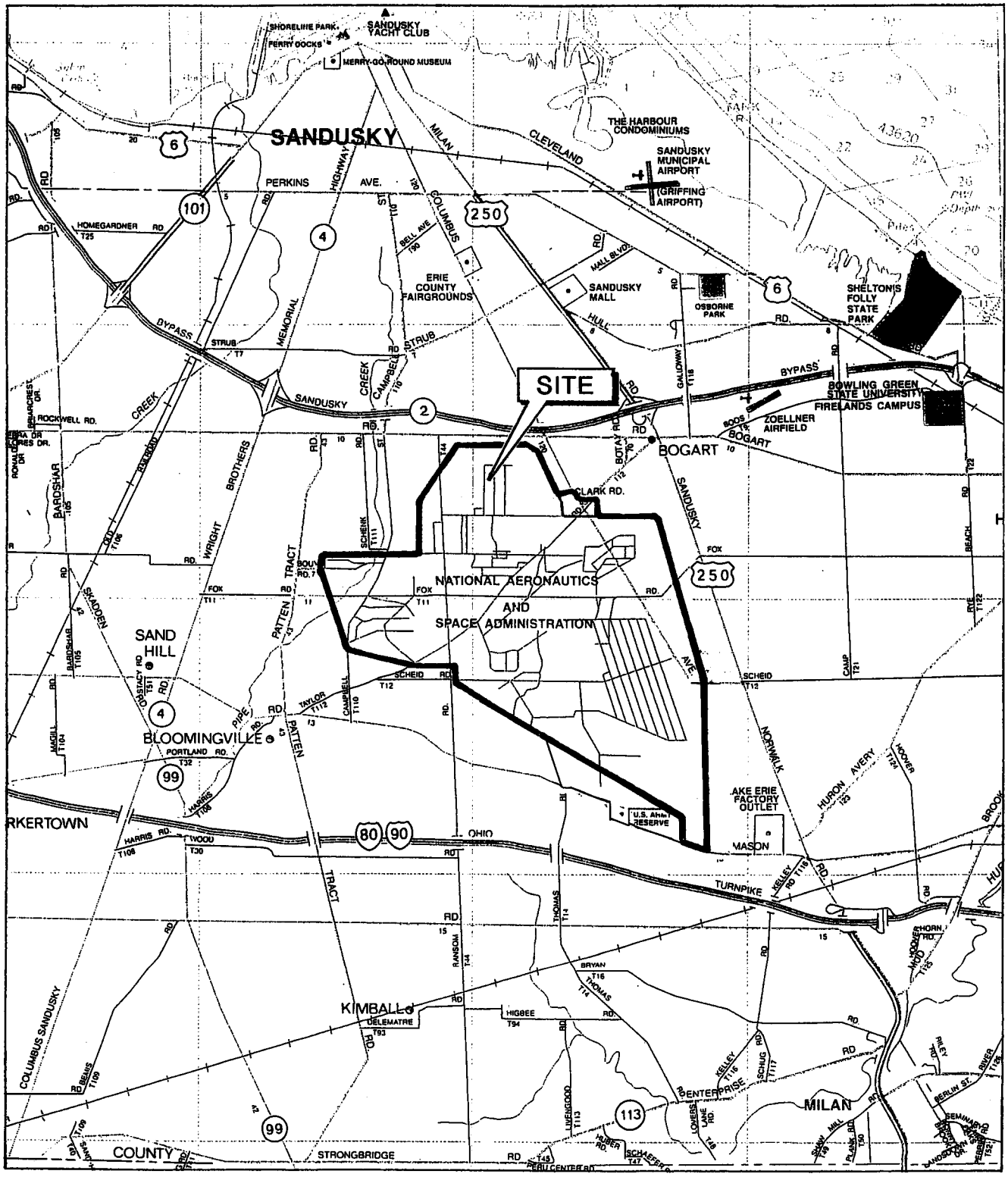

Figure 1-1

SITE LOCATION MAP

Plum Brook Ordnance Works
Sandusky, Ohio

DAMES & MOORE

1.1.2 Site History

The original PBOW site consisted of 9,071.06 acres of primarily agricultural land which were acquired by DoD for construction of an explosives manufacturing plant. From 1941 to 1945, the Trojan Powder Company manufactured trinitrotoluene (TNT), dinitrotoluene (DNT), and pentolite at the PBOW. Production of explosives ceased 2 weeks after Victory Over Japan (V-J) Day. During the 4-year operating period, over one billion pounds of explosives were manufactured.

After manufacturing activities ceased in 1945, the U.S. Army conducted decontamination and decommissioning of many of the structures used to manufacture ordnance. Decontamination of TNT, acid, and pentolite manufacturing lines was performed until the end of 1945. Typical decontamination procedures consisted of moving all structures, equipment, and manufacturing debris to a burning ground, where everything was burned. In their 1994 Site Inspection Report, MK Ferguson estimated that 65 percent of the decontamination of the PBOW was completed by the end of 1945 (MK Ferguson, 1994).

The magazine area of the PBOW was renamed the Plum Brook Depot and was used for ammunition storage. Otherwise, virtually the entire site was mothballed from 1946 to 1954 when the Plum Brook Reactor Facility (PBRF) was constructed on a 500 acre parcel in the northern part of the site. NASA acquired the entire site on March 15, 1963. Many of the remaining original structures from the PBOW were removed by NASA soon after it acquired the property.

NASA uses the site to conduct space research as a satellite operation of the NASA Lewis Research Center in Cleveland, Ohio. Throughout the 1960's and early 1970's a variety of test and research facilities were constructed and operated. NASA also operated the PBRF from 1963 to 1973. In 1974, PBS was placed in standby condition.

On April 18, 1978, NASA declared 2,152.15 acres of land excess. Of this excess, 46.023 acres were conveyed to the Perkins Board of Education on June 2, 1978. This area is used as a bus transportation center. The General Services Administration

retained the remaining acreage and currently has a use agreement with the Ohio National Guard for 604 acres of the land. In 1988, PBS began to emerge from standby status and started utilizing several of the research and test facilities again.

There are approximately 106 permanent structures and 99 munitions bunkers at the site, including a variety of structures that were a part of the original PBOW. Utilities are provided from off site, while sanitary waste discharge is processed on site. Ohio Edison Company provides the electrical power and the City of Sandusky provides the potable water supply. A PBS-owned water intake at Lake Erie supplies water for cooling, testing, and fire protection. PBS has five sanitary waste treatment systems, three of which are currently operating. The largest is a 110,000 gallon per day, high rate, trickling-filter, secondary treatment plant located on Taylor Road.

1.1.3 Environmental Investigation History

Hazardous waste disposal practices during the period of explosives manufacturing and DoD site control are unknown. Explosives manufacturing and/or handling at the site resulted in the operation of holding ponds ("red water ponds") for process waste water. Typical red water contains residues of the explosives manufacturing process and is acidic in nature. Out-of-specification explosives may have been burned or discarded on the site. Possible effects of these materials on soil, groundwater, and surface water at the site are unknown. Some of the remaining original structures (e.g., the power plants) and site features (e.g., the red water ponds) have not been remediated (USACE, 1994).

A number of environmental investigations have been conducted at the PBOW. In 1989, IT Corporation (IT) performed a limited investigation of areas of potential concern to the DoD. The field investigation activities included: collection of soil, surface water, sediment, and groundwater samples for geotechnical or chemical analysis and performance of one hydraulic conductivity test. MK Ferguson performed a preliminary sitewide environmental investigation for NASA in 1993 (report date 1994). Additional investigations have been performed by NASA (e.g., investigation

of underground storage tanks) and other interested parties (the U.S Army Reserve conducted a limited investigation of the West Area Red Water Ponds).

Three additional environmental investigations have been performed at the PBS. Science Applications International Corporation (SAIC) completed a Preliminary Assessment of the PBS in 1991. Also in 1991, Ebasco Environmental performed an assessment of underground storage tanks. H^{+}GCL characterized the Snake Road Burn Ground and the adjacent burn grounds used by NASA (referred to as "Disposal Area Three") in 1992.

1.2 PROJECT OBJECTIVES

Previous investigations at the PBS have included minimal assessment of the groundwater quality in the overburden aquifer. None of the investigations addressed groundwater quality in the bedrock aquifer. However, based on the limited investigations that have been performed, groundwater contamination of the overburden aquifer by nitroaromatics (explosives residues) is expected in the red water ponds areas and may be present in the overburden aquifer in other parts of the site (e.g., the former TNT manufacturing areas) and/or in the bedrock aquifer.

Nitroaromatics could be present in the site soils and groundwater as a direct results of manufacturing and disposal activities that occurred while the plant was in operation. Explosives residues in the soil could have migrated into the underlying groundwater. Possible human exposure to contamination could result through inhalation, ingestion, or absorption of contaminated groundwater. Disposal of contaminated waste water in artificially created surface water bodies during operation of the PBOW could have resulted in contamination of groundwater in the vicinity of those surface water bodies.

The objectives of the Sitewide Groundwater Investigation were to evaluate groundwater occurrence and flow conditions in the overburden and bedrock aquifers; to assess the groundwater quality in the overburden aquifer at the former Red Water Ponds and TNT manufacturing areas with respect to the primary chemicals of concern from the former manufacturing operations - nitroaromatics and metals; to investigation

on a sitewide basis the baseline groundwater quality of the bedrock aquifer; and to evaluate whether additional investigation of the groundwater in either or both aquifers is warranted.

1.3 SCOPE OF WORK

The Sitewide Groundwater Investigation was performed as part of the Statement of Work for Delivery Order 0020 of Dames & Moore's Indefinite Delivery Order Contract DACA62-92-D-0015 with CEORN. This Statement of Work also included a Site Investigation of the TNT areas (reported separately) and a Focused Remedial Investigation of the Red Water Ponds areas (reported separately). The field work for all three investigations was performed concurrently. The primary tasks to be performed for the Sitewide Groundwater Investigation included:

- Performance of a fracture trace analysis of aerial photographs of the site to identify optimal locations for installation of groundwater monitoring wells in the bedrock;
- Installation of shallow groundwater monitoring wells completed in the unconsolidated overburden materials;
- Installation of deep groundwater monitoring wells completed in the consolidated bedrock;
- Assessment of the groundwater flow regime in both the overburden and bedrock hydrostratigraphic units based on water level measurement made in the newly installed wells and well installed during previous investigations;
- Collection of groundwater samples from the newly installed wells and from selected wells installed during previous investigations for laboratory analysis and evaluation of groundwater quality, including baseline groundwater quality in the bedrock aquifer; and
- Preparation of the Sitewide Groundwater Investigation Report presenting the results of the investigation.

The original Statement of Work included in Delivery Order 0020 was modified by mutual agreement between Dames & Moore and CEORN at meetings conducted at the PBS on August 29 to 31, 1994 and on September 19 through 22, 1994. The

modifications, generally changes in the sampling locations based on review of historical documents and access limitations identified when sample locations were staked in the field, were incorporated into the Final Sampling and Analysis Plan (Dames & Moore, 1994).

Additional modifications were made during the course of the field investigation. The modification that related to the Sitewide Groundwater Investigation included:

- Deletion of the overburden groundwater monitoring well at TNT Area B due to the shallow depth to bedrock;
- Relocation of the bedrock groundwater monitoring well planned for TNT Area B to the West Area Red Water Ponds along the northern property boundary downgradient from the West Area Red Water Ponds;
- Relocation of one of the overburden wells within the Pentolite Road Red Water Ponds based on conditions observed during the field work;
- Addition of analysis of nitrates for all groundwater samples;
- Deletion of laboratory analysis for three dry overburden wells, one at the West Area Red Water Ponds and two at TNT Area C;
- Addition of analysis of a groundwater sample from one overburden well at the West Area Red Water Ponds that had been installed as part of a previous investigation;
- Addition of analysis of one water sample collected from a pit excavated on the north side of the west pond for explosives residues; and
- Addition of Diesel Range Hydrocarbons analysis of an oily substance present in the bedrock monitoring well installed near the toluene tanks in the central portion of the site to try to identify the substance.

All modifications to the field investigation were approved by representatives of CEORN during the course of the field work.

1.4 REPORT ORGANIZATION

The Sitewide Groundwater Investigation Report is organized in seven sections preceded by an Executive Summary.

This section, Section 1.0, presents the project background, the Sitewide Groundwater Investigation objectives, the Scope of Work, and the report organization.

Section 2.0 describes the PBOW environmental setting.

Section 3.0 provides a general history and descriptions of the red water ponds areas and the TNT manufacturing areas.

Section 4.0 outlines the investigation methods and activities.

Section 5.0 describes the groundwater flow conditions at the site.

Section 6.0 discusses the groundwater quality assessment.

Section 7.0 provides conclusions.

References are provided after Section 7.0. The tables and figures are included in the text after the page on which they are first mentioned.

Nine appendices are included in this report.

Appendix A includes a copy of the NASA Drilling and Excavation Permit.

Appendix B provides the Boring Logs for the overburden and bedrock groundwater monitoring wells.

Appendix C contains the Monitoring Well Construction Diagrams.

Appendix D provides the sieve analysis results.

Appendix E contains the well development documentation.

Appendix F includes the well survey documentation.

Appendix G provides the Groundwater Sampling Records.

Appendix H provides Dames & Moore's Data Quality Assessment of the analytical laboratory data.

Appendix I provides the laboratory reports.

Appendix J includes the fracture trace analysis.

2.0 ENVIRONMENTAL SETTING

This section describes the environmental setting at PBS.

2.1 PHYSIOGRAPHY AND TOPOGRAPHY

The PBS is located within the Eastern Lake section of the Central Lowland Province near the southwestern shore of Lake Erie (U.S. Department of Agriculture, Soil Conservation Service [SCS], 1971). The region is characterized by lake plains, outwash plains, and till plains with occasional small hills produced during the retreat of the Wisconsin ice sheet. Approximately two-thirds of Erie County was once covered by a glacial lake that produced features such as beach ridges and wave-cut cliffs.

The area was originally a flat lake bottom resulting from glacial melt waters. Across PBS, the topography is relatively flat with a gentle NNE slope towards Lake Erie. Elevations at the site range from 675 feet above mean sea level (msl) at the southwest edge of the site to 625 feet msl in the northern portion of the property at Bogart Road (U.S. Geological Survey [USGS] Topographic Quadrangles Sandusky and Kimball, Ohio; 1969). The land surface has an average slope of less than 1 percent with steeper areas having approximately 2 percent slope.

2.2 LAND USE

Prior to acquisition of the site for construction of the PBOW, the area was largely agricultural. During construction of the PBOW, most of the forested areas were cleared. Today, second generation forests have returned to large portions of the site that are not used by NASA. Other undeveloped areas of the site are maintained in open fields. The surrounding area is mostly agricultural and residential.

2.3 CLIMATE

The climate for the Sandusky area is continental, but strongly influenced by Lake Erie. Predominately westerly winds parallel the shoreline of Lake Erie. In a 1956 study by the National Advisory Committee for Aeronautics, the wind direction at PBS was from the southwest approximately 55 percent of the time throughout the year (SAIC, 1991). The frequency of northerly and northeasterly winds increases during the spring and summer.

The average annual precipitation for the city of Sandusky from 1961 to 1990 is 34.05 inches (Midwestern Climate Center, 1997). The mean monthly precipitation at the U.S. Weather Bureau Station for Sandusky for that 30 year period ranged from a low of 1.65 inches for February to a high of 3.70 inches for July. The monthly average precipitation for all months for the period 1961 to 1990 is provided on Table 2-1. This table also lists the extreme total high and low monthly precipitation for the period 1936 to 1996 and the year the extreme occurred. Finally, Table 2-1 lists the mean snowfall for the period 1961 to 1990.

Average annual temperatures for Sandusky for the 30 year period 1961 to 1990 ranged from 32.2° F in January to 82.3° F in August. The average this period was 32.2° F. Summers are moderately warm and humid, with temperatures occasionally exceeding 90° F. The monthly average maximum, minimum, and mean temperatures for all months for the period 1961 to 1990 are provided on Table 2-2. This table also lists the extreme mean high and low monthly temperatures for the period 1936 to 1996 and the year the extreme occurred. Winters are cold and cloudy, with sub-zero temperatures an average of 5 days per winter. The temperature usually first falls to freezing in October and the last freezing temperature normally occurs in April. Weather changes often occur every few days as fronts pass through the region.

TABLE 2-1

PRECIPITATION DATA FOR SANDUSKY, OHIO

Month	Mean (inches)	Extreme High (inches)	Year of Extreme High	Extreme Low (inches)	Year of Extreme Low	Mean Snowfall (inches)
January	1.73	6.58	1937	0.19	1961	8.0
February	1.65	4.53	1950	0.02	1987	7.0
March	2.60	5.44	1985	0.74	1958	3.6
April	2.95	7.19	1961	0.75	1946	0.6
May	3.44	9.04	1943	0.70	1988	0.0
June	3.85	12.51	1937	0.68	1988	0.0
July	3.70	12.60	1966	0.80	1944	0.0
August	3.41	9.93	1975	0.40	1996	0.0
September	3.12	7.72	1950	0.91	1963	0.0
October	2.18	4.91	1954	0.03	1963	0.0
November	2.80	6.53	1982	0.23	1976	0.3
December	2.62	6.44	1990	0.65	1943	6.1
Annual	34.05	50.50	1950	18.29	1963	24.8

Source: Midwestern Climate Service, 1997

TABLE 2-2

TEMPERATURE DATA FOR SANDUSKY, OHIO

Month	Average Monthly Temperature			Mean Extreme High Temperature (°F)	Year of Extreme High	Mean Extreme Low Temperature (°F)	Year of Extreme Low
	Maximum (°F)	Minimum (°F)	Mean (°F)				
January	32.2	17.5	24.8	37.2	1950	11.9	1977
February	34.3	19.2	26.7	37.1	1954	14.9	1978
March	44.4	28.8	36.7	49.2	1945	26.7	1960
April	56.6	39.3	48.0	56.5	1955	42.1	1975
May	68.1	50.5	59.3	66.5	1962	53.8	1967
June	78.0	60.1	69.1	74.9	1949	64.1	1972
July	82.4	64.8	73.6	79.1	1949	70.7	1992
August	80.6	62.9	71.7	77.8	1947	67.3	1992
September	74.1	56.1	65.1	70.2	1961	59.9	1975
October	62.2	44.5	53.4	62.0	1947	47.6	1988
November	49.9	35.3	42.6	47.4	1975	34.9	1976
December	37.2	25.7	30.5	39.7	1982	17.2	1989
Annual	58.3	41.9	50.1	54.2	1949	45.6	1982

Source: Midwestern Climate Service, 1997

2.4 SOILS

Most of the soils of Erie County were formed from either glacial till or glacial melt-water deposits. The dominant soil material was deposited by glacial till, outwash, and lacustrine deposits. Glacial till is material laid down directly from glaciers with minimum water action. Typically, it consists of particles of different sizes, and many pebbles in glacial till have sharp corners, indicating that they have not been rounded or worked by water. Outwash materials were deposited by running water from melting glaciers. The size of the particles that make up the outwash material varies according to the speed of the water in which particles were carried. Outwash deposits generally consist of layers of particles of similar size, such as sand and gravel. Lacustrine deposits, material settled from still, ponded glacial melt water, contain only the finer particles such as very fine sand, silt, and clay because the coarser material dropped out as outwash. Other soils formed from more recent deposits of alluvium or the weathering of parent rock (SCS Soil Survey of Erie County, Ohio).

Within the PBS, the soil origins are listed as lacustrine (Erie Planning Commission Report on Land Capability, 1967). The glacial drift is less than 20 feet on average and bedrock is exposed in many places (Ohio Department of Natural Resources, Division of Geological Survey; Drift Thickness of Erie County, Ohio; Open File Map 209).

The General Soil Map of Erie County, Ohio (SCS, 1970) identified four soil associations at the PBS site: Arkport-Galen, Prout, Del Rey-Lenawee, and Lewisburg. The Arkport-Galen and Prout soil associations make up the majority of soils at PBS. The Arkport-Galen soils are present in the western, central, and northern portions of the site. The Prout soils occur in the southeastern portion of PBS. The Del Rey-Lenawee soils are listed for the extreme southeast corner of PBS and Lewisburg soils are listed for the southwestern edge of PBS.

The Arkport-Galen association is characterized by deep, nearly level to moderately sloping, well-drained to moderately-well-drained soils that have a subsoil of loamy fine sand and fine sand. The Arkport soils are gently to moderately sloping, and well drained, formed in fine sand deposited by wind and water at the edge of a glacial lake. The permeability of the Arkport soils is estimated to be approximately 12 inches/hour.

The Galen soils are mostly level and moderately well-drained, formed as small sandy deposits on outwash plains and deltas. Galen soils have a fine sand or sandy loam surface layers, a subsurface of fine sand which is underlain by silt or clay. Runoff is slow, permeability is rapid, and the available moisture capacity is low. The permeability of the Galen soils is estimated to be between 6 and 12 inches/hour. The Arkport-Galen association is made up of about 40 percent Arkport soils, 30 percent Galen soils, and 30 percent minor soils.

Prout soils are moderately-deep to deep, nearly level to gently sloping, somewhat poorly drained soils that have a subsoil of heavy silt loam to silty clay loam. Prout soils are commonly underlain by shale bedrock. They are somewhat poorly drained, with slow runoff and permeability. The permeability of the Prout soils is estimated to be between 0.2 and 0.6 inches/hour. Prout soils commonly occur in uplands such as the sides of stream valleys and shale outcrop ridges.

Del Rey-Lenawee soils generally lie on old lake beds and are deep, nearly level, somewhat poorly-drained to very poorly-drained soils that have a subsoil of silty clay to clay loam. The Lewisburg association are moderately deep to deep, nearly level in depressions, and are narrow strips along natural drainageways. Runoff is slow, and permeability is moderately slow.

The thickness of soils at PBS ranges from approximately 5 feet or less for most of the site to approximately 20 feet for the extreme northern portion of the site (Erie Planning Commission Report on Land Capability, 1967).

2.5 BEDROCK GEOLOGY

The bedrock formations of northwestern Ohio consist of Devonian and Silurian carbonates (limestones and dolomites) and clastics (sandstones and shales). The regional dip is to the southeast, with younger rocks outcropping to the east. The Silurian and Devonian formations unconformably overlie sedimentary sequences of Ordovician and Cambrian Age, which in turn unconformably overlie the Pre-Cambrian crystalline Grenville basement (Ohio Department of Natural Resources, Division of

Geology, Generalized Column of Bedrock Units in Ohio, 1990). A generalized stratigraphic section of the Silurian and Devonian strata which underlie the site was presented by SAIC in their Preliminary Assessment and is reproduced in Figure 2-1 of this report.

At PBS, four Devonian formations crop out beneath the glacial drift cover. From oldest to youngest, these formations are the Delaware Limestone, the Plum Brook Shale, the Prout Limestone, and the Huron Shale. The formations dip to the southeast with a regional dip angle of approximately 35 feet per mile (Campbell, 1955). Structurally, these formations are located on the eastern limb of the Findlay Arch (Campbell, 1955). Figure 2-2 shows the estimated outcrop areas of each of the four formations beneath the PBS site.

The Delaware Limestone conformably overlies the Columbus Limestone, and is approximately 75 feet thick. The contact between the two formations occurs to the northwest of PBS. The Delaware Limestone crops out beneath the extreme northwestern corner of PBS. It is described as a massive to thin-bedded brown to gray fossiliferous limestone and dolomite. According to the PBS Preliminary Assessment (SAIC, 1991), karst topography occurs selectively in some of the Silurian and Devonian carbonates in the northern and western sections of Erie County. Subsequently, cavernous porosity occurs in some areas of the underlying carbonates.

The Plum Brook Shale unconformably overlies the Delaware Limestone and crops out underneath most of the northwest portion of the site. It is approximately 35 feet thick, and is described as a blue, soft, fossiliferous shale containing thin layers of dark, hard, fossiliferous limestone.

The Prout Limestone is a 15 foot thick limestone which conformably overlies the Plum Brook Shale. The Prout Limestone crops out as a thin (1000 to 2000 foot wide) northeast striking band across the middle of PBS. It is described as a dark-gray to bluish-gray to blue, very hard, silicious, fossiliferous limestone or dolomitic mudstone.

The Huron Shale is the lower member of the Ohio Shale and crops out under much of the southern and eastern portions of PBS. It is described as a grayish-black, dense,

Age	Formation/Group	Depth to Top (ft)	Thickness (ft) a	Hydrologic Unit b	Rock Description
DEVONIAN	Ohio Shale	c	300	Zone 3	Shale : *black, thin-bedded with bituminous and carbonaceous material.*
	Prout Limestone/ Plum Brook Shale	Surface	210		Shale : *light grey, calcareous.*
	Delaware Limestone	40	50	Zone 1 and Zone 2	Limestone : *buff, earthy, foss. interbedded with brown crystalline dolomite.*
	Columbus Limestone	90	110		Limestone : *brown to grey, fine crystalline, foss. with tan to buff-grey, partly sandy dolomite at base.*
	Lucas Dolomite	200	70		Dolomite : *brown, crystalline, porous, chert.*
SILURIAN	Amherstburg Dolomite	270	20		Dolomite : *tan to grey, microcrystalline, sl. argillaceous.*
	Bass Island Dolomite	290	30		
	Salina	320	590'		Dolomite : *anhydrite and shale sequence. Interbedded and intercalated. Dolomite is tan to brown and mostly tight. Scattered shale laminae. Few scattered oil stains. Some dolomite is shaly. few massive beds of dolomite and anhydrite.*

a. Depth to formation, formation thickness, and lithology based on deep borehole located at N 288+68, E 155+54.

b. Refer to Figure 5. for areal distribution of Zones 1, 2, and 3.

c. The Ohio shale was not encountered in the deep borehole, it outcrops in the southeasternmost portion of Plum Brook Station.

Figure 2-1

GENERALIZED STRATIGRAPHIC SECTION OF SILURIAN AND DEVONIAN STRATA UNDERLYING PLUM BROOK STATION

Plum Brook Ordnance Works
Sandusky, Ohio

REFERENCE: Reproduced from SAIC Preliminary Assessment, 1991

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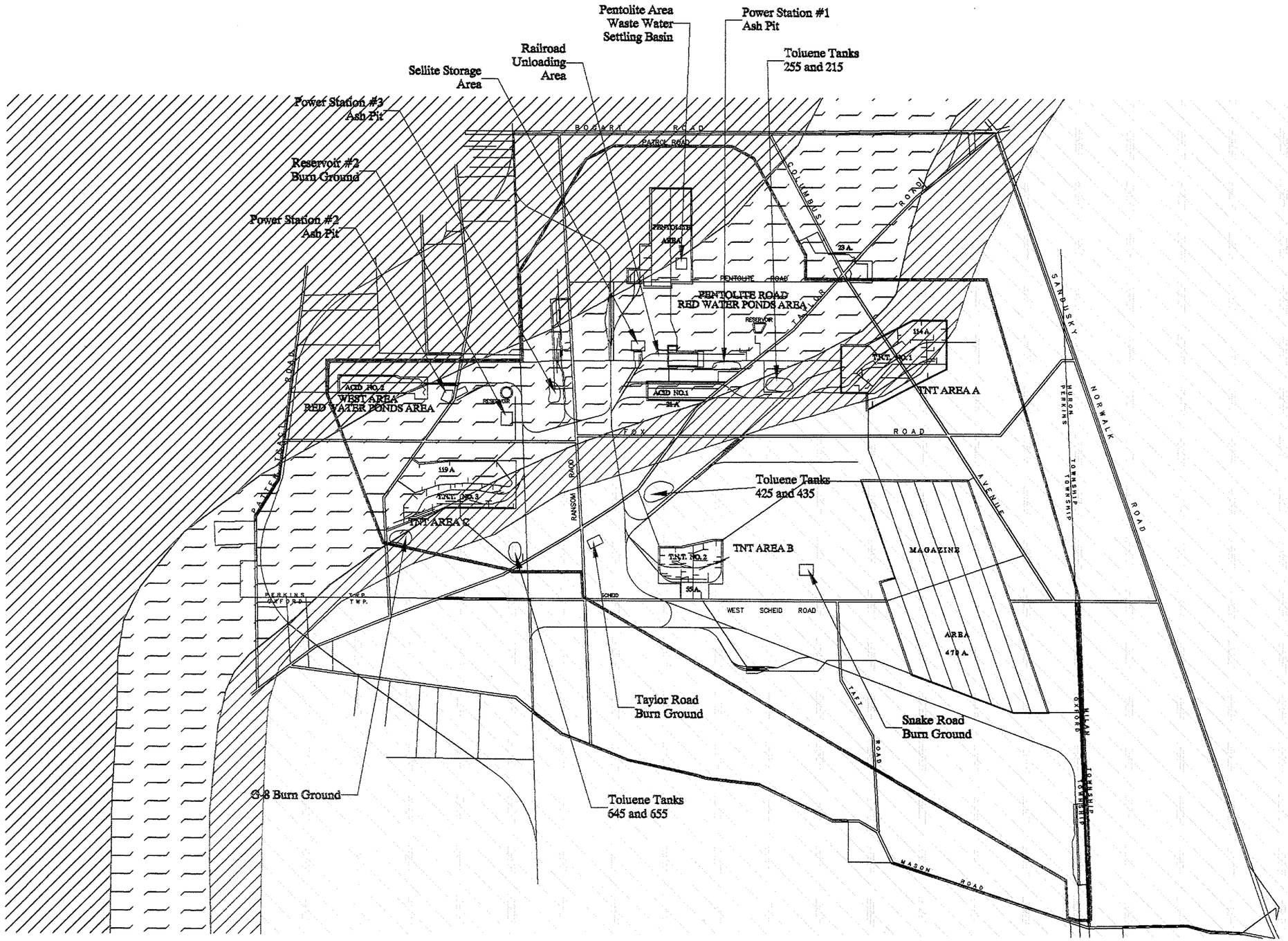

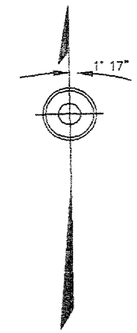

N

Scale: 1" = 2800'

- Ohio (Huron) Shale
- Prout Limestone
- Plum Brook Shale
- Delaware Limestone

Source: Geologic contact and bedrock unit information is from a portion of the "Bedrock Geology" map of the "Comprehensive Planning Study" included in the "Land Capability Report" by the Erie Planning Commission, 1967

Figure 2-2
Bedrock Units at NASA Plum Brook Station
Plum Brook Ordnance Works
Sandusky, Ohio

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A DAMES & MOORE GROUP COMPANY

Government Services Division; Atlanta, Georgia
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platy to fissile shale containing large pyrite/carbonate concretions (1 to 6 feet in diameter). It is up to 300 feet thick. The glacial drift cover over the Huron Shale is generally thinner than over the other formations, in many places the shale is within several feet of the surface.

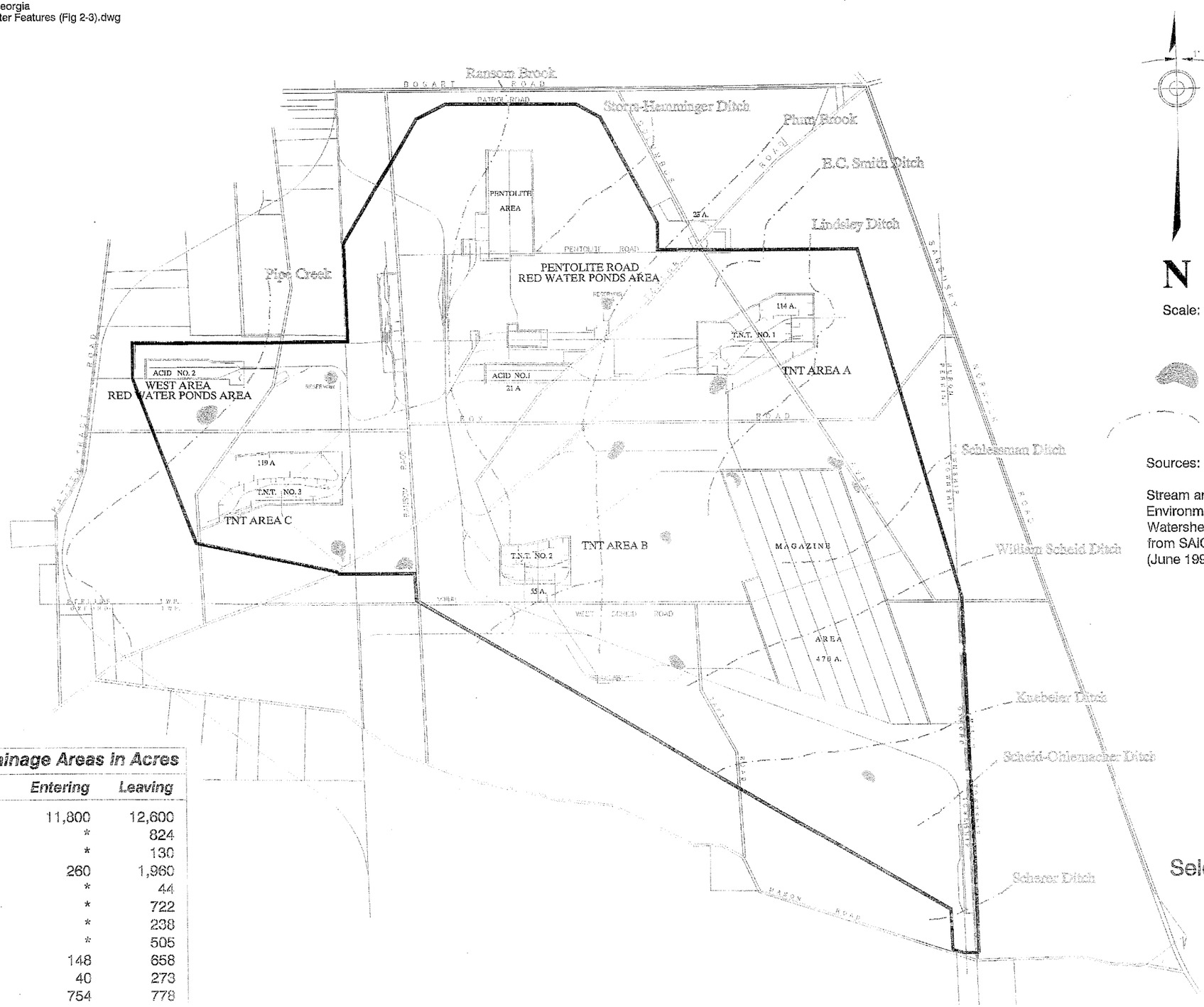
2.6 SURFACE WATER

PBS lies in the eastern region of the Pickeral Creek-Pipe Creek Basin, which, in turn, lies within the St. Lawrence River drainage basin (Ohio Department of Natural Resources Availability of Underground Water, Pickeral Creek -Pipe Creek Area, 1962 and Ground Water Pollution Potential of Erie County, Ohio; 1994). The Huron River Basin lies approximately 3.5 miles east of PBS. Sandusky Bay and Lake Erie are the largest surface water bodies within a 15 mile radius of PBS, approximately 4.5 miles north of the site.

Eleven streams pass through or originate within PBS and are a part of four drainage areas: (1) Sawmill Creek (southern PBS), (2) Plum Brook (central PBS), (3) Pipe Creek (western PBS) and (4) Storrs-Hemminger Ditch (USGS Topographic Quadrangles Sandusky and Kimball, Ohio; 1969 and SAIC, 1991). All streams flow north or northeasterly into Sandusky Bay. The locations of these streams and other selected surface water features are illustrated on Figure 2-3.

Although Sawmill Creek does not pass through PBS itself, several ditches cross the southern portion of PBS, flow easterly and feed into Sawmill Creek. The ditches, listed in order from north to south, are Schlessman Ditch, W. Scheid Ditch, Kuebelar Ditch, Scheid-Olemacher Ditch and Scherer Ditch. Lindsley and E.C. Smith Ditches flow north along the northern portion of PBS into Plum Brook just north of PBS. Ransom Ditch (northern PBS) flows northward into Pipe Creek. Additionally, ditches totalling 380,000 lineal feet are within PBS (SAIC, 1991). Numerous ponds lie within and around PBS. Seventeen isolated ponds and reservoirs and one former red water pond are located on PBS. The ponds are probably fed from shallow groundwater, and the pond water levels remain high even during dry months. (SAIC, 1991)

Government Services Division; Atlanta, Georgia
D:\COE-PLUM\January 1997\Surface Water Features (Fig 2-3).dwg



N

Scale: 1" = 2800'

Pond or Reservoir

Surface Water Drainage Feature

Sources:

Stream and ditch locations and names from NASA Environmental Resources Document (August 1990). Watershed areas and locations of ponds and reservoirs from SAIC Plum Brook Station Preliminary Assessment (June 1991).

Stream	Drainage Areas in Acres	
	Entering	Leaving
Pipe Creek	11,800	12,600
Ransom Brook	*	824
Storrs-Hemminger Ditch	*	130
Plum Brook	260	1,960
E.C. Smith Ditch	*	44
Lindsley Ditch	*	722
Schlessman Ditch	*	238
William Scheid Ditch	*	505
Kuebeler Ditch	148	658
Scheid-Ohlemacher Ditch	40	273
Scherer Ditch	754	778

* Stream originates within station boundaries

Figure 2-3
Selected Surface Water Features at Plum Brook Station

Plum Brook Ordnance Works
Sandusky, Ohio

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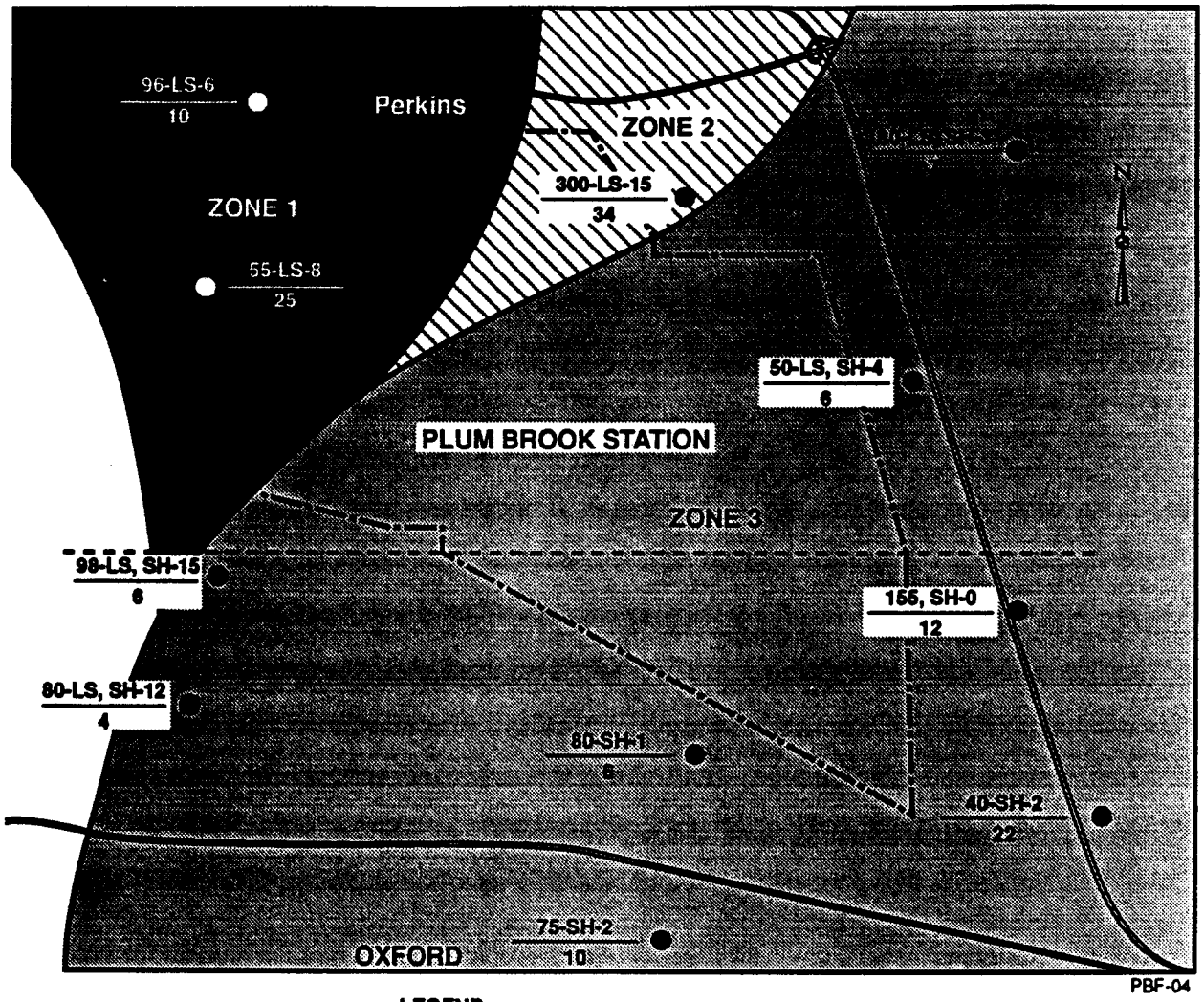
2.7 GROUNDWATER USE

Two aquifer systems are utilized for drinking water in the area surrounding PBS: a carbonate aquifer cropping out in the western portion of Erie County and a shale aquifer cropping out in the eastern portion. PBS covers the transition of the two aquifer systems. Both aquifer systems are overlain by a veneer (generally less than 20 feet) of glacial drift that is considered a poor source of ground water except in areas of sand and gravel lenses (Ground Water Pollution Potential of Erie County, Ohio; 1994).

The carbonate aquifer is subdivided into two zones by the Ohio Department of Natural Resources based on their areas of usage and yields. The shale aquifer and overlying discontinuous sand and gravel deposits are designated as zone three. Figure 2-4. reproduced from SAIC's Preliminary Assessment, illustrates the three zones. Zone one occurs in the north and northwestern portion of PBS and includes wells with yields of 100 to 500 gallons per minute (gpm) developed in cavernous limestone and dolomite, generally obtained from depths of around 100 feet. Zone two occurs in the north portion of PBS and includes wells with yields of 15 gpm or less developed in a deeper carbonate aquifer at an approximate depth of 300 feet. Zone three occurs over all of the eastern and southern portions of PBS and includes wells with yields that seldom exceed 3 gpm.

Yields from zone one are high in the karst terrain of western Erie County. From west to east in zone one yields decrease as evidenced by a well just west of PBS that has a yield of 8 gpm. Additionally, the carbonate aquifer beneath the shale aquifer will yield larger quantities of water than the shale aquifer, but the quality is considered likely to be poor due to high mineral content (Ohio Department of Natural Resources, Availability of Underground Water, Pickeral Creek - Pipe Creek Area, 1962).

According to SAIC (1991), 179 permitted private drinking water wells, listed at the Erie County Health Department, were within a 4-mile radius of PBS. Permits are not required for agricultural use.



LEGEND

ZONE 1

AREAS IN WHICH YIELDS OF 100 TO 500 GALLONS PER MINUTE MAY BE DEVELOPED.

Yields of more than 500 gallons per minute have been developed at depths of less than 200 feet in cavernous limestone and dolomite. Domestic supplies are generally obtained at depths of around 100 feet.

Hydrogen sulfide, in varying amounts, may be encountered in the bedrock.

ZONE 2

AREAS IN WHICH YIELDS OF 5 TO 25 GALLONS PER MINUTE MAY BE DEVELOPED.

Yields of 15, or less, gallons per minute are developed from wells drilled into the limestone. Hydrogen sulfide may be present in varying amounts.

ZONE 3

AREAS IN WHICH YIELDS SELDOM EXCEED 3 GALLONS PER MINUTE

Limited quantities of ground water are obtained from thin, discontinuous sand and gravel deposits interbedded in fine, sandy clay or from the underlying shale. Drilling deeper than 30 feet into the shale is not recommended. Occasional gas or salt noted in the eastern half of the county.

Larger yields may be obtained in western Huron and Oxford townships and southeastern Perkins Township. Wells may encounter water-bearing limestone beneath as much as 60 feet of impervious shale.

SCALE

1 0 1 mile

Depth (ft)

75-SH-2 → Water-bearing formation

10 → Yield (gpm)

Depth to bedrock (ft.)

● Existing Domestic Wells

Figure 2-4

REGIONAL WATER-BEARING ZONES IN THE BEDROCK AQUIFERS (Modified from Walker, 1986)

Plum Brook Ordnance Works
Sandusky, Ohio

REFERENCE: Reproduced from SAIC Preliminary Assessment, 1991

DAMES & MOORE

Residences to the north and east of PBS are served by city, county and rural water departments. Residences south and west of PBS are supplied by wells and cisterns (SAIC, 1991). According to SAIC (1991) the nearest recorded well is at 6115 Schenk Road; however a closer well was observed at 1810 Schenk Road. Additionally, two other wells are considered public drinking water supplies (used by 25 or more people for 60 days or more a year): Woussickett Golf Course clubhouse (6311 Mason Road) and Stanley's Tavern (4408 Mason Road), (SAIC, 1991).

Prior to the construction of a sewage treatment facility by Bellevue in 1971, the carbonate aquifer was contaminated by the injection of waste water through privately and municipally owned wells (Ground Water Pollution Potential of Erie County, Ohio, 1994). Samples of potable wells in the Bellevue-Castille area in 1961 contained alkyl benzene sulfonate (indicative of household detergents), ammonium nitrogen, as well as higher concentrations of nitrogen compounds than the adjacent limestone areas (Ohio Department of Natural Resources Availability of Underground Water, Pickeral Creek - Pipe Creek Area, 1962).

2.8 SURFACE WATER USE

Surface water intakes within 15 miles of PBS include Lake Erie, Huron River, and reservoirs fed by tributaries of the west branch of Huron River or the west branch itself.

The Erie County Health Department does not permit the use of surface water for private drinking water supply and no surface water within PBS is used as a drinking water supply (SAIC, 1991). It is unknown if surface waters are used for livestock in the local area. Crop irrigation is not common in Ohio (SAIC, 1991). Lake Erie and Sandusky Bay are a resource for recreational sports including fishing, swimming, and boating.

3.0 DESCRIPTION AND HISTORY OF RED WATER PONDS AND TNT AREAS

While a number of explosives and related materials, including DNT and pentolite, were manufactured at the PBOW, TNT was the primary product of the facility. The PBOW used a batch manufacturing process to produce TNT. Sequential steps were performed in a series of separate buildings comprising a process line. A general description of the process is provided in Section 3.1.

Waste water, known as "red water," was generated by washing impurities from the final TNT product. The red water was disposed in two red water ponds areas, the Pentolite Road Red Water Ponds and the West Area Red Water Ponds. These areas are described in Sections 3.2 and 3.3, respectively.

TNT was manufactured in three areas on site, TNT Areas A, B, and C. The TNT manufacturing areas are described in Section 3.4.

3.1 GENERAL TNT MANUFACTURING PROCESS

TNT is made by nitrating toluene in a three-step process (USATHAMA 1990). In this process, nitration is the substitution of a nitro group ($-NO_2$) for a hydrogen on the benzene ring of the toluene molecule. A mixture of three nitrotoluene (NT) isomers (2-NT, 3-NT, and 4-NT) and a layer of waste acid are formed during the first nitration. The second nitration produces six DNT isomers, with 2,4-DNT; 2,6-DNT; and 3,4-DNT being most abundant. Ninety five percent of the production in the third nitration step is 2,4,6-TNT, which is the desired product. To effect nitration, toluene is mixed with a solution of sulfur trioxide in sulfuric acid (oleum) and nitric acid, and heated. Water is formed by the nitration reaction, and the water combines with the sulfur trioxide to form sulfuric acid. The production of additional sulfuric acid makes the mixture of oleum and nitric acid a more effective nitrating agent than a combination of sulfuric and nitric acids. Each nitration step is progressively more difficult and stronger acid solutions are required in order to complete the reactions.

In the TNT manufacturing process, the acid mixture and the organic compounds flow in opposite directions. A fresh feed of oleum and nitric acid is used in the third step, and the acid waste is used, after fortification with nitric acid, in the second nitration. Acid from the second step is fortified and reused in the first nitration. The waste acid from the first nitration is separated from the organic phase and denitrated using steam; the nitrogen oxide is recovered in water and heated to produce nitric acid. This acid is used to fortify the acid mixtures for the first and second nitration steps.

Each step in the nitrating process has some inherent amount of inefficiency. In each nitrating step, some of the isomers will not be converted to the next level (e.g., not all NT isomers are converted to DNT and not all DNT isomers are converted to TNT). Additionally, a small amount of NT is converted to other products during the process, nitrobenzenes being the most common. These unconverted isomers and non-nitrotoluene products are carried through the process as "impurities" until the final wash step.

Following the final nitration, the crude TNT is washed to remove acids, neutralized with soda ash, and crystallized by adding cold water. Sodium sulfite (sellite) is added to the crystalline TNT because it forms a water-soluble salt with the unwanted TNT isomers and impurities, which are removed in a water wash. The purified TNT is then melted, dried to remove water, and solidified in flake form.

The waste streams from normal production include spent sulfuric and nitric acids and red water from the purification process. The red water contains sodium salts of sulfite, sulfate, nitrite, nitrate, and sulfonates of the unwanted TNT isomers (2-NT, 3-NT, 4-NT, 2,4-DNT, 2,6-DNT, 3,4-DNT), plus other organic compounds such as 1,3,5-trinitrobenzene (TNB), 1,3-dinitrobenzene (DNB), and nitrobenzene (NB). Some of the other organics found in red water include trinitrobenzoic acid, trinitrobenzaldehyde, and trinitrobenzyl alcohol (USATHAMA 1990). The red water is disposed of in settling basins and disposal ponds where the suspended particulate matter is allowed to settle out of the water.

In addition to the waste water stream, unusual occurrences can create liquid waste from intermediate steps in the process, which could include 2-NT, 3-NT, 4-NT, 2,4-

DNT, 2,6-DNT, and 3,4-DNT. For example, the contents of reaction vessels may be dumped when the process is thought to be out of control.

3.2 PENTOLITE ROAD RED WATER PONDS

3.2.1 Description of the Pentolite Road Red Water Ponds

The Pentolite Road Red Water Ponds are located between Maintenance Road and Pentolite Road, northwest of Reservoir #1 at the location shown on Figure 3-1. During field reconnaissances of the area conducted in March 1994 and fall 1994, the area consisted of thick masses of cattails with bare areas which seasonally contain ponded water, as shown on Photos 3-1 through 3-4. Ponded water within this area was observed to have a reddish tint, as shown on Photo 3-5.

An approximately 10-foot deep southwest-northeast trending ditch traverses the area to the east. This ditch flows northeasterly into another ditch which parallels Pentolite Road. According to information provided by NASA PBS employees, an underground clay pipe ("drainage tile") drains the Pentolite Road Red Water Ponds area and discharges into the ditch which parallels Pentolite Road. Photo 3-6 shows the drainage pipe where it discharges into this ditch.

The ponds received waste water from TNT Areas A and B from initiation of plant operations to 1945. Review of historical site drawings indicate that waste water from the waste water settling basins at the TNT areas flowed through wooden flumes and pipes to a waste water treatment and incineration area (Waste Water Disposal Plant #1), then to the pond disposal area via an elevated 12-inch diameter discharge pipe.

Drawing No. 1663-W-2 (E.B. Badger & Sons Co., October 1941) illustrates construction details of the waste water disposal area. Figure 3-2 is derived from this Drawing No. 1663-W-2. The waste water basin measured 200 feet in width and 400 feet in length. It was 3 feet in depth and was surrounded by a 1-foot high levee. A note on the 1941 drawing states that 3-foot boreholes were to be drilled at the corner

2000 1000 0 2000 4000 Feet

APPROXIMATE SCALE

BASE PHOTOGRAPH: October 19, 1950; Photo PW-3G-62; Site - Plum Brook Ordnance Works, Sandusky, Ohio

N

Figure 3-1

LOCATIONS OF RED WATER POND AREAS

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PHOTO 3-1. Bare areas containing ponded surface water at Pentolite Road Red Water Ponds (photo taken in March 1994)

PHOTO 3-2. View looking northeast towards bare areas at Pentolite Road Red Water Ponds (photo taken in March 1994)

PHOTO 3-3. Dry bare area at Pentolite Road Red Water Ponds (photo taken in November 1994)

PHOTO 3-4. Ponded surface water in the same bare area as shown in Photo 4-3 (photo taken in December 1994)

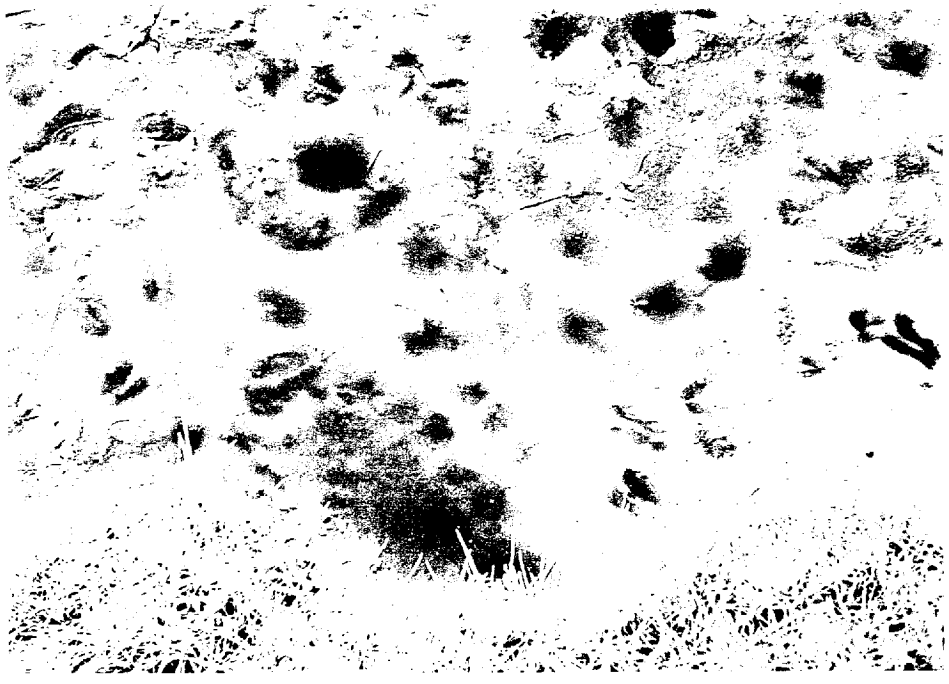
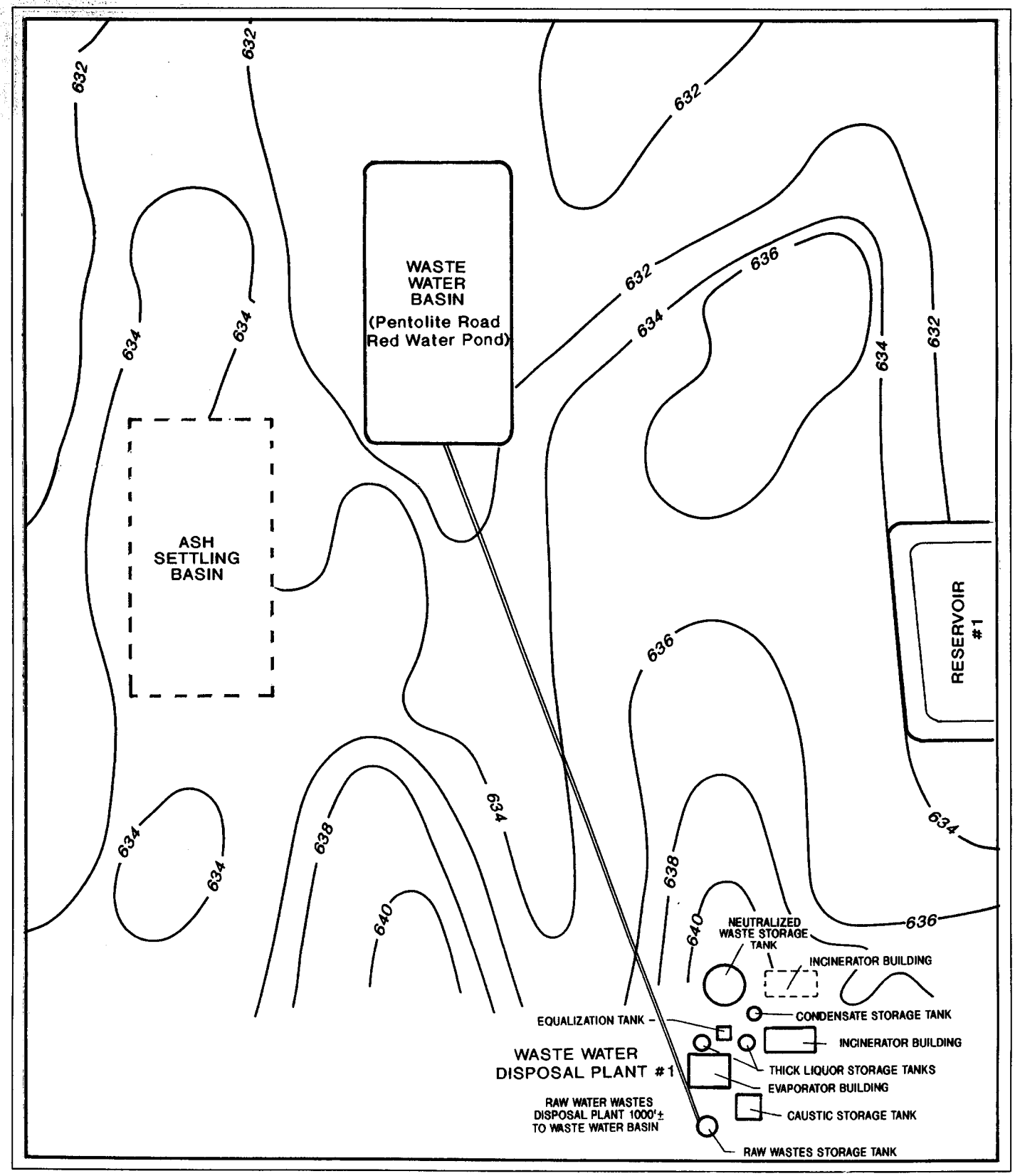


PHOTO 3-5. Close-up view showing reddish tint of ponded water at Pentolite Road Red Water Ponds (photo taken in fall 1994)

PHOTO 3-6. Drainage tile from Pentolite Road Red Water Ponds; tile discharges into ditch parallel to Pentolite Road (photo taken in fall 1994)



200 100 0 200 400 FEET

REFERENCE DRAWING No. 1663-W-2 "Temporary Storage Pit for Neutralized Waste Water", E.B. Badger & Sons, 1941

Figure 3–2

CONSTRUCTION DIAGRAM FOR PENTOLITE ROAD RED WATER POND AND WASTE WATER DISPOSAL PLANT #1

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of each square yard within the basin, and pop shots of dynamite were to be inserted into the holes and detonated to loosen the subsoil. Production at the PBOW actually started in December 1941 (2 months after this drawing was prepared); no information was found which verified the construction details shown on the drawing.

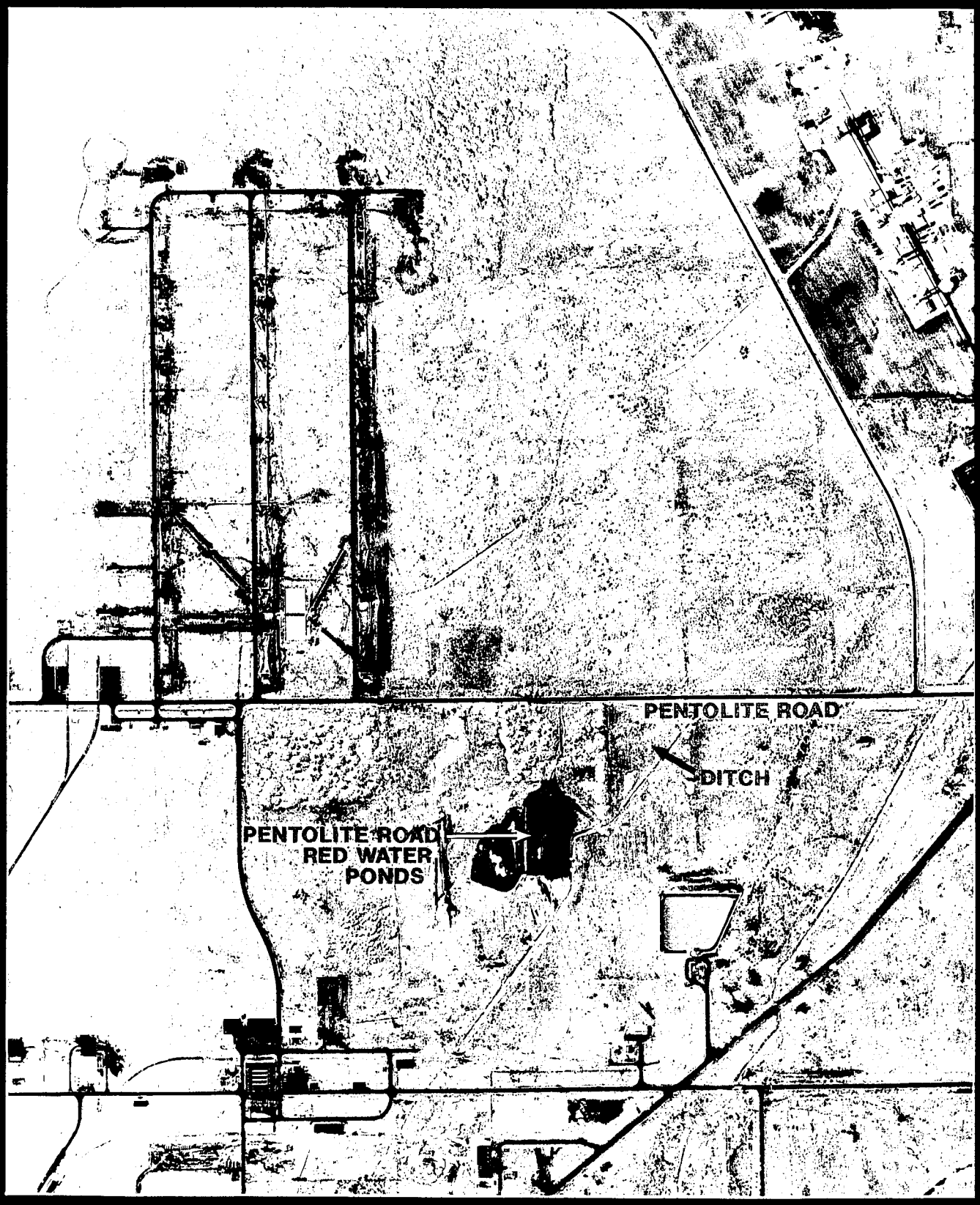
Figure 3-1 is an aerial photograph of the area taken in October 1950. This photograph shows a disturbed area where the Pentolite Road Red Water Ponds were located. The eastern portion of the disturbed area resembles the shape of the waste water basin shown on Figure 3-2. It appears to be predominately dry. The western portion of the disturbed area, which is irregularly shaped but is approximately the same size, appears to contain water. Figure 3-3, which is an aerial photograph of the area taken in 1956 shows a similarly shaped area. A close-up aerial photograph of the Pentolite Road Red Water Ponds (photograph obtained from NASA; no title or date) showed two distinct ponds in this location; the ponds appeared to be diked (in agreement with Drawing No. 1663-W-2, referenced above). The ponds in this close-up photograph (not reproduced herein) resemble the shape of the ponds shown on Figure 3-3.

Review of additional historical drawings (such as Plan No. R-32, "Unit Layout Map, Waste Disposal & Water Supply Area No. 1" [E.B. Badger & Sons Co., no date] indicates that waste water was transported to the Pentolite Road Red Water Ponds via an elevated 12-inch discharge pipe from a raw waste water tank at Waste Water Disposal Plant #1 (the location and layout of this plant are shown on Figure 3-2). Apparently, waste water was transported from the waste water settling basins at TNT Areas A and B to a raw waste water tank at this plant prior to disposal at the Pentolite Road Red Water Ponds.

3.2.2 Post-PBOW Actions

3.2.2.1 Ravenna Arsenal, Inc. Actions in 1960s

A letter to Ravenna Arsenal, Inc. from the U.S. Army Ammunition, Procurement, and Supply Agency in Joliet, Illinois (Braig, 1963) describes work to be accomplished by Ravenna Arsenal, including apparent decontamination and decommissioning activities.



600 300 0 600 1200 FEET

(APPROX.)

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Figure 3-3

1956 AERIAL PHOTOGRAPH SHOWING PENTOLITE ROAD RED WATER POND AREA

Plum Brook Ordnance Works

Sandusky, Ohio

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of the contaminants and re-route drainage to reduce amount of red water flowing into Plum Brook." The leaching bed referred to in this letter may be the Pentolite Road Red Water Ponds.

3.2.2.2 1977 Actions

In an April 1977 memorandum (Teledyne Isotopes, 1977), PBS personnel reported an observation of localized pockets of reddish brown water in the small surface ditch east of, and adjacent to, the Pentolite Road Red Water Ponds area, which was referred to as a surface spoils site. The source was discovered to be a broken drain tile on the southeast corner of the "spoils area." The memorandum stated that retention dikes and sump pits were promptly excavated to prevent leakage of the material to surface streams. From April 13, 1977 to May 3, 1977, approximately 60,000 gallons of the "red" water were removed by a private disposal contractor. Grading and drainage improvements were made to the area to alter surface runoff patterns.

The memorandum further described actions being undertaken by the local Air National Guard which included backfilling the original settling basin to bring it higher in elevation than the surrounding area. The memorandum stated that a new drainage ditch would be dug approximately 300 feet east of the original ditch, which would then be backfilled. The intent of these activities was to eliminate ponding in the area, thus reducing the amount of surface water that could mix with the red water residue, thus producing red-colored water.

On April 14, 1977, one surface water sample was collected from the surface drain tile pool; on April 15, 1977, a second sample was collected from the retention trench that was dug to prevent runoff to surface streams. The memorandum states that both samples were "deep red in color, odorless and aqueous in nature, with a pH of 7.3." Several minnows were observed in the contaminated drain tile pool of water.

"Flame tests gave a bright yellow-orange flame suggesting the presence of sodium. Sodium was subsequently verified by atomic absorption spectrophotometry to be

present in a ratio of 2 to 1 to sulfate. This suggests strongly that the major inorganic constituent is Sodium Sulfate (Na_2SO_4)." (Teledyne Isotopes, 1977)

The Lewis Chemistry Lab analyzed replicate samples of these samples and reported that tannin was the prime constituent present in the samples as determined by infra red analysis.

Additionally, PBS laboratory personnel collected soil samples at different strata within the "spoils area." A thin layer (approximately 1/8-inch) of salt-like crystalline material was reported at or near the surface. About 1 foot of sand and top soil covered a clay sub-strata. The top soil samples were dispersed in water and the water turned red in color. The clay sub-strata samples did not cause discoloration of water. (Teledyne Isotopes, 1977) The memorandum further stated that the salt-like surface strata samples had the highest concentrations of sulfate and the clay sub-strata apparently did not absorb the chemical spoils.

Under a "Data Interpretation" heading in the memorandum, the author stated:

> The major constituent in the spoils area is sodium sulfate probably resulting from the neutralization of acid wastes by use of caustics. The presence of significant quantities of tannin probably resulted from acid reaction with wooden vats and plumbing in the old arsenal days at Plum Brook. The presence of significant quantities of iron in the range of 20 [parts per million] ppm probably resulted from acid/chemical reaction with iron plumbing. Other trace elements identified are consistent with what could be expected to be present in soil or are consistent with process materials used 3 decades ago. The presence of phenols in two samples cannot be explained.
>
> This red water as such does not appear to be an acute toxin to aquatic life based on abundant minnow population in the local ditches and subsequent downstream ditches and creeks (approximately 1,000 feet away).

3.2.2.3 1989 Actions

In 1989, NASA personnel (Ms. Amy L. Bower and Mr. Harry McCune) observed reddish-brown water emanating from the drainage tile into Pentolite ditch (NASA, 1989). Water samples were collected and analyzed for chemical oxygen demand

(COD), pH, chromium, copper, lead, iron, and zinc. The iron and COD concentrations were approximately 6 to 10 times higher at the discharge pipe than at the National Pollutant Discharge Elimination System (NPDES) sampling weir located downstream.

3.2.2.4 1990 Actions

In April 1990, Ms. Amy Bower of NASA noticed rust-colored water discharging into Pentolite Ditch from the drainage tile which originates in the vicinity of the Pentolite Road Red Water Ponds. Ms. Bower assumed the water to be "red water" which had leached into the drainage tile (NASA, 1990). She notified several NASA and PBS individuals as well as the Ohio Environmental Protection Agency (OEPA), the National Emergency Response Center, and the U.S. Environmental Protection Agency (EPA).

Water samples were collected and analyzed for total chromium, COD, total copper, total iron, total lead, total nickel, nitrate, nitrite, total phosphorus, total sodium, sulfate, total zinc, TNT, 2,4-DNT, 2,6-DNT, cyclotetramethylene tetranitramine (HMX), cyclotrimethylene trinitramine (RDX), o-NT, m-NT, and p-NT. None of the NPDES limits were exceeded as a result of the discharge. However, levels of iron, nickel, nitrate, sulfate, and zinc at the outfall were significantly higher than the upstream levels as a result of the discharge. Concentrations of explosives were below the detection limit of the analytical method (NASA, 1990).

3.2.2.5 1991 Actions

In April 1991, Ms. Amy Bower of NASA observed another discharge of rust-colored water into Pentolite ditch from the drainage tile (NASA, 1991). The OEPA was notified and incident number 2-72-0508 was assigned. The National Response Center was also notified; incident report number 60215 was assigned. Ms. Bower also notified Mr. Doug Webb of the CEORN regarding the incident.

Analysis of a NPDES sample collected 2 days later at a downstream location indicated levels for COD, suspended solids, nitrate, zinc, copper, and pH to be within daily NPDES permit levels.

3.2.3 Environmental Investigations

IT investigated the Pentolite Road Red Water Ponds area during their 1989 Contamination Evaluation. In their report (IT, 1991), IT refers to this area as "Waste Disposal Area #1", and stated that areas of surface contamination were evident.

Monitoring well IT-MW5 was installed in the northern portion of the area to a total depth of 21 feet. Groundwater in this well was measured at approximately 15 feet below ground surface. IT also installed six soil borings and collected soil samples (SB-13 through SB-18). Soil samples collected from either 0 to 2 feet or 4 to 6 feet were submitted for analysis. IT also collected one surface water sample (SW-04) from standing water within the area.

Groundwater, surface water, and soil samples collected by IT were analyzed for volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), nitrates, metals, and nitroaromatic explosive compounds. IT reported that significant concentrations (greater than or equal to 740 parts per billion [ppb]) of 2,4-DNT and 2,6-DNT were detected in the soil samples collected from the Pentolite Road Red Water Ponds area. No nitroaromatic explosive compounds were reported in the groundwater sample collected from monitoring well IT-MW5 or in the surface water sample collected from this area.

MK Ferguson's investigation of the Pentolite Road Red Water Ponds area was limited to collection of surface water and sediment samples from a drainage swale north of the Pentolite Road Red Water Ponds. No explosive contaminants were detected.

3.2.4 Current Use

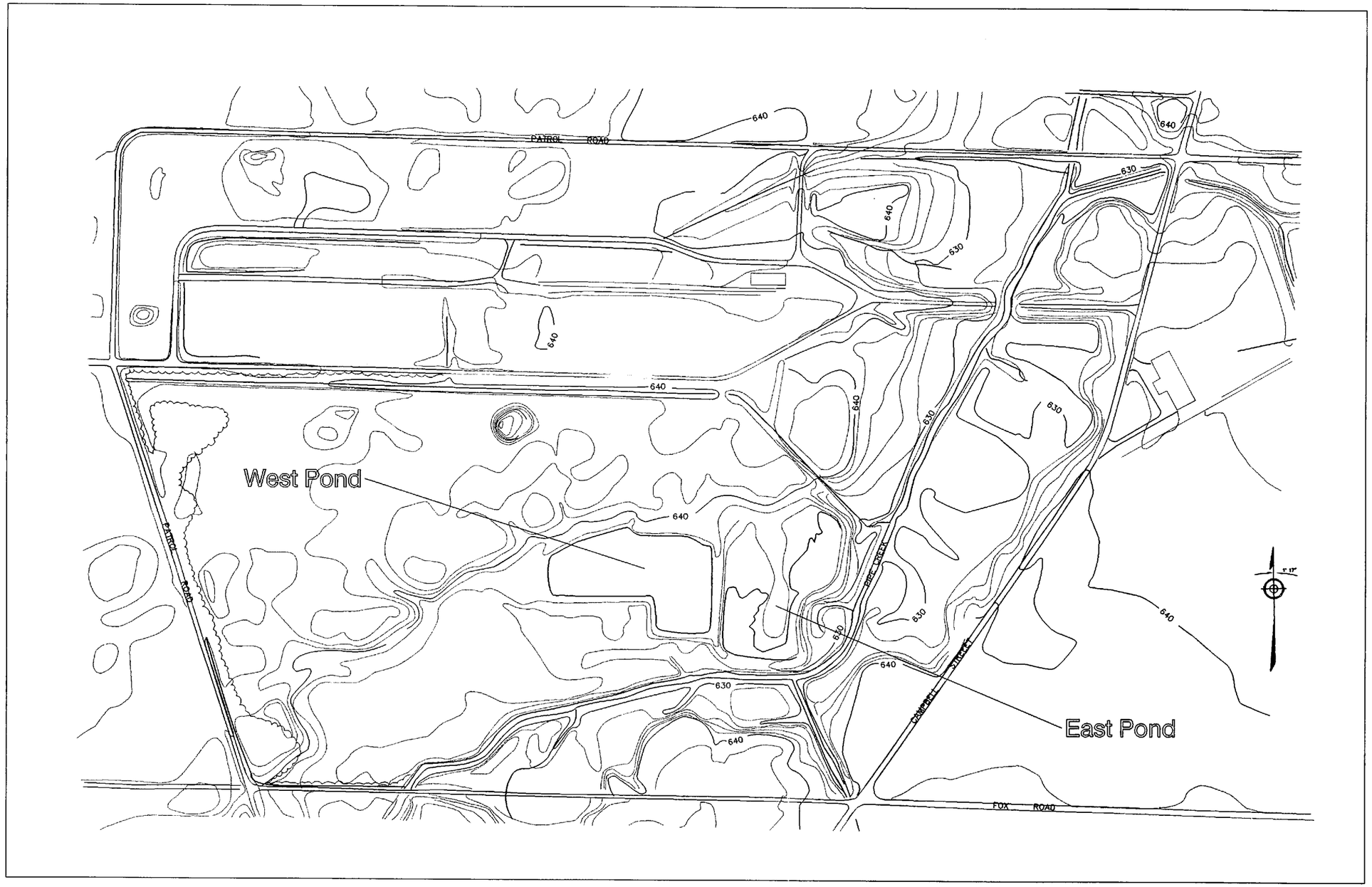
The Pentolite Road Red Water Ponds area is not currently used for any NASA-related activities. It is normally covered with vegetation including cattails and grasses.

3.3 WEST AREA RED WATER PONDS

3.3.1 Description of West Area Red Water Ponds

The West Area Red Water Ponds are located in the western portion of the site near Pipe Creek, as shown on Figure 3-1. Figure 3-4 provides a site plan of the West Area Red Water Ponds using the USGS topographic map as a base. As illustrated on Figure 3-4, the two ponds which comprise this area are designated as the "east" pond and the "west" pond. During operation of the PBOW the ponds were separated by a berm. NASA drained the east pond and it is generally dry, except for small areas of standing water that accumulate during periods of wet weather. Pipe Creek is located south of both ponds and east of the east pond. A northwest-southeast trending ditch is located to the northeast of the east pond (Figure 3-1); this ditch flows in a southeasterly direction and discharges into Pipe Creek. The area surrounding the ponds is predominately wooded.

The West Area Red Water Ponds received waste water from TNT Area C from initiation of plant operations until 1945, when the production of ordnance ceased (SAIC, 1991). Review of historical site drawings indicate that the waste water from the waste water settling basins at the TNT production areas flowed through wooden flumes and pipes to a waste water treatment and incineration area (Waste Water Disposal Area No. 2), then to the West Area Red Water Ponds via an elevated 12-inch diameter vitreous pipe. Review of historic aerial photographs indicates that the west pond has existed and contained standing water from the 1940s to present. The east pond existed and contained standing water from the 1940s to the late 1970s. According to information provided by Mr. Jim Knoll, an employee at the PBS, the berm around the east pond was breached at its southwestern corner in the late 1970s to try to drain the pond (personal communication with P. Westermann, 1994).



Scale: 1" = 350'

Figure 3-4
Site Plan of West Area
Red Water Ponds
Plum Brook Ordnance Works
Sandusky, Ohio

DAMES & MOORE
A DAMES & MOORE GROUP COMPANY

Government Services Division; Atlanta, Georgia
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PHOTO 3-7. Northern portion of existing pond at West Area Red Water Ponds (photo taken in March 1994)

PHOTO 3-8. View looking south at berm and western portion of existing pond at West Area Red Water Ponds (photo taken in September 1994)

PHOTO 3-9. View looking south at berm and former eastern pond of the West Area Red Water Ponds; note the reddish tint of the water (photo taken in

PHOTO 3-10. Pipe Creek south of West Area Red Water Ponds (photo taken in March 1994)

During field reconnaissances of the area conducted in March 1994 and fall 1994, the western pond contained standing water as shown on Photos 3-7 and 3-8. The sides of the earthen berm separating the eastern and western ponds were predominantly wooded (Photo 3-8). The eastern pond was generally dry except for small areas of standing water that appear to accumulate during periods of wet weather (Photo 3-9). Shallow red-tinted water was observed in the former eastern pond area adjacent to the earthen berm separating this area from the western pond.

3.3.2 Construction Details

Drawing R-36 "Power Hse., Waste Water Disposal Area No. 2" (E.B. Badger & Sons Co., undated) illustrates the buildings located within Waste Disposal Area No. 2 and the waste water discharge line to the western pond. The drawing indicates that an elevated 12-inch diameter line carried water from the Waste Disposal Area No. 2 Raw Waste Tank to the West Area Red Water Ponds.

Drawing No. 1763-S-954 "Details of Flume Connecting Raw Wastes Storage Tank and Waste Water Basin Including Basin Layout" (E.B. Badger & Sons Co., March 1942) illustrates construction details of the flume connecting the Raw Water Storage Tank at Waste Water Disposal Area No. 2 to the western pond. Review of the drawing indicates that the western pond was originally designed to be 200 feet wide by 400 feet long with an approximately 4 feet high earthen berm surrounding the basin. The area depicted on this drawing generally corresponds to the rectangular shaped eastern portion of the western pond. Figure 3-5 presents a historic aerial photograph (date unknown) of the western pond area. Based on the apparent absence of vegetation in the areas north and south of the pond (which were also observed on a 1944 aerial photograph of the area, but not on a 1950 aerial photograph of the same area), this photograph is believed to represent early 1940 West Area Red Water Ponds conditions. As shown on Figure 3-5, the western pond appears to have been expanded to the approximate limits shown on Figure 3-1 during PBOW operation. Review of Figure 3-5 also indicates that several trees are apparent within the western pond, suggesting that extensive grading of the pond bottom was not performed during construction of the western pond.

Figure 3–5

ASSUMED EARLY 1940s AERIAL PHOTOGRAPH SHOWING WESTERN POND

Plum Brook Ordnance Works
Sandusky, Ohio

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Drawing 1763-S-954 also indicates that the elevated 12-inch diameter line from the Waste Water Disposal Area No. 2 Raw Waste Tank discharged water in the middle of the northern berm of the rectangular shaped eastern portion of the western pond. No information regarding discharge from the pond was included on the drawing.

Drawing No. 1763-T-901-2 "Waste Water Disposal No. 2 Pond No. 2" (Trojan Powder Company, 1943) illustrates construction details for the eastern pond. Review of the drawing indicates that the eastern pond was designed to be approximately 407 feet wide in an east-west direction at its maximum extent. The eastern pond was constructed with an approximately 10 foot high earthen berm (typical), which varied in elevation from approximately 637.1 to 640.6 feet. The lowest top of berm elevation (637.1 feet) noted on the drawing occurred in the northeast corner of the pond near the northwest-southeast trending ditch. Based on the design water level (noted on the drawing) of 637.71 feet, discharge from the pond may have occurred at this location. An 8- to 10-inch diameter pipe penetrating the earthen berm in this area of the eastern pond was observed during a fall 1994 site reconnaissance. Evidence of former concrete pedestals that may have supported a discharge pipe were also observed in the area between the eastern pond and the northwest-southeast trending ditch.

The drawing also indicates that the elevation of the bottom of the pond varied significantly, further evidence suggesting that extensive grading of the pond bottom was not performed during construction. The drawing estimates the total volume of the eastern pond to be approximately 5,400,000 gallons. No information regarding influent or effluent lines was included on the drawings.

As noted above, specific information regarding the discharge of the eastern or western ponds or the transfer of water from the western pond to the eastern pond was not documented on the available drawings. SAIC (1991) noted that the western pond was constructed with an 8-inch diameter overflow tile that allows the ponds to overflow into Pipe Creek, but did not document the location of this overflow tile in their Preliminary Assessment Report. No evidence of this reported drain tile from the western pond to Pipe Creek was observed during a site reconnaissance of Pipe Creek conducted in fall 1994. During the March 1994 site reconnaissance, Pipe Creek

contained approximately 3 to 5 feet of flowing water (Photo 3-10). Seeps of reddish water into Pipe Creek south of the western pond were also observed as shown on Photo 3-11. Pipe Creek was predominantly dry, with no flowing water, during the fall 1994 site reconnaissance. A breach and overflow area in the southwestern corner of the rectangular shaped eastern portion of the western pond was also observed during the field reconnaissances (Photo 3-12).

Figure 3-6 presents a 1960 aerial photograph of the eastern and western pond area. As shown on the figure, an apparent wooden structure is located on the berm separating the eastern and western ponds. A roadway to the area of the structure is also apparent on this photograph, as well as the 1950 (Figure 3-1) and 1958 aerial photographs. Information documenting the nature of this structure was not included in the documents reviewed. However, a figure included in the Ohio Army National Guard Report (Ohio Army National Guard, 1985) shows an influent pipe at this location. No evidence of the former structure was observed during the 1994 and 1995 site reconnaissances of this area. However, the roadway to the former structure location apparent on the photograph was observed during the site reconnaissances.

Figure 3-7 presents a layout of the West Area Red Water Ponds and Waste Water Disposal Area No. 2. The figure is derived from Dames & Moore's review of available information including drawings R-36, 1763-S-954, and 1763-T-901-2. The western limits of the western pond have been modified from those presented on Drawing No. 1763-S-954, and approximate those shown on Figure 3-1. Specifically, the western pond's width (east-west direction) at the center is depicted as being approximately 550 feet, rather than 200 feet. This western pond configuration was depicted based on a review of a presumed early 1940s aerial photograph (Figure 3-5) and a 1944 aerial photograph which indicate the expanded western pond configuration during PBOW operation. Figure 3-7 also illustrates the approximate location of the elevated discharge pipe from the Waste Water Disposal Area No. 2 Raw Waste Tank to the western pond and the location of the pipe penetrating the eastern pond berm observed during the 1994 field reconnaissances. The location of the apparent former structures shown on the 1960 aerial photograph and the apparent natural breach in the western pond berm observed during the 1994 field reconnaissances are also documented on Figure 3-7.

PHOTO 3-11. Reddish water seep into Pipe Creek south of West Area Red Water Ponds (photo taken in March 1994)

PHOTO 3-12. Breach and overflow area south of existing pond [illegible] Ponds (photo taken in September 1994)

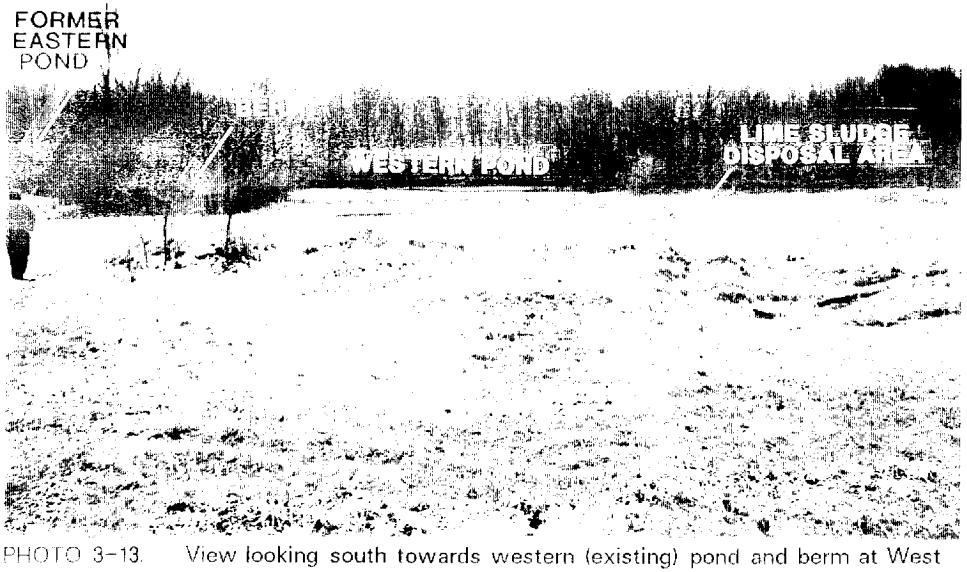

PHOTO 3-13. View looking south towards western (existing) pond and berm at West Area Red Water Ponds; lime sludge was disposed of in foreground (photo taken in March 1994)

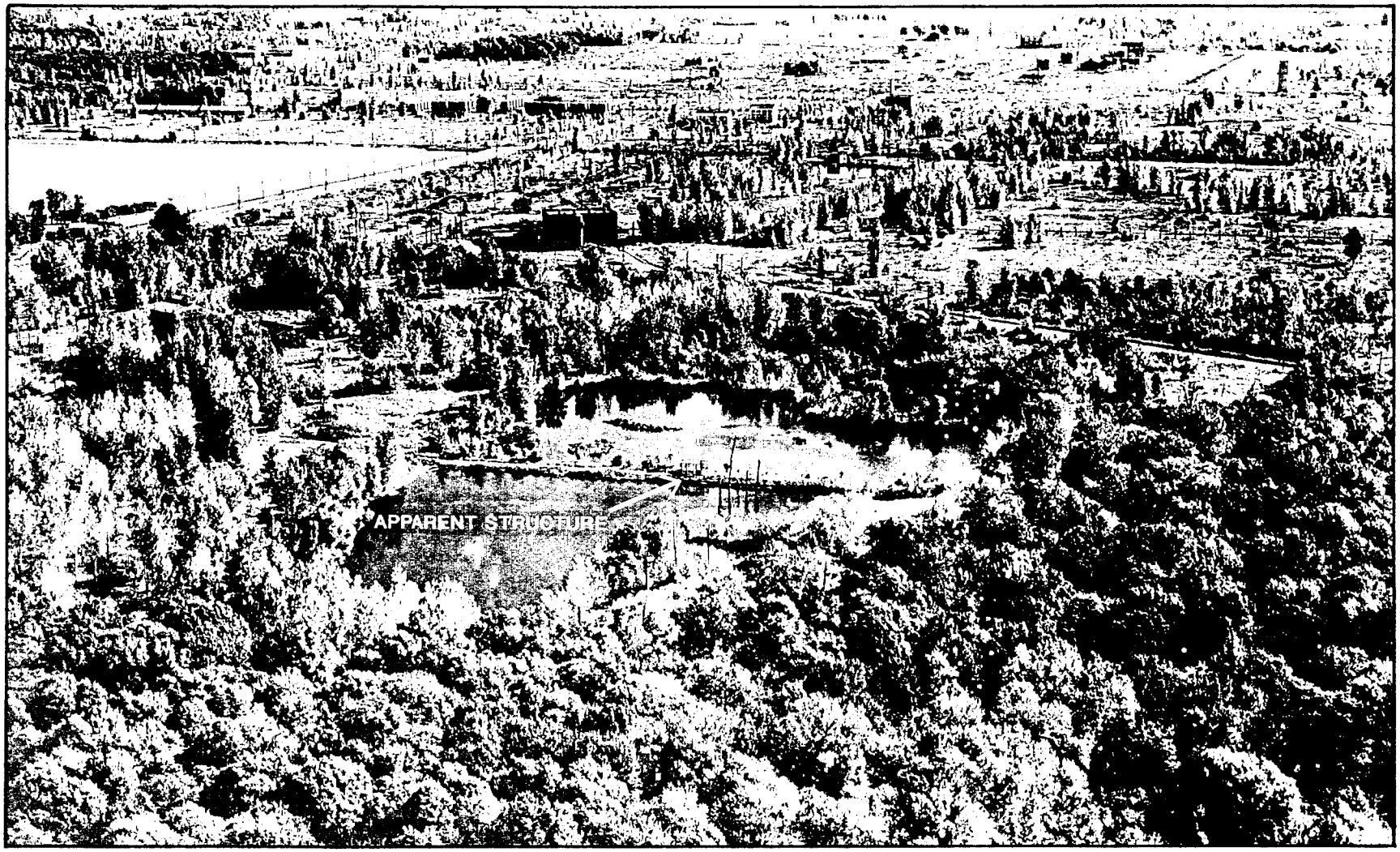

Figure 3–6

1960 AERIAL PHOTOGRAPH SHOWING WEST AREA RED WATER PONDS AREA

Plum Brook Ordnance Works

Sandusky, Ohio

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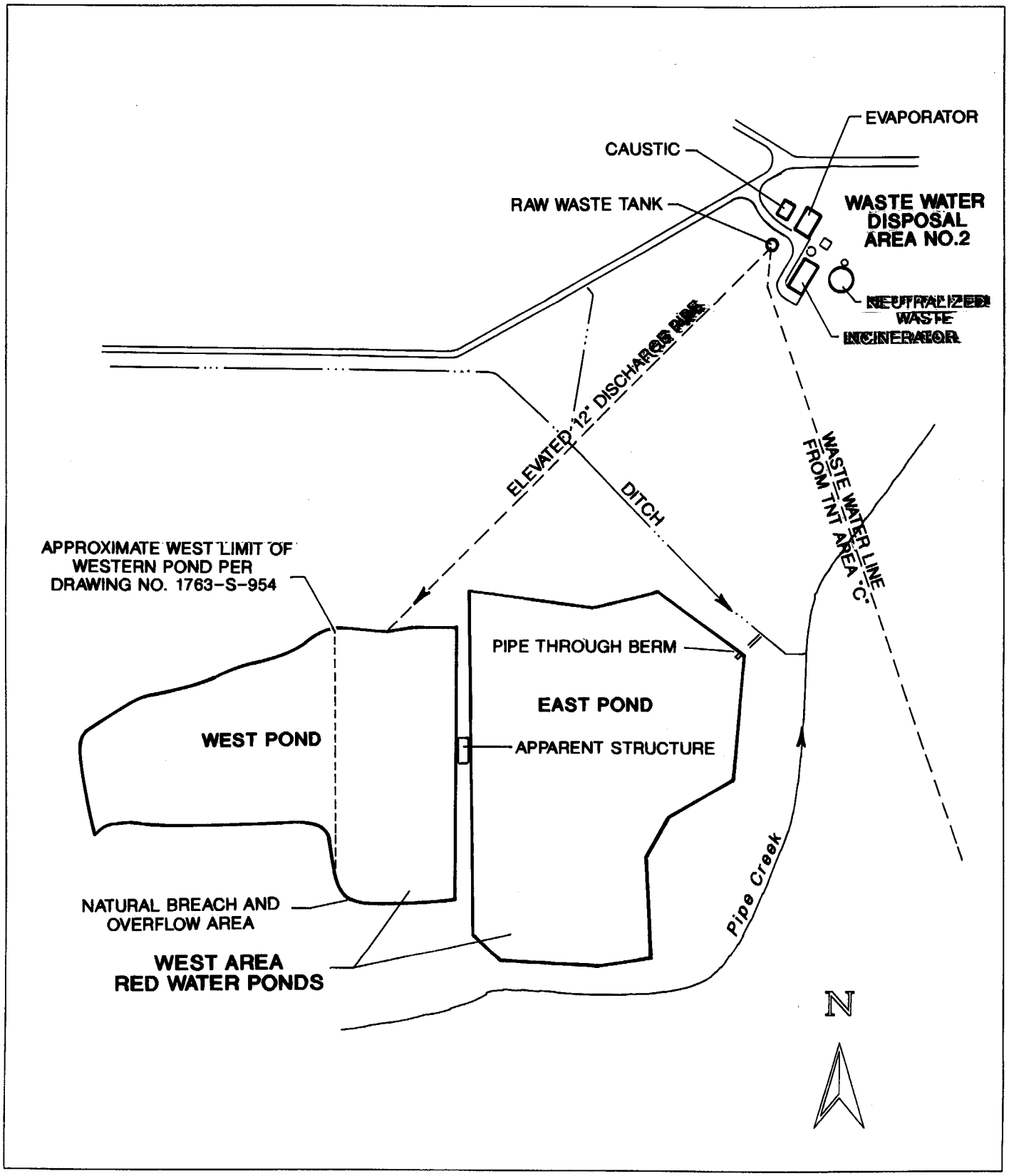

200 100 0 200 400 FEET

REFERENCE DRAWING NUMBERS:

R-36 "POWER HSE., WASTE DISPOSAL AREA NO.2", E.B. Badger & Sons

1763-S-954 "DETAILS OF FLUME CONNECTING RAW WASTES STORAGE TANK AND WASTEWATER BASIN INCLUDING BASIN LAYOUT", E.B. Badger & Sons, 1942

1763-T-901-2 "WASTEWATER DISPOSAL NO.2 POND NO.2", Trojan Powder Company, 1943

Figure 3-7

CONSTRUCTION DIAGRAM FOR WEST AREA RED WATER PONDS

Plum Brook Ordnance Works
Sandusky, Ohio

DAMES & MOORE

3.3.3 Post PBOW Actions

3.3.3.1 Lime Sludge Disposal

The Preliminary Assessment (SAIC, 1991) states that 8,000 cubic yards of lime sludge was removed from the reactor settling basins and disposed at Waste Water Disposal Area No. 2. NASA personnel responsible for the lime sludge disposal indicated, however, that lime sludge was also disposed of within and immediately north of the western pond in an attempt to fill in the western pond (personnel communication with P. Westermann, 1994). The practice of on-site lime sludge disposal was discontinued in 1973 (SAIC, 1991). The 1968 aerial photograph (Figure 3-8) shows apparent disposal of materials north of and into the western pond (disturbed area within and immediately north of western pond). During the 1994 and 1995 field reconnaissances of this area, uneven ground and white material at the surface were observed (Photo 3-13).

3.3.3.2 Late 1970s Actions

According to information provided by Mr. Jim Knoll, an employee at the PBS, the berm around the eastern pond was breached at its southwestern corner in the late 1970s to attempt to drain the eastern pond (personal communication with P. Westermann, 1994). With the exception of a localized area of shallow standing water immediately adjacent to the earthen berm separating the eastern and western ponds, the eastern pond was dry during the field reconnaissance (Photo 3-9).

3.3.3.3 1985 Investigations

In May 1985, the Resident Department of Interior Fisheries Research Unit placed trap nets in the western pond to evaluate the types of aquatic life present in the West Area Red Water Ponds. Based on the results of this study, it was concluded that "the red

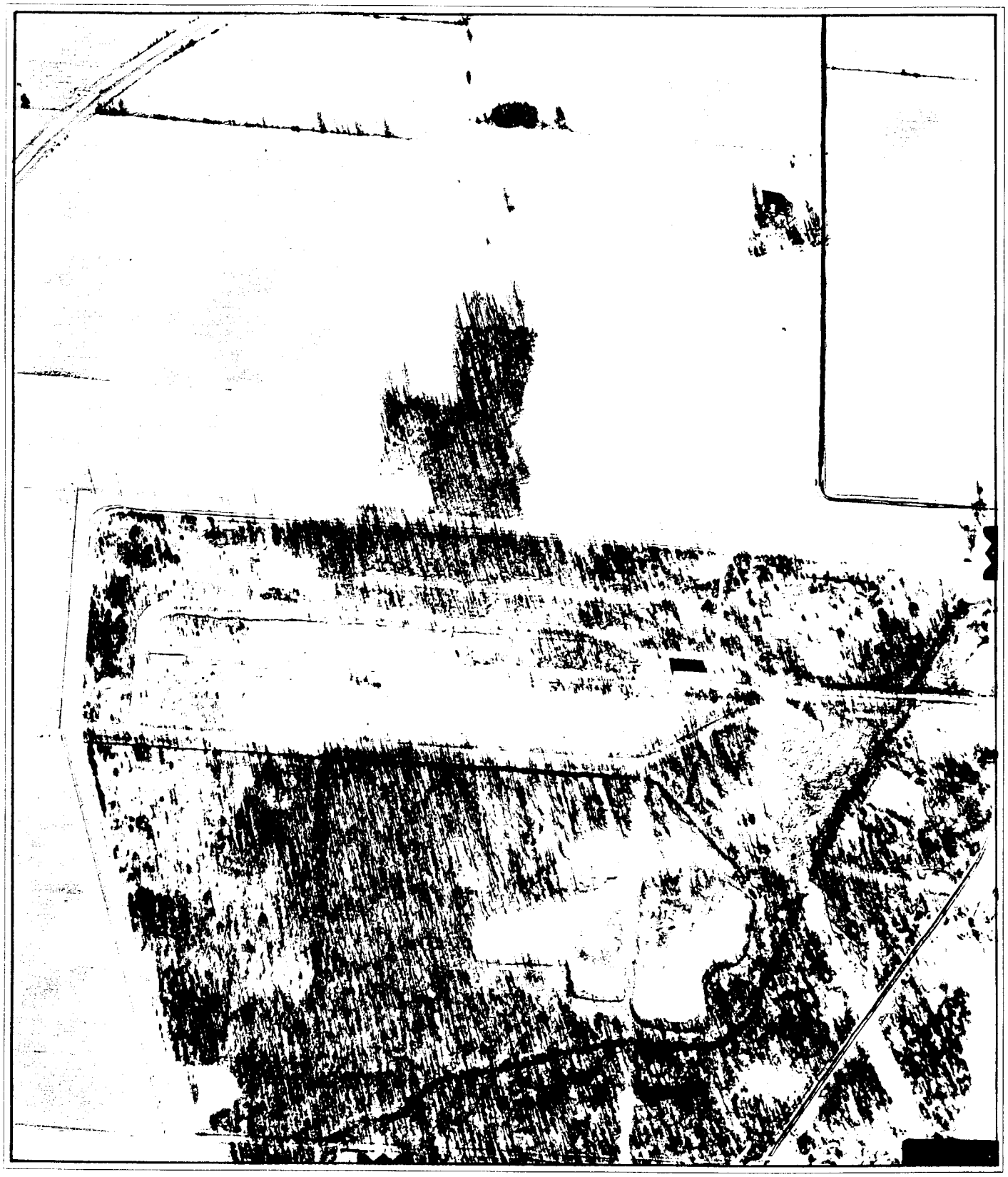

Figure 3-8

1968 AERIAL PHOTOGRAPH SHOWING WEST AREA RED WATER PONDS AREA

Plum Brook Ordnance Works
Sandusky, Ohio

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water residue has no adverse effect on aquatic life and that there is sufficient plant life to sustain aquatic species" (NASA, 1985).

During the summer 1985, sediment sampling was performed throughout the western pond by the State of Ohio Environmental Officer and Army Trained Environmental Specialists. Sediment samples were obtained from 34 locations within the western pond and composite samples were analyzed for TNT and DNT concentrations. Selected composite samples were also analyzed for metal concentrations. The results of this study indicated that low levels of TNT and DNT were present within the western pond sediments (Ohio Army National Guard, 1985).

Pipe Creek was tested for water quality in both December 1986 and January 1987. Surface water samples were obtained both upstream, downstream, and adjacent to the West Area Red Water Ponds. Based on the results of these studies it was concluded that "comparisons between samples and between studies show very little difference in any of the samples, and the concentration of elements seemed in no way related to the distance up or downstream of the West Area Red Water Ponds" and "aquatic and terrestrial life thrive in and around Pipe Creek just as they do at the West Area Red Water Ponds" (Ohio Army National Guard, 1985).

3.3.4 Environmental Investigations

IT investigated the West Area Red Water Ponds area during their 1989 Contamination Evaluation. In their report (IT, 1991), IT refers to this area as "Waste Disposal Area #2, and stated that areas of surface contamination were evident.

Monitoring well IT-MW2 was installed at the northwestern corner of the former eastern pond to a total depth of 18.3 feet. Groundwater in this well was measured at approximately 11 feet below the top of riser. IT also installed five soil borings and collected soil samples (SB-07 and SB-09 through SB-12). SB-07 was installed south of the western pond and SB-09 through SB-12 were installed in the former eastern pond area. Soil samples collected from a depth of 0 to 2 feet were submitted for laboratory analysis.

Groundwater and soil samples collected by IT were analyzed for VOCs, SVOCs, nitrates, metals, and nitroaromatic explosive compounds. IT reported that significant concentrations of 1,3,5-TNB, 1,3-DNB, 2,4,6-TNT, and 2,4-DNT were detected in soil samples from the West Area Red Water Ponds area. Although no nitroaromatic compounds were reported in the groundwater sample collected from monitoring well IT-MW2, 2,4-DNT and 2,6-DNT were detected as SVOCs at concentrations of 16 micrograms per liter (*u*g/L) and 27 *u*g/L, respectively.

MK Ferguson's investigation of the immediate West Area Red Water Ponds area during their Site Investigation included the installation of three monitoring wells (MK-MW9, MK-MW10, and MK-MW11) at locations north of the West Area Red Water Ponds. The wells were installed to sample groundwater which may have been influenced by the West Area Red Water Ponds. Surface water and sediment samples were also collected from Pipe Creek. Red water was noted seeping out of the northern bank of Pipe Creek during the sampling (summer 1993). Surface water and sediment samples (SW03 and SD03, respectively) were collected immediately below the seeps. No VOCs, SVOCs, pesticides/polychlorinated biphenyls, or nitroaromatic compounds were detected in the groundwater, surface water, and sediment samples.

3.3.5 Current Use

The West Area Red Water Ponds are located in the western portion of the PBS. NASA has no significant facilities in this part of the site although some of the existing structures in the general vicinity are used for storage. The area on the north side of the ponds is mowed by NASA on a regular basis. Otherwise the surrounding area is wooded.

3.4 TNT AREAS

3.4.1 Locations and Descriptions of the PBOW TNT Manufacturing Areas

The PBOW included three manufacturing areas designated TNT Areas A, B, and C. These areas are also identified in some historical documents as Areas 1, 2, and 3, respectively. Each manufacturing area consisted of widely scattered buildings of wood frame construction and asbestos and sheet metal covering. The locations of the three TNT manufacturing areas are illustrated on the aerial photograph reproduced as Figure 3-9. Site plans of TNT Areas A, B, and C are provided as Figures 3-10, 3-11, and 3-12, respectively.

TNT Area A, comprising approximately 114 acres, is located in the northeast portion of the site between Fox and Taylor Roads. The portion of Columbus Avenue which bisects what was TNT Area A was constructed by NASA and was not present when the PBOW was in operation. TNT Area B is located immediately north of West Scheid Road in the south central part of the site and consists of approximately 55 acres. TNT Area C, which comprises approximately 119 acres, is located on the western side of the site between Campbell Street and Ransom Road.

Twelve process lines were constructed at the PBOW, four in TNT Area A, three in TNT Area B, and five in TNT Area C. Each process line consisted of a Mono House in which the first toluene nitration was performed, a Bi-Tri-House in which the second and third nitrations were performed, a Fortifier House for acid recovery and fortification, and a Wash House which was used to wash the finished TNT. Process waste water from all process lines for each TNT area was directed to a common waste water disposal facility which generally consisted of a set of three settling tanks and a pump house. Additional structures in each area included Acid and Fume Recovery Buildings, Change Houses, Maintenance Buildings, Laboratories, and Nailing Houses. TNT Areas A and B each included a DNT Sweating and Graining House. Raw materials and intermediate products were moved between the various buildings by a series of overhead pipes and flumes. Process waste water was removed by a series of buried and/or overhead wooden flumes and pipes.

2000 1000 0 2000 4000 Feet

APPROXIMATE SCALE

BASE PHOTOGRAPH: October 19, 1950; Photo PW-3G-62; Site - Plum Brook Ordnance Works, Sandusky, Ohio

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Figure 3-9

LOCATIONS OF TNT AREAS

Plum Brook Ordnance Works
Sandusky, Ohio

DAMES & MOORE

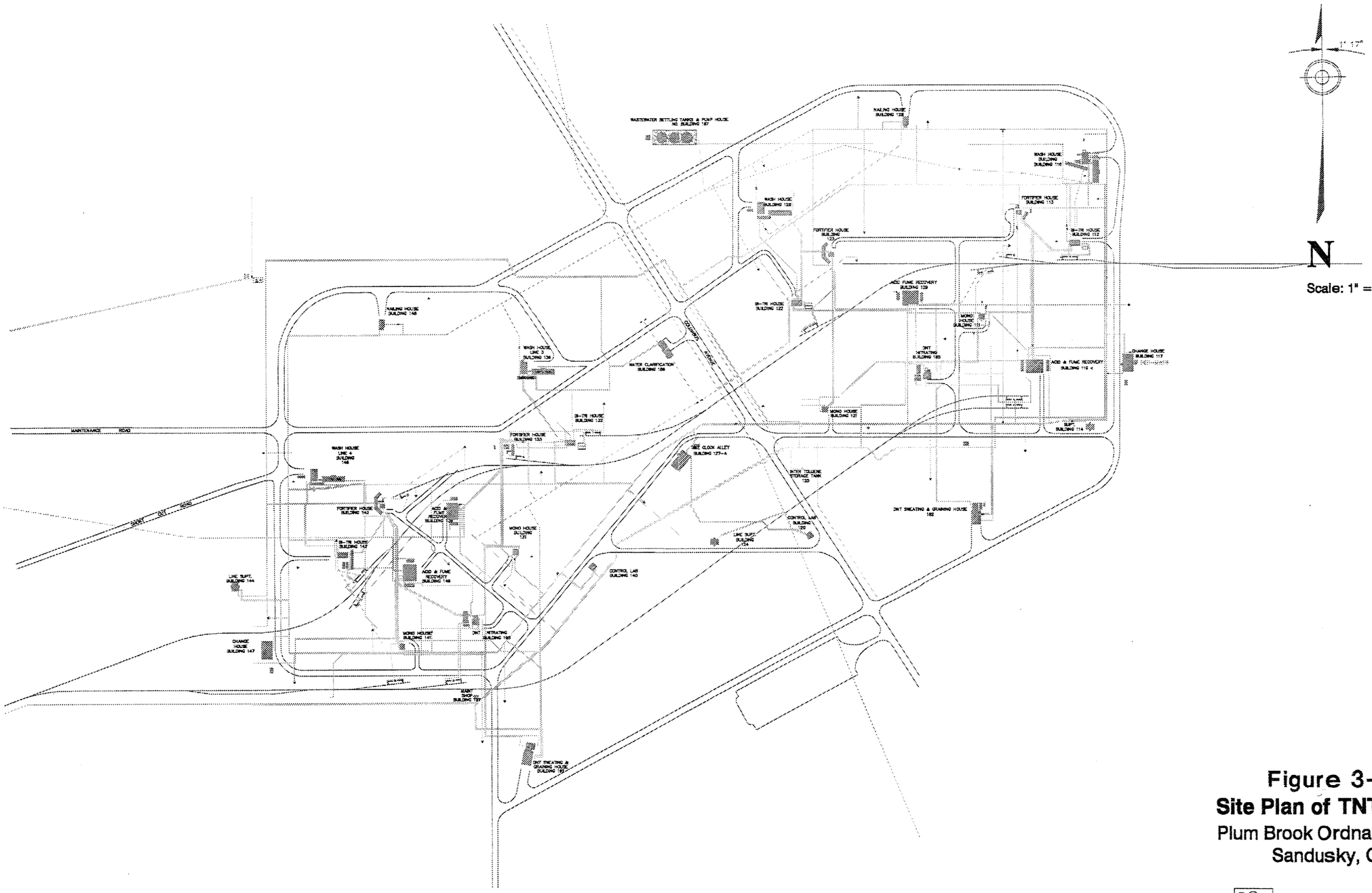

Figure 3-10
Site Plan of TNT Area A
Plum Brook Ordnance Works
Sandusky, Ohio

DAMES & MOORE
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Government Services Division; Atlanta, Georgia
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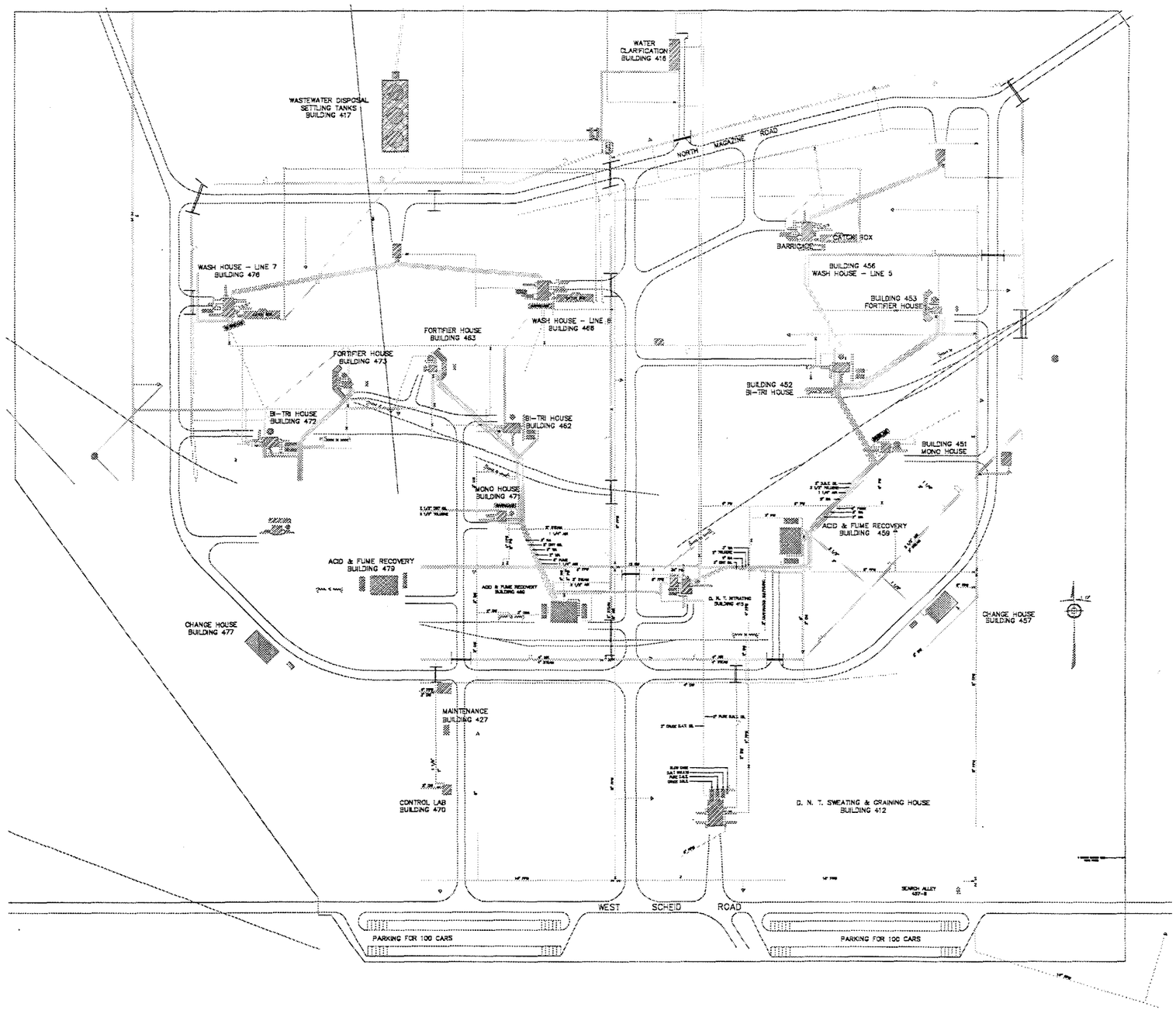

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Scale: 1" = 250'

Figure 3–11
Site Plan of TNT Area B
Plum Brook Ordnance Works
Sandusky, Ohio

DAMES & MOORE
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Government Services Division; Atlanta, Georgia
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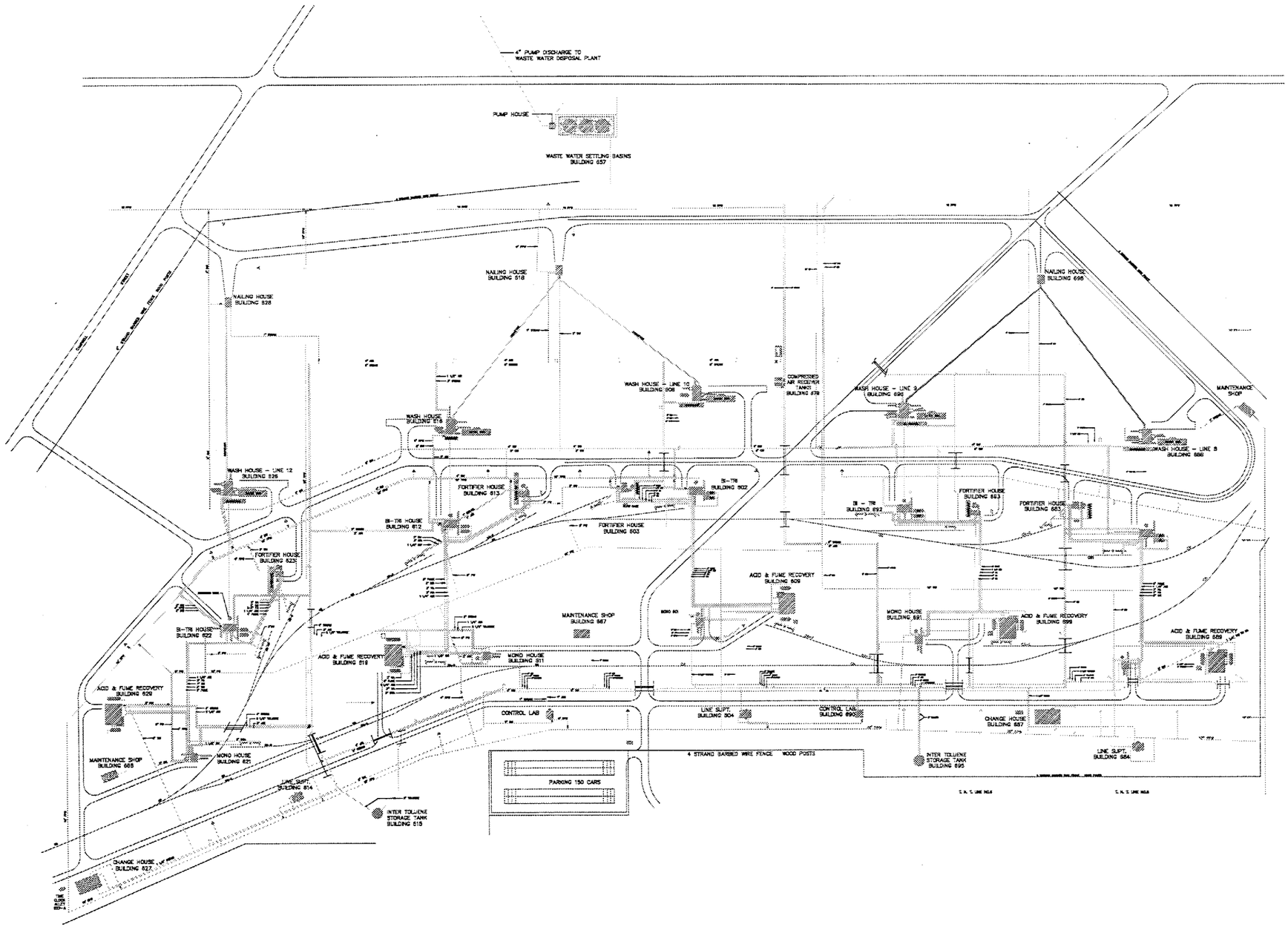

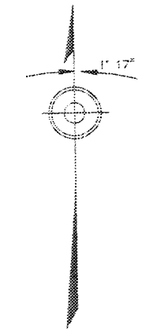

Scale: 1" = 300'

Figure 3-12
Site Plan of TNT Area C
Plum Brook Ordnance Works
Sandusky, Ohio

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Government Services Division; Atlanta, Georgia
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3.4.2 Previous Decontamination of TNT Areas

A 1955 letter (Sanders to Commanding Officer, Ravenna Arsenal) indicates that the TNT areas were significantly contaminated at the surface and in the subsurface due to the TNT manufacturing process.

Significant decontamination was performed at TNT Area A in the summer of 1955. Sanders' 1955 letter documents this work.

> The ground around four wash houses in Area A -- Buildings 116, 126, 136, and 146 --, the ground around the Bi-Tri Houses -- Buildings 112, 122, 132, and 142 --, the Fortifier Buildings 113, 123, 133, and 143, sweating and graining building 182 and 192, DNT nitrating building 185 and 195, and nail houses 128 and 148 was taken up to a depth necessary to obtain samples of earth that showed no contamination according to the rapid method procedure as outline in Appendix 1 of our PIM RVA-1164 . . . Contaminated waste disposal sewers showing from 1 inch to 2 1/2 inch thickness or more deposit of TNT were removed as follows: Approximately 700 feet of 4 inch wooden waste disposal sewer, 600 feet of 6 inch wooden waste disposal sewer, 400 feet of 5 inch wooden waste disposal sewer and various random lengths of ceramic sewers were carefully dug up and removed to the Burning Ground where they were disposed of by burning. Many of the waste disposal sewers were not shown on the drawings but were discovered in the course of digging for known sewers. It appears in many instances that a disposal line was used for a while until it became plugged for one reason or another, after which it was abandoned and a new line laid in close proximity.
>
> In addition and beyond Area A approximately 1,050 feet of a wooden waste disposal sewer going due west from settling basin No. 187, pump house, was removed. The 6 inch wooden sewer disposal line outside of Area A lying in the direction of west southwest from pump house and extending several thousand feet remains intact.
>
> Catch basins at No. 187 were decontaminated to the extent of removing all wood and scrap lumber that was in the concrete basin. Approximately 6,000 pounds of TNT found on the concrete surface underneath the wood was removed to the Burning Ground and destroyed by burning.
>
> All in all, better than 16,000 pounds of TNT was removed from Area A.

According to Sanders' letter, the decontamination efforts at TNT Area A were the first portion of the work originally planned for the PBOW. The decontamination procedures utilized at TNT Area A were to have been implemented at TNT Areas B and C as well.

However, the Sanders letter states that the decontamination process was substantially modified in August 1955. Additional decontamination was to be limited to "surface contamination reasonably possible to detect by visual inspection." Underground flumes were to be left "as is."

The letter indicates that an exception was requested to this policy with regard to the "catch basins similar to No. 187" at TNT Areas B and C, "which, based on the one in Area A, obviously contained considerable quantities of TNT." The letter indicates that a plan for decontaminating these two catch basins at TNT Areas B and C was submitted but there is no documentation that the decontamination was authorized and implemented.

A letter from Alan D. Johnson, Director, Plum Brook Station, NASA, to Thrift G. Hanks of Aerojet-General Corporation, dated October 24, 1966 describes additional decontamination activities at the PBOW. This effort included the TNT Areas. Johnson's letter states that work was accomplished in five steps:

(1) The first phase of the decontamination consisted of inspecting the surface area above the drain tiles, flumes, etc. for contamination. Surface contamination was then removed.

(2) The second phase involved digging into the earth at intervals to spot check the tiles, flumes, etc. for contamination. Where contamination was found, tiles, flumes, etc., were removed in sections.

(3) Equipment which had been previously decontaminated and placed into three X (XXX) condition was removed and placed into storage or further decontaminated and placed in five X (XXXXX) condition for sale to outside users.

(4) Complete destruction of all building by fire followed. Removal of debris, concrete foundations, flashing of same, and flashing of complete earth area were then accomplished. Upon completion of the above, the entire area was rough graded.

(5) The fifth and final phase consisted of decontamination of sump basins and removal of concrete.

The letter does not specify the date this work was accomplished, but does indicate by inference that the work was performed in order that title to the property could be transferred to NASA. Such transfer was accomplished in 1963.

The available information on previous decontamination of the TNT areas indicates that significant subsurface decontamination has been performed at TNT Area A; decontamination at TNT Areas B and C has probably not been as thorough. The methods of decontamination utilized, including rough grading of the areas, has likely altered the original locations of contamination remaining in all three TNT areas. Significant subsurface contamination associated with underground sewer and flume lines is probably still present in all three TNT areas and in other portions of the site that were connected to the TNT areas by the underground flume and sewer lines. As indicated in Sanders' 1955 letter, underground lines were replaced during operation of the PBOW when they plugged and the locations of replacement lines were generally not documented.

3.4.3 Current Uses of Former TNT Manufacturing Areas

NASA constructed its administration building on the east side of Columbus Avenue in the central portion of former TNT Area A. As noted previously, significant previous remediation activities have been performed in TNT Area A. Very little above ground evidence of the former PBOW structures and features, other than abandoned railroad tracts and ditches, remains in the area once occupied by TNT Area A.

NASA's HTF test building was constructed on the outside northwest corner of what was TNT Area B. Some modifications to the northwestern portion of TNT Area B were made during the construction activities. However, significant above ground evidence of the PBOW facility remains in the form of roads, structural foundations, and remnants of utilities.

TNT Area C is located in the western portion of the PBS. NASA has no significant facilities in this part of the site although some of the existing structures in the general vicinity are used for storage. Most of TNT Area C is overgrown with trees and brush

which obscure evidence of the PBOW structures and features. However, the location of the waste water settling basins, many roads, and most ditches can be discerned in TNT Area C.

3.4.4 Previous Environmental Investigations

The 1993 MK Ferguson investigation was the only environmental assessment at the PBS to include the TNT areas. MK Ferguson collected a limited number of samples of surface water, sediment, groundwater, and surface soils.

3.4.4.1 TNT Area A

MK Ferguson installed and sampled three monitoring wells in the vicinity of TNT Area . No explosives residues were detected in 1993 in the groundwater at TNT Area A.

One surface water and one sediment sample were collected east of TNT Area A in Lindsley Ditch. No explosives residues were detected in these samples.

One soil sample was collected in the southwestern corner of TNT Area A. No explosives residues were detected.

3.4.4.2 TNT Area B

One sediment and one surface water sample were collected near the beginning of Ransom Brook north of TNT Area B. No explosives residues were detected in these samples.

MK Ferguson installed and sampled two monitoring wells near TNT Area B. One well was installed on the south side of TNT Area B in an area assumed to be upgradient with respect to the direction of groundwater flow. The other well was installed north

of North Magazine Road on the downgradient side of TNT Area B near the waste water settling basins. No explosives residues were detected in the samples from these wells.

Two shallow soil samples were collected at TNT Area B. Toluene was detected in one sample at a concentration of 0.033 milligrams per kilogram (mg/Kg). The other soil sample was collected from the upper 2 feet of soil from the boring drilled for well MK-MW17 which was installed near the waste water settling basins. 2,4,6-TNT was detected at a concentration of 12 mg/Kg and 2,6-DNT was detected at a concentration of 0.06 mg/Kg.

3.4.4.3 TNT Area C

One surface water and one sediment sample were collected just downstream of the confluence of Pipe Creek and a small stream which traverses TNT Area C. No explosives residues were detected.

MK Ferguson did not install groundwater monitoring wells in the vicinity of TNT Area C.

Two surface soil samples were collected in the southeast corner of TNT Area C. One of the samples was collected in a location identified as "near a flume." Toluene was reported in both surface soil samples at concentrations above the Method Detection Limit, but below the Quantitation Limit. No explosives residues were reported.

4.0 INVESTIGATION PROCEDURES

The field procedures for the Sitewide Groundwater Investigation were performed in accordance with the Final Work Plan (Dames & Moore, 1994) and are summarized in this section of the Sitewide Groundwater Investigation Report.

Sampling activities were conducted between October 12 and December 17, 1994. CEORN representatives, including Captain Mike Riebel, Mr. Doug Webb, Mr. Tom Lerner, and Mr. Bob Hoyle, observed portions of the field investigation activities. Copies of the A/E Daily Quality Control Reports prepared for each field day were provided to CEORN during the course of the field work.

Environmental samples were analyzed by Analytical Services, Inc. (ASI) of Atlanta, Georgia. Quality Assurance samples were submitted to the USACE Ohio River Division (ORD) laboratory.

4.1 COORDINATION OF SITE ACCESS AND UTILITY CLEARANCE

Dames & Moore coordinated site access and utility clearance for field work activities with appropriate NASA personnel. A NASA "Digging and Excavation Permit" was prepared to identify proposed subsurface sampling locations to NASA for clearance at the beginning of the field work. A copy of the permit is provided in Appendix A. NASA personnel checked and cleared all sampling locations prior to initiation of subsurface activities. Sampling locations were adjusted as necessary to avoid underground utilities.

NASA personnel cleared brush and vegetation from overgrown areas of the site providing access for field sampling personnel and equipment. NASA also provided storage and staging facilities, decontamination areas, and a storage facility for investigation-derived waste.

Dames & Moore and NASA coordinated the schedule for performing field activities to avoid conflicts among site uses and identify access limitations to specific areas during certain portions of the field work.

4.2 HEALTH AND SAFETY PROGRAM

The Final Site-Specific Safety and Health Plan (Dames & Moore, 1994) prepared for this project was followed during the field investigation of the PBOW. An initial site safety briefing/kick-off meeting was held prior to the initiation of field work including all Dames & Moore field personnel; field personnel from the subcontracted drilling company, Belasco Drilling Company; and the on-site CEORN representatives. The briefing addressed pertinent sections of the site Health and Safety Plan, including the potential constituents of concern and their recognition, field procedures, emergency procedures, and the type of monitoring and personal protective equipment (PPE) to be used during the field work. CEORN personnel provided a review of the types of ordnance and ordnance-related items which could be encountered on the PBOW and the safety considerations related to the same. The participants also discussed how to recognize potential contamination and the actions to be followed in the event that contamination was suspected or encountered. An additional site safety briefing for all field team members was held each morning to address specific health and safety concerns and to review health and safety protocol.

No significant health and safety issues arose during the field activities. Level D PPE, including latex gloves, nitrile gloves, safety glasses, and work boots and clothes were utilized. A photoionization detector, HNu, was calibrated and zeroed to background each day and used during the soil sampling activities; readings against background were noted on the boring logs. The buddy system, whereby two personnel worked together at all times, was adhered to during all phases of the field work.

4.3 GROUNDWATER MONITORING WELL INSTALLATION AND SAMPLING PROCEDURES

Groundwater monitoring wells were installed in accordance with procedures outlined in the Final Monitoring Well Installation Plan (Dames & Moore, 1994) and in the USACE guidance document EM 1110-7-XX(FR) (Draft). Groundwater sampling procedures described in the Final Sampling and Analysis Plan (Dames & Moore, 1994) were followed during the sample collection.

Eleven shallow groundwater monitoring wells were installed in the unconsolidated overburden materials, two at TNT Area A, four at TNT Area C, two at the West Area Red Water Ponds, and three at the Pentolite Road Red Water Ponds. The purpose of the shallow wells was to evaluate groundwater flow and groundwater quality in the uppermost water-bearing unit. The shallow wells were constructed so that the screened interval intersected the water table.

Eight deep groundwater monitoring wells were installed in the bedrock, two at TNT Area A, one at TNT Area C, two at the West Area Red Water Ponds, one at the Pentolite Road Red Water Ponds, one at the central toluene tanks area, and one at a background location in the southern portion of the site. The purpose of the bedrock wells was to evaluate whether nitroaromatics had migrated from the site soils into the local bedrock aquifer and to establish baseline information on groundwater flow and groundwater quality in the bedrock aquifer.

The monitoring wells were installed under the technical observation of experienced Dames & Moore geologists. The Dames & Moore geologists coordinated the drilling operations, maintained a detailed boring log of each monitoring well, collected samples of subsurface materials and classified them in accordance with geologic classification systems, developed well construction diagrams, and maintained a field log of events and procedures. Drilling for the monitoring wells was performed by Belasco Drilling Company, a drilling company experienced in the construction of monitoring wells in north central Ohio.

4.3.1 Monitoring Well Installation in the Overburden

A D-50 diesel or a CME-45 all terrain vehicle (ATV) truck mounted rotary drill rig equipped with 4-1/4 inch inside diameter (ID) hollow-stem augers was used to drill boreholes for wells to be completed in the overburden stratigraphic unit. The boring for each overburden well was advanced from ground surface using hollow stem augering techniques and was extended to the top of rock as defined by auger refusal. Soil samples were collected continuously using a 2-inch outside diameter (OD) stainless steel split spoon sampler attached to drill rods. The drill rods were attached to a 140-pound free fall hammer used to drive the split spoon sampler into the undisturbed soil in advance of the hollow stem augers.

Samples collected in the split spoon sampler were used to document and classify the soils. Soil samples were also scanned with an HNu for the presence of contamination. The boring logs prepared during the drilling are included in Appendix B.

After reaching terminating depth in each boring, a groundwater monitoring well was constructed in each borehole. The monitoring wells were constructed of 2-inch ID flush joint, threaded, schedule 40 polyvinyl chloride (PVC) riser pipe and No. 10 (0.010-inch) slot size PVC well screen.

A bottom cap was placed on the end of the screen which was then placed directly on the bottom of the borehole, with 2-inch riser pipe extending from the top of the screen to the ground surface. The annular space between the well screen and the inside wall of the boring was filled with a 20/30 silica sand pack, a material in which the grain size is such that the majority of the material should be retained on No. 20 and No. 30 slot sieves. The sand pack was extended above the top of the screen. A bentonite seal was placed above the sand pack to inhibit fluid movement vertically along the casing and to prevent grout migration into the sand pack from above. The remaining annular space from the top of the bentonite seal to near the ground surface was grouted with a cement grout.

The well was then completed above grade with a stand-up lockable protective steel casing cemented in the center of a concrete pad. Concrete-filled posts were installed

at each corner of the concrete pad. The posts were painted orange for easy visibility. A plate which listed the well identification and other well specific information was adhered to the top of the lockable protective steel casing.

Monitoring well construction details are provided in Table 4-1, Overburden Monitoring Well Details. Well construction diagrams are included in Appendix C.

Construction of each of the wells was discussed with the on-site CEORN representative during the field activities.

Soil samples from the screened interval in each well were collected for grain size analysis. Additionally, one sample of each type of filter pack material used in the construction of the monitoring wells was collected for grain size analysis. The samples were analyzed by Dames & Moore's geotechnical laboratory located in Salt Lake City, Utah, in accordance with American Society for Testing and Materials Test Procedure D422, "Particle Size Distribution in Soils." The laboratory reports and interpretation of the grain size analyses are included in Appendix D.

Overburden groundwater monitoring well DM-MW12 was to be installed in TNT Area B. During drilling, bedrock was encountered at a depth of approximately 5.5 feet. In accordance with the provisions of the project Statement of Work, a casing was installed in the borehole. This temporary well installation was dry from the time it was installed until the groundwater sampling was completed. The borehole was grouted to the surface at the conclusion of the field work.

All waste soil from the well boreholes was placed in 55-gallon drums.

4.4.2 Monitoring Well Installation in the Bedrock

A Diedrich D-120 truck-mounted rotary drill rig, NX and NQ core equipment, and a 6-inch roller cone were used for the bedrock well installation. The bedrock monitoring wells were advanced through the overburden to the top of rock using 12-inch inside diameter hollow stem augers, while continuously sampling with a split spoon sampler.

TABLE 4-1

OVERBURDEN MONITORING WELL DETAILS

Well Identification	Ground Surface Elevation (feet MSL)	TOC Elevation (feet MSL)	Total Depth of Well (feet BGS)	Screened Interval (feet BGS)	Top of Sand Pack (feet BGS)	Top of Bentonite Seal (feet BGS)
PB-WA-MW1	642.32	644.43	22.3	4.3 - 22.3	3.7	2.0
PB-WA-MW2	631.16	633.65	12.0	3.0 - 12.0	2.5	2.0
PB-TNTC-MW3	642.57	645.41	14.0	5.0 - 14.0	3.2	1.7
PB-TNTC-MW4	651.89	654.43	18.8	8.8 - 18.8	6.0	3.5
PB-TNTC-MW5	649.07	651.81	29.7	4.7 - 29.7	3.7	2.0
PB-TNTC-MW6	656.82	659.40	12.2	3.2 - 12.2	2.5	2.0
PB-PR-MW7	631.50	633.99	22.3	4.3 - 22.3	3.0	1.8
PB-PR-MW8	632.50	635.02	27.5	5.0 - 27.5	4.0	3.0
PB-PR-MW9	630.70	633.70	19.0	4.0 - 19.0	3.0	2.0
PB-TNTA-MW10	637.50	640.18	11.0	3.0 - 11.0	2.5	2.0
PB-TNTA-MW11	637.86	640.50	11.4	3.4 - 11.4	2.5	2.0

MSL - Mean Sea Level
BGS - Below Ground Surface
TOC - Top of Casing

After encountering the top of rock, the boring was advanced until competent rock was encountered using a 10-inch diameter roller cone bit. The boring logs prepared during the drilling are included in Appendix B.

In order to ensure the integrity of the bedrock well, at least 20 feet of 4-inch diameter PVC casing was installed in each bedrock well to seal off the unconsolidated overburden materials and incompetent bedrock near the bedrock surface. Once the borehole had been cleaned of loose material, a 4-inch PVC riser casing was installed into the borehole and grouted in place. The casing was grouted to the surface.

The grout was allowed to cure for a minimum of 48 hours before continuing coring operations on the well. When the grout had cured, NQ coring equipment was placed through the 4-inch surface casing and a 3-inch diameter open hole was cored until the first water bearing zone was reached. Bedrock monitoring well construction details are presented on Table 4-2. Well construction diagrams are included in Appendix C.

The rock cores were stored in covered core boxes and labeled. The core within each complete box was photographed.

4.4.3 Monitoring Well Development

Following construction, the monitoring wells were developed by hand bailing water until the well water met the conditions set forth in the USACE guidance document EM 1110-7-XX(FR)(draft). Difficulty was encountered in achieving well water clarity in several of the wells after all other well development criteria were met. After concurrence with the on-site CEORN representative on when to stop well development, it was decided that, if after additional bailing was performed and no improvement in water quality was recognized, development could be terminated. After development was terminated, a water sample was collected from each well and photographed. A well development record was completed for each monitoring well. Copies of the well development records and photographs of the water collected from the wells after development are included in Appendix E.

TABLE 4-2

BEDROCK MONITORING WELL DETAILS

Well Identification	Ground Surface Elevation (feet MSL)	TOC Elevation (feet MSL)	Depth to Top of Rock (BGS feet)	Top of Rock Elevation (feet MSL)	Depth to Bottom 4" Casing (BGS)	Length of Open Rock Hole (feet)	Total Depth of Well (BGS feet)
PB-BED-MW13	645.81	648.27	40.7	605.1	46.0	29.5	75.5
PB-BED-MW14	643.05	646.04	24.5	618.6	29.0	23.2	52.2
PB-BED-MW15	629.08	631.64	24.3	604.8	31.5	42.9	74.4
PB-BED-MW16	633.68	636.02	44.2	589.5	49.2	24.8	74.0
PB-BED-MW17	627.34	629.97	37.3	590.0	45.0	19.4	64.4
PB-BED-MW18	648.83	651.50	30.8	618.0	51.0	24.4	75.4
PB-BED-MW19	640.51	643.07	19.1	621.4	32.0	17.5	49.5
PB-BED-MW20	673.57	676.33	21.5	652.1	35.0	14.5	49.5

MSL = Mean Sea Level
TOC = Top of Casing
BTOC = Below Top of Casing
BGS = Below Ground Surface

Development water from each well was placed in 55-gallon drums which were moved to the drum storage area on Pentolite Road for later disposal.

4.3.4 Survey of Well Locations

Coordinates and elevations were established for each of the monitoring wells installed by Dames & Moore in accordance with EM 1110-7-XX(FR)(draft). The top of casing and ground surface elevations are included in Tables 4-1 and 4-2. The locations of wells installed by MK Ferguson and IT during previous investigations and used in this investigation were surveyed. The top of casing and ground surface elevations for the MK Ferguson and IT wells are listed in Table 4-3. Also, the locations of the four NASA wells in the Reactor Area were surveyed. The top of casing and ground surface elevations for the four NASA Reactor wells are listed in Table 4-4. A tabulated list of the sample location coordinates and elevations is included in Appendix F.

4.3.5 Monitoring Well Sampling

Groundwater samples were collected approximately 2 weeks after the development was completed to allow the groundwater to chemically stabilize from impacts caused by drilling and construction of the monitoring wells. The procedures outlined in the Final Sampling and Analysis Plan (Dames & Moore, 1994) were followed during the sampling of the monitoring wells.

Prior to sampling, the volume of water in each monitoring well was calculated utilizing water level measurements and well construction information. The monitoring wells were then purged of five volumes of water contained in the casing, screen and filter pack (or until dry) using a new dedicated bailer for each well. After purging, groundwater samples were collected from the approximate upper 5 feet in each well using each well's dedicated bailer.

Specific conductance, pH, and temperature were recorded in the field at the time of sampling. Groundwater sampling records are provided in Appendix G.

TABLE 4-3

MK FERGUSON AND IT WELL ELEVATIONS

Well Identification	Ground Surface Elevation (feet MSL)	TOC Elevation (feet MSL)
MK-MW10	638.06	640.89
MK-MW11	634.71	637.69
MK-MW16	671.33	674.32
MK-MW17	660.97	664.64
MK-MW22	635.56	638.05
MK-MW23	636.95	639.47
MK-MW24	654.44	657.12
IT-MW2	636.69	639.60*
IT-MW5	631.91	634.99

MSL - Mean Sea Level
TOC - Top of Casing

Wells MK-MW10, MK-MW11, MK-MW16, MK-MW17, MK-MW22, MK-MW23, and MK-MW24 were installed for the MK Ferguson Site Inspection performed in 1993.

Wells IT-MW2 and IT-MW5 were installed for the 1989 IT investigation.

* Measuring Point Elevation is 639.63. This elevation is used in Table 6-2.

TABLE 4-4

NASA REACTOR WELL ELEVATIONS

Well Identification	Ground Surface Elevation (feet MSL)	TOC Elevation (feet MSL)
Reactor Well 1	630.21	630.12
Reactor Well 2	630.72	630.68
Reactor Well 3	630.73	630.88
Reactor Well 4	630.76	631.15

MSL - Mean sea level

TOC - Top of Steel Casing

In association with the groundwater sampling, Dames & Moore sampled the oily substance present as a separate phase in bedrock well BED-MW16. The thickness of the oil layer and depth to water were measured using an oil/water interface probe. Once the amount of and depth to the oil was established, a Kemmerer sampler was used to sample the oil layer because traditional bailers experience difficulty with thick viscous materials. The Kemmerer sampler is similar to a traditional bailer except that it is open on both end which allows the thicker, oilier liquids to enter the chamber. The Kemmerer sampler was lowered to the measured depth of the oil layer, the weight on the sampler was released closing the sample chamber, and the sampler was removed from the well. At the surface, the chamber was opened and the oil was placed in sample containers.

4.4 SAMPLE PACKAGING, SHIPPING, AND DOCUMENTATION OF CUSTODY

Sample packaging, shipping and documentation procedures described in the Final Sampling and Analysis Plan (Dames & Moore, 1994) were followed during the field investigation. Samples were packaged and shipped to the analytical laboratories via Federal Express.

4.5 EQUIPMENT DECONTAMINATION

Equipment decontamination procedures described in the Final Sampling and Analysis Plan (Dames & Moore, 1994) and Final Monitoring Well Installation Plan (Dames & Moore, 1994) were followed during the field investigation.

All drilling and sampling equipment used to install the groundwater monitoring wells was steam cleaned prior to drilling; between each well; and at the conclusion of the field work prior to taking the equipment from the PBOW. During drilling of each well, sampling equipment was decontaminated in accordance with procedures outlined in the Final Sampling and Analysis Plan (Dames & Moore, 1994).

Two main decontamination areas were established, one for cleaning sampling equipment and one for cleaning drilling equipment. The sampling equipment was decontaminated in NASA's Red Barn, a facility made available for field work support during the investigation. The drill rig decontamination area was set up near the parking lot at the Maintenance Building. Care was taken during decontamination to avoid contaminating the surrounding area. Upon completion of the field activities, the decontamination materials were removed and placed in 55-gallon drums for later disposal.

4.6 HANDLING OF INVESTIGATION-DERIVED WASTES

Investigation-derived wastes were managed and handled in accordance with procedures described in the Final Sampling and Analysis Plan (Dames & Moore, 1994) and Final Monitoring Well Installation Plan (Dames & Moore, 1994).

Soil cuttings and decontamination waste water were placed in separate 55-gallon drums which were labeled and stored on-site north of Pentolite Road, east of the intersection of Ransom Road and Pentolite Road.

4.7 ANALYTICAL LABORATORY ANALYSIS AND DATA EVALUATION

As a preface to the presentation of the results of the investigation, it is useful to describe the laboratory analytical methods and data evaluation, and discuss the limitations of the data presented herein. These are discussed in the following sections.

4.7.1 Laboratory Analysis

Groundwater samples and their associated equipment blank samples were analyzed for explosives residues concentrations using EPA Method 8330, for total and dissolved concentrations of 14 metals (13 priority pollutant metals plus manganese) using methods outlined in the Final Sampling and Analysis Plan (Dames & Moore, 1994), and

for nitrates using EPA Method 353.2. Additionally, groundwater samples from the bedrock wells were analyzed for VOCs and SVOCs.

ASI, Dames & Moore's subcontracted analytical laboratory provided laboratory Quality Control (QC) documentation with the sample results. This documentation included the results of matrix spike and matrix spike duplicates analyses; the results of method blanks and laboratory control standards analyses; analyses of surrogates, calculations of percent recovery and precision of the above (as applicable); and inclusion of the extraction and analysis dates. A brief case narrative was included with each sample set to document methods used and any QC problems encountered.

4.7.2 Evaluation of Laboratory Data

4.7.2.1 Data Quality Assessment

Dames & Moore evaluated approximately 10 percent of the data collected during the field work. A combined data quality assessment was completed for samples collected for the Site Investigation of the TNT areas, the Focused Remedial Investigation of the Red Water Ponds areas, and the Sitewide Groundwater Investigation. Data sets which included samples from all media and all areas of the site were included in the review. The Data Quality Assessment was performed in accordance with guidance provided in the "USEPA Contract Laboratory Program National Functional Guidelines for Organic Data Review" (EPA, 1993) and the "USEPA Contract Laboratory Program National Functional Guidelines for Inorganic Data Review (EPA, 1994). The Data Quality Assessment is provided as Appendix H. The qualifiers applied to the data are listed on the laboratory reports provided in Appendix I, as described in the referenced report, should be acknowledged whenever reviewing the data or assessing the qualitative or quantitative reliability of the data.

4.7.2.2 Establishment of Practical Quantitation Limits for Groundwater Analysis

Groundwater samples for this project were analyzed using a Cold Regions Research and Engineering Laboratories (CRREL) modification of EPA Method 8330. The modified method was used to try to obtain the lowest possible detection limits for groundwater samples. Extremely low detection limits are necessary in some of the risk calculations which may eventually be performed for the site. Dames & Moore and ASI, in coordination with CEORN, established a Practical Quantitation Limit (PQL) of 5 micrograms per liter (μg/L) for use in interpreting the results for groundwater samples. The rationale for use of a PQL was prepared by ASI and is presented in Appendix I with the laboratory reports. Only sample results above the PQL are interpreted in this Sitewide Groundwater Investigation Report. However, the laboratory reports included in Appendix I list all results, including those below the PQL and above the method detection limit (MDL) which is referred to as Below Detection Limit (BDL) on the laboratory reports.

4.7.3 Groundwater Data Limitations

Several limitations were identified with respect to the laboratory data generated during this investigation. These limitations are discussed in the following sections.

4.7.3.1 Explosives

Dames & Moore collected a sample of the potable water from PBS at the conclusion of the field work on December 15, 1994. Water from this source was utilized during drilling of the bedrock wells during rock coring. Duplicate samples were submitted to the ORD laboratory and to ASI.

No explosives residues were detected in the sample analyzed by ORD. However, ASI detected 1,3,5-TNB at a concentration of 13 μg/L; 4-Am-2-NT at a concentration of 1.6 μg/L; and 2-Am-DNT at a concentration of 0.4 μg/L. The PBS potable water supply does not originate on site and the presence of explosives residues in the sample

was suspect. Therefore, in order to confirm the results, a second sample was collected on February 13, 1995 and analyzed by ASI. Explosives were again detected. In the February 1995 sample, 1,3,5-TNB was detected at a concentration of 1.1 μg/L and 4-Am-DNT was detected at a concentration of 1.7 μg/L.

A third sample was collected on August 15, 1995. Four replicate samples were collected and analyzed by ASI, a private laboratory contracted by CEORN, the USACE Missouri River Division (MRD) laboratory, and the USACE Waterways Experiment Laboratory. No explosives residues were detected in any of the four replicate samples collected in August 1995. Therefore, it is reasonable to assume that explosives residues are not present in the potable water supply at PBS.

The reason explosives residues were detected by ASI in the first two samples is not known. Most of the concentrations are below the PQL and are considered estimated. However, the concentration of 13 μg/L 1,3,5-TNB in the December 1994 sample is well above the PQL. Personnel from the USACE MRD laboratory who reviewed the laboratory data considered the 1,3,5-TNB concentration a false positive. However, ASI considered that the method requirements for reporting the compound were technically satisfied. Users of the groundwater data are advised to interpret it with caution in the event false positives were detected in one or more of the groundwater samples. For purposes of this report all concentrations reported above the PQL were interpreted.

4.7.3.2 Metals

Groundwater monitoring wells installed for the TNT Areas Site Investigation, Red Water Ponds Focused Remedial Investigation, and Sitewide Groundwater Investigation were all sampled within a few days of each other in December 1994. Three groundwater equipment blanks were collected during the sampling, one from a bedrock monitoring well (BED-MW18) and two from overburden wells (WA-DM-MW2 and TNTA-DM-MW10). This provided an equipment blank-to-sample type ratio of at least 10 percent. Both filtered and unfiltered equipment blanks were submitted for metals analysis.

Two metals were detected in the equipment blanks. Zinc was detected in the unfiltered equipment blanks prepared during sampling of wells BED-MW18 and WA-DM-MW2. The concentrations were 28 μg/L and 37 μg/L, respectively. Zinc was also detected in the equipment blank prepared during collection of background soil samples. This may indicate that some of the zinc detected in the samples is related to the sampling procedures. However, because zinc was not consistently detected in the equipment blanks, all of the zinc detected in the samples cannot be attributed to collection procedures.

Antimony was detected in eight groundwater samples during the PBOW investigation. Seven of the eight times, it was reported in the filtered sample and not in the corresponding unfiltered sample. Antimony was also detected in the filtered drill water sample collected on December 15, 1994 at a concentration of 10 μg/L but not in the corresponding unfiltered sample. Finally, antimony was detected in two of the three equipment blank samples collected during the groundwater sampling. In both samples, it was detected in the filtered sample, but not in the unfiltered sample. The consistent presence of antimony only in filtered samples appears to indicate that it is related to the filtering process. The equipment blanks were prepared with distilled water which should have contained no metals.

5.0 GROUNDWATER FLOW CONDITIONS

Groundwater at the site occurs in two basic hydrostratigraphic units: the overburden and the bedrock. The overburden is composed of glacial outwash materials, and varies in thickness from a few feet to over 40 feet. The bedrock consists of both limestone and shale. The hydrostratigraphic units were previously described in Section 2.0.

Eleven groundwater monitoring wells were installed in the overburden hydrostratigraphic unit for the PBOW investigation, three at the Pentolite Road Red Water Ponds, two at the West Area Red Water Ponds, two at TNT Area A, and four at TNT Area C. Additionally, eight wells installed in the overburden during previous investigations were utilized for this investigation.

A total of eight bedrock wells were installed as part of the Sitewide Groundwater Investigation. A fracture trace analysis was performed to try to delineate optimal locations for installation of wells in the limestone and shale bedrock underlying the site. The results of the fracture trace analysis are presented in Appendix J. Additionally, one of the four bedrock wells at the NASA Reactor Area was sampled.

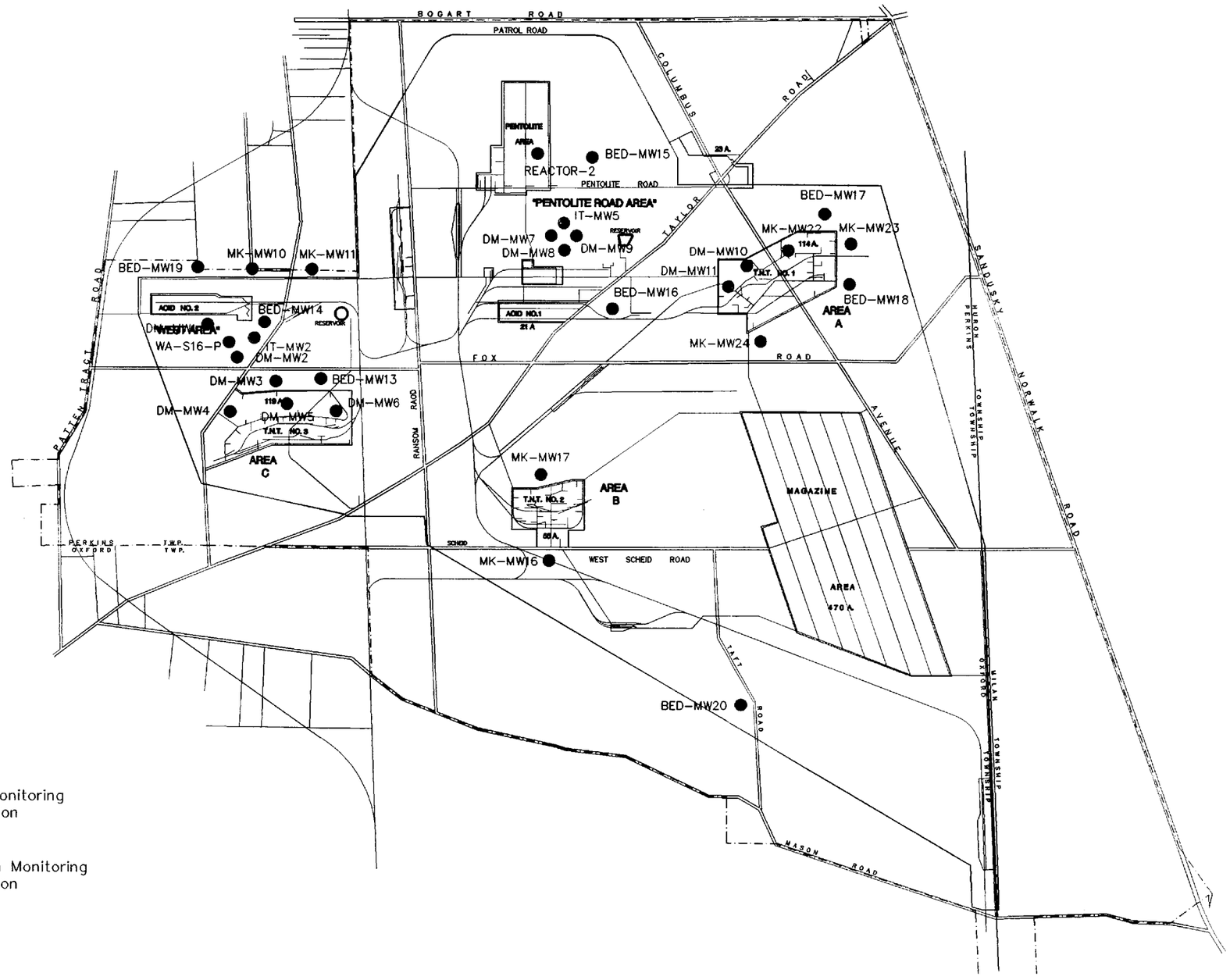
The locations of all of the wells utilized for this investigation are shown on Figure 5-1 and are described below.

At the Pentolite Road Red Water Ponds, three overburden wells were installed for this investigation and one overburden well installed by IT was used.

- Well DM-MW7 was installed in the southwest portion of the former ponds area. It is within the boundary of the westernmost of the two ponds that composed the Pentolite Road Red Water Ponds. The borehole for well DM-MW7 was created by continuing to advance soil boring PR-S4 beyond the 10 foot target depth for the soils investigation.

- Well DM-MW8 was installed in the southern portion of what was the easternmost of the two ponds. Soil boring PR-S14 was converted into well DM-MW8.

- Well DM-MW9 was installed in soil boring PR-S19 which was drilled on the eastern edge of the easternmost pond.



1" = 3000'

BED-MW13 — Bedrock Monitoring Well Location

DM-MW6 — Overburden Monitoring Well Location

FIGURE 5-1
SITEWIDE WELL LOCATION MAP

Plum Brook Ordnance Works
Sandusky, Ohio

Dames & Moore, Inc.

FILENAME: H:\CAD\COE-PLUM\PHASE2\FIG5-1.DWG

...2\FIG5-1 Thu Apr 03 20:50:25 1997 Dames & Moore - Atlanta, GA

- Well IT-MW5 is located on the northeast corner of the former pond area.

Also at the Pentolite Road Red Water Ponds, one bedrock well was installed and one of the four NASA Reactor Area wells was sampled.

- Well BED-MW15 was installed downgradient of the Pentolite Road Red Water Ponds on the north side of Pentolite Road.
- PBS Reactor Well 2 is located downgradient of the Pentolite Road Red Water Ponds, on the north side of Pentolite Road, within the reactor compound.

At the West Area Red Water Ponds two new overburden wells were installed. Additionally, two existing wells, one installed by IT and one installed by MK Ferguson, were used.

- Well DM-MW1 was installed on the northwest side of the west pond at the West Area Red Water Ponds. It is located at the edge of the cleared area surrounding the pond.
- Well DM-MW2 was installed on the south side of the West Area Red Water Ponds. It is located in a relatively flat area at the base of an embankment south of the western pond and just west of the dike that separated the two ponds. Pipe Creek is located immediately south of the well. Two soil samples were collected from boring WA-S10 which was converted into well DM-MW2.
- Well IT-MW2 is located on the northwest corner of the former east pond.
- Well MK-MW11 is located north of the east pond on the north side of Patrol Road. It is one of three overburden wells installed along Patrol Road on the north side of the West Area Red Water Ponds and Acid Area No. 2.

Two other overburden wells installed by MK Ferguson are located along Patrol Road on the north side of the West Area Red Water Ponds. These wells were dry in December 1994 and, thus, were not sampled.

Two bedrock wells were installed downgradient of the West Area Red Water Ponds.

- Well BED-MW14 is located immediately downgradient of the east pond.

- Well BED-MW19 is located on the north side of Patrol Road along the northern property boundary. This well was installed to evaluate whether contamination was moving off site from this portion of the property.

In TNT Area A, two new overburden wells were installed and three wells installed by MK Ferguson were used.

- Well DM-MW10 was installed immediately downgradient of the Wash House for TNT manufacturing line 3.
- Well DM-MW11 was installed downgradient of the Wash House and Fortifier House.
- Well MK-MW22 is located on the southeast corner of the intersection of Columbus Avenue and the unnamed loop road surrounding former TNT Area A. This location is west of manufacturing line 2 and generally upgradient of the waste water settling basins.
- Well MK-MW23 is located on the far east side of TNT Area A outside the unnamed loop road that surrounds TNT Area A. This location is northeast of the Wash House for manufacturing line 1.
- Well MK-MW24 is located on the extreme south side of TNT Area A, south of the unnamed loop road. It is south of the TNT Area A DNT Sweating and Graining Building.

Two bedrock wells were installed in the vicinity of TNT Area A.

- Well BED-MW17 was installed north of the eastern side of TNT Area A, generally downgradient of manufacturing lines 1 and 2.
- Well BED-MW18 was installed on the east side of TNT Area A.

In TNT Area B, two overburden wells which had previously been installed as part of the MK Ferguson investigation were used.

- Well MK-MW16 is located on the south (upgradient) side of TNT Area B in the former PBOW parking area.
- Well MK-MW17 is located on the north side of TNT Area B, east of the Waste Water Disposal Settling Tanks. The well is located at the bottom of an embankment on the north side of North Magazine Road.

One overburden well was to have been installed in TNT Area B for this investigation on the south side of North Magazine Road downgradient from the Wash House for TNT manufacturing line 5. However, bedrock is present within a few feet of the surface in this area precluding installation of an overburden well.

Additionally, one bedrock well was to be installed in TNT Area B. However, the well was not installed during this investigation because of access limitations. Therefore, no bedrock wells are present at TNT Area B.

In TNT Area C, four overburden wells were installed as part of the Site Investigation.

- Well DM-MW3 was installed at the Waste Water Settling Basins for TNT Area C which are located generally on the downgradient of the former manufacturing facilities.
- Well DM-MW4 was installed downgradient of the Wash House for manufacturing line 12.
- Well DM-MW5 was installed downgradient of the Wash House for manufacturing line 10.
- Well DM-MW6 was installed downgradient of the Wash House for manufacturing line 8.

One bedrock well, BED-MW13, was installed in the vicinity of TNT Area C. It is located along Fox Road in an area generally downgradient from manufacturing lines 9 and 10.

The characterization of groundwater flow patterns on a sitewide basis for both the overburden and the bedrock hydrostratigraphic units is presented in Section 5.1. Section 5.2 assesses the overburden groundwater flow pattern in each of the specific investigation areas, based on the information available at each area.

5.1 SITEWIDE GROUNDWATER FLOW CHARACTERIZATION

Groundwater flow patterns are characterized on a sitewide basis for both the overburden and the bedrock hydrostratigraphic units using groundwater level measurements obtained from nine bedrock wells and the 19 overburden wells installed at the PBS. These patterns are evaluated from the two rounds of groundwater level measurements performed in December 1994 and March 1995 and data from earlier studies. Groundwater monitoring wells are clustered around areas of the site where environmental investigations have been performed. Large areas of the site have no well data. The available information was synthesized to evaluate the elevation of the bedrock surface and the thickness of the overburden since both the depth to bedrock and thickness of the overburden impact groundwater flow patterns. The available data was also used to characterize the groundwater flow patterns for both hydrogeological regimes.

In order to contour the bedrock surface, overburden thickness, and water table elevations, it was necessary to create continuous fields from the data collected from point observations through an interpolation method. Several interpolation methods were tested, including inverse distance, minimum curvature, kriging using a linear covariance structure, and hand contouring. Except for the hand contouring, the interpolations were performed using the commercially available SURFER software (Golden Software).

Kriging uses a statistical method to calculate the autocorrelation between data points and produce a minimum variance unbiased estimate. It honors the original data points, and interpolates between the data points. In theory, no other method of grid generation can produce better estimates of the form of a mapped surface than kriging. In practice, the effectiveness of the techniques depends on the correct specification of several parameters that describe the semivariogram and the model of the drift. However, because kriging is robust, even with a naive selection of parameters the method will do no worse than conventional grid estimation procedures. The price that must be paid for optimality in estimation is computational complexity.

For the site-wide maps, the inverse distance method did not perform well, because the distribution of the data resulted in a "bulls-eye" pattern for some of the surfaces. The kriging, minimum curvature, and hand contouring methods all resulted in similar surfaces. For the maps presented in the report, kriging was used an the interpolation method. Default SURFER kriging parameters were used, which assume ordinary kriging with a linear variogram.

The only purpose of the kriging was to develop maps of the surfaces that made sense, and were consistent with the data. A detailed geostatistical and variogram analysis of the site-side data was not performed for the site-side maps. The sparsity of data, coupled with the irregular distribution of the data points, made a detailed variogram analysis inappropriate. Performing a detailed variogram analysis for the sole purpose of developing generalized site-side maps of the various surfaces would have also been inappropriate.

5.1.1 Top of Bedrock and Thickness of the Overburden Aquifer

In order to adequately assess the groundwater flow patterns in the overburden unit, both the top of bedrock elevations and the thickness of the overburden unit were established. In addition to the 19 wells installed for this investigation, 41 wells have been installed previously, 13 during the MK Ferguson investigation, four during the IT investigation, four during the H^{+}GCL investigation and 20 during the Ebasco investigation. The drilling logs for all of the wells were analyzed to evaluate the surface elevations, thickness of overburden, depth to bedrock, and type of bedrock. This information is summarized in Table 5-1 for all wells.

Some of the information from the boring logs is incomplete. For instance, ground surface elevations and/or well coordinates are not available for some of the borings. Some of the borings did not extend to the top of the bedrock, therefore the depth to bedrock and the type of bedrock are unknown. However, most of the boring logs contain sufficient information to evaluate the thickness of the overburden and the elevation of the top of bedrock.

The information contained in Table 5-1 is used to construct two contour maps:

TABLE 5-1

SUMMARY OF WELL INFORMATION

Monitoring Well ID	General Area	Top of Casing Elevation (ft)	Ground Surface Elevation (ft)	Well Depth (ft bgs)	Easting	Northing	Depth to Top of Bedrock (ft)	Top of Bedrock Elevation (ft)	Bedrock Type
MK WELLS									
MK-MW09		645.91					no	N/A	none
MK-MW10	WA RWP	640.89	638.06	15.0	14646.65	31784.09	no	N/A	none
MK-MW11	WA RWP	637.69	634.71	14.0	15926.81	31782.65	no	N/A	none
MK-MW12		641.73					13.0	628.7	LS
MK-MW14		681.93					11.5	670.4	?
MK-MW15		681.45					9.0	672.5	?
MK-MW16	TNT B	674.32	671.33	5.5	22260.12	24938.51	8.0	663.3	SH
MK-MW17	TNT B	664.64	660.97	8.0	22019.82	26670.71	6.0	655.0	SH
MK-MW19		639.85					no	N/A	none
MK-MW20		637.86					no	N/A	none
MK-MW22	TNT A	638.05	635.56	9.5	27844.34	32580.36	9.5	626.1	?
MK-MW23	TNT A	639.07	636.95	16.0	29414.52	32934.09	16.0	621.0	?
MK-MW24	TNT A	657.12	654.44	9.5	27420.48	30494.71	9.5	644.9	?
IT WELLS									
IT-MW1		678.24	674.52	9.0	19783.00	24944.00	3.0	671.5	SH
IT-MW2	WA RWP	639.63	636.53	18.3	14437.00	30425.00	18.3	618.2	LS
IT-MW5	PR RWP	634.99	631.91	21.0	23518.73	33481.14	no	N/A	none
IT-MW6		632.97	628.90	18.5	22732.00	36752.00	18.5	610.4	?
DM WELLS									
TNTA-MW10	TNT A	640.18	637.50	11.0	27478.66	32093.12	11.0	626.5	SH
TNTA-MW11	TNT A	640.50	637.86	11.4	26832.65	31731.51	11.4	626.5	SH
TNTC-MW3	TNT C	645.41	642.57	14.0	15532.75	29408.88	14.5	628.1	SH
TNTC-MW4	TNT C	654.43	651.89	18.8	14634.99	28332.11	18.0	633.9	SH
TNTC-MW5	TNT C	651.81	649.07	29.7	15972.14	28645.94	29.5	619.6	SH
TNTC-MW6	TNT C	659.40	656.82	12.2	17169.56	28413.03	12.0	644.8	SH
WA-MW1	WA RWP	644.43	642.32	22.3	14060.58	30549.40	22.3	620.0	LS
WA-MW2	WA RWP	633.65	631.16	13.0	14301.25	30038.91	12.0	619.2	SH
PR-MW7	PR RWP	633.99	631.50	22.3	23074.69	33122.14	22.3	609.2	SH
PR-MW8	PR RWP	635.02	632.50	27.5	23364.70	33022.17	27.5	605.0	SH
PR-MW9	PR RWP	633.70	630.70	19.0	23564.68	33227.19	19.0	611.7	SH
BED-MW-13	TNT C	648.27	645.81	75.5	16324.84	29004.74	40.7	605.1	
BED-MW-14	WA RWP	646.04	643.05	52.2	14564.93	30640.67	24.5	618.6	
BED-MW-15	PR RWP	631.64	629.08	74.4	23310.10	34311.28	24.3	604.8	
BED-MW-16		636.02	633.68	74.0	24688.03	31461.03	44.2	589.5	
BED-MW-17	TNT A	629.97	627.37	64.4	28164.75	33667.92	37.3	590.1	
BED-MW-18	TNT A	651.50	648.83	75.4	29536.00	32128.05	30.8	618.0	
BED-MW-19	WA RWP	643.07	640.51	49.5	14256.32	31780.91	19.1	621.4	
BED-MW-20	Background	676.33	673.57	49.5	27305.63	20645.12	21.5	652.1	
REACTOR-2		630.68	630.72		22017.22	34762.68	unknown	N/A	
HGCL WELLS									
HG-MW1	Snake Rd BG	674.74	671.31		25489.00	25945.00	9.5	661.8	SH
HG-MW2A	Snake Rd BG	672.66	669.68		25186.00	26316.00	7.0	662.7	SH
HG-MW2B	Snake Rd BG	673.07	669.60		25208.00	26321.00	6.0	663.6	SH
HG-MW3	Snake Rd BG	671.52	668.67		24970.00	25984.00	6.0	662.7	SH
EB WELLS									
GM-01	GM Area		638.49		22328.00	31667.00	27.0	611.5	SH
GM-02			635.80		21889.00	32525.00	29.0	606.8	SH
GM-03			636.69	18.0	21849.00	32220.00	no	N/A	none
GM-04			634.49	16.0	21517.00	32132.00	no	N/A	none
GM-05			637.79	18.0	21882.00	31961.00	no	N/A	none
GM-06			637.80	18.0	21884.00	31813.00	no	N/A	none
SP-01			654.29		31880.00	21936.00	9.0	645.3	SH
SP-03			657.29		31172.00	21716.00	7.0	650.3	SH
SP-04			657.25		31279.00	21483.00	7.0	650.3	SH
SP-05			656.87		31242.00	21371.00	7.0	649.9	SH
SP-06			657.70		31418.00	21381.00	8.0	649.7	SH
PS-02			636.48	18.0	24134.00	32492.00	no	N/A	none
PS-03			635.13	18.0	24261.00	32476.00	no	N/A	none
PS-04			636.07	16.0	24334.00	32452.00	no	N/A	none
RA-01			632.30	16.0	21813.00	34061.00	no	N/A	none
RA-02			632.06	20.0	22289.00	35053.00	no	N/A	none
RA-03			631.73	22.0	22357.00	34898.00	no	N/A	none
RA-04			631.65	10.0	22402.00	34842.00	no	N/A	none
RA-05			631.41	10.0	22504.00	34831.00	no	N/A	none
RA-06			630.72	10.0	22761.00	34868.00	no	N/A	none

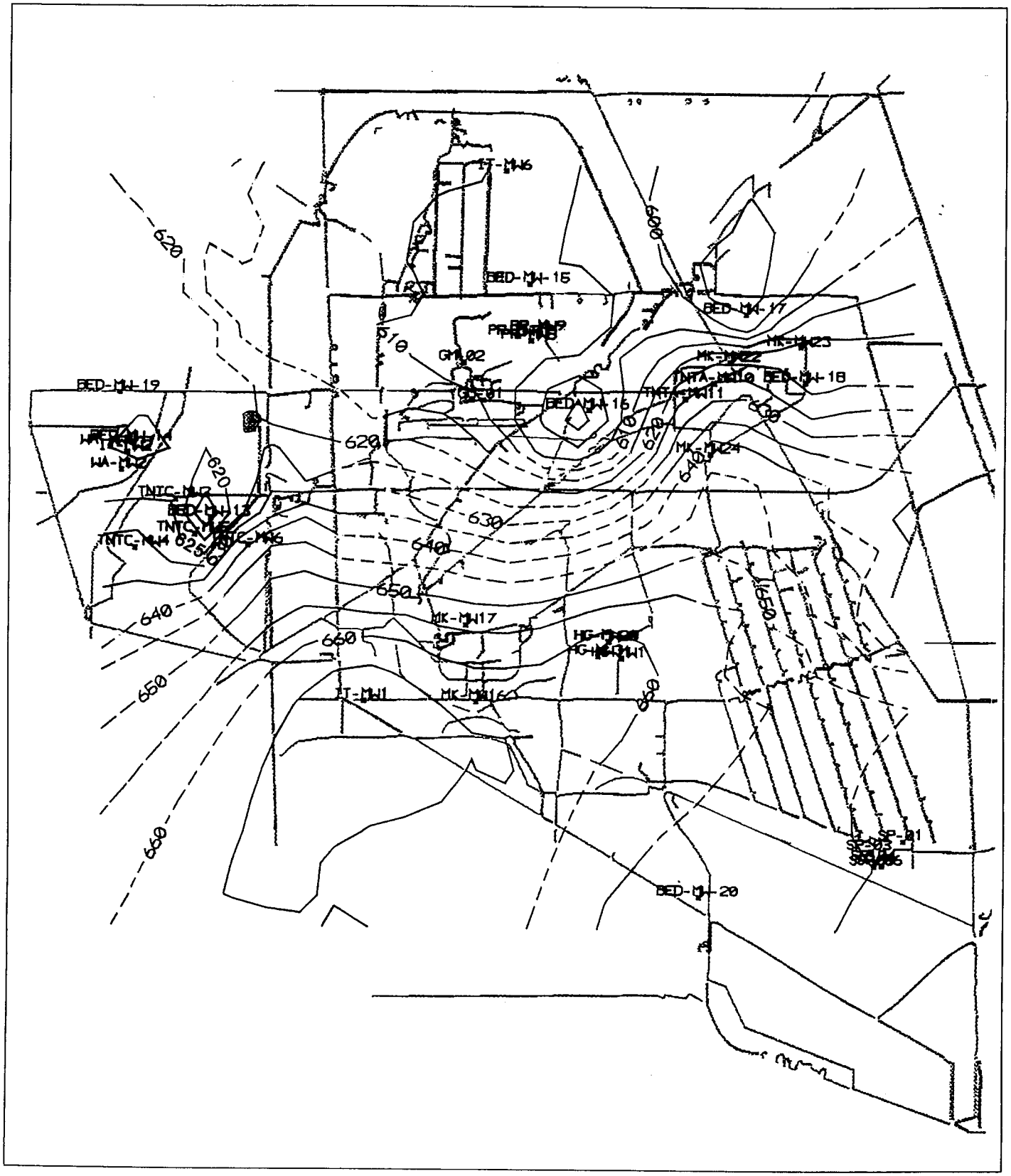
- Figure 5-2 provides a map of the top of bedrock elevations throughout PBS; and
- Figure 5-3 provides a map of the overburden thickness throughout PBS.

Only those wells which had sufficient information to establish the thickness of the overburden were used to construct these contour maps. Thirty-eight wells fit this criteria. For reference, the locations of the wells used to construct the contour maps are plotted on the maps.

Before interpreting these contour maps, it is important to note that the data are mainly clustered around specific investigation areas, and large portions of the site have no data available. The contour maps were constructed by kriging using the available data, and represent the best fit kriged surface to the data. The contours in the regions which have no data available should be considered speculative. However, enough data is present and the data is distributed such that general conclusions can be drawn from these maps.

The top of bedrock elevations are presented in Figure 5-2. The bedrock surface is highest in the south, and slopes towards the north at an average gradient of 0.0046 ft/ft (25 ft/mile) across the site. A local bedrock high occurs just to the southwest of the TNT Area B, at an elevation of approximately 667 feet. From this local high, bedrock elevations decrease gradually to the east and more steeply to the north. Insufficient data is available to assess the bedrock surface to the south and west of this bedrock high.

In the western portion of the site, top of bedrock elevations decrease uniformly toward the north until the TNT Area C, where a local bedrock low is present at an elevation of approximately 605 feet. North of TNT Area C, the top of bedrock elevations are relatively uniform at approximately 620 feet to the site boundary. In the eastern portion of the site, a top of bedrock trough is present between well BED-MW16 (near the intersection of Taylor and Maintenance Roads) and well BED-MW17. This trough is slightly south of and approximately parallel to Taylor Road. The elevation of this bedrock trough is approximately 590 feet. North of this trough, near the Pentolite Road area, top of bedrock elevations are approximately 605 feet.



3000 1500 0 3000 6000 FEET

Approximate Scale

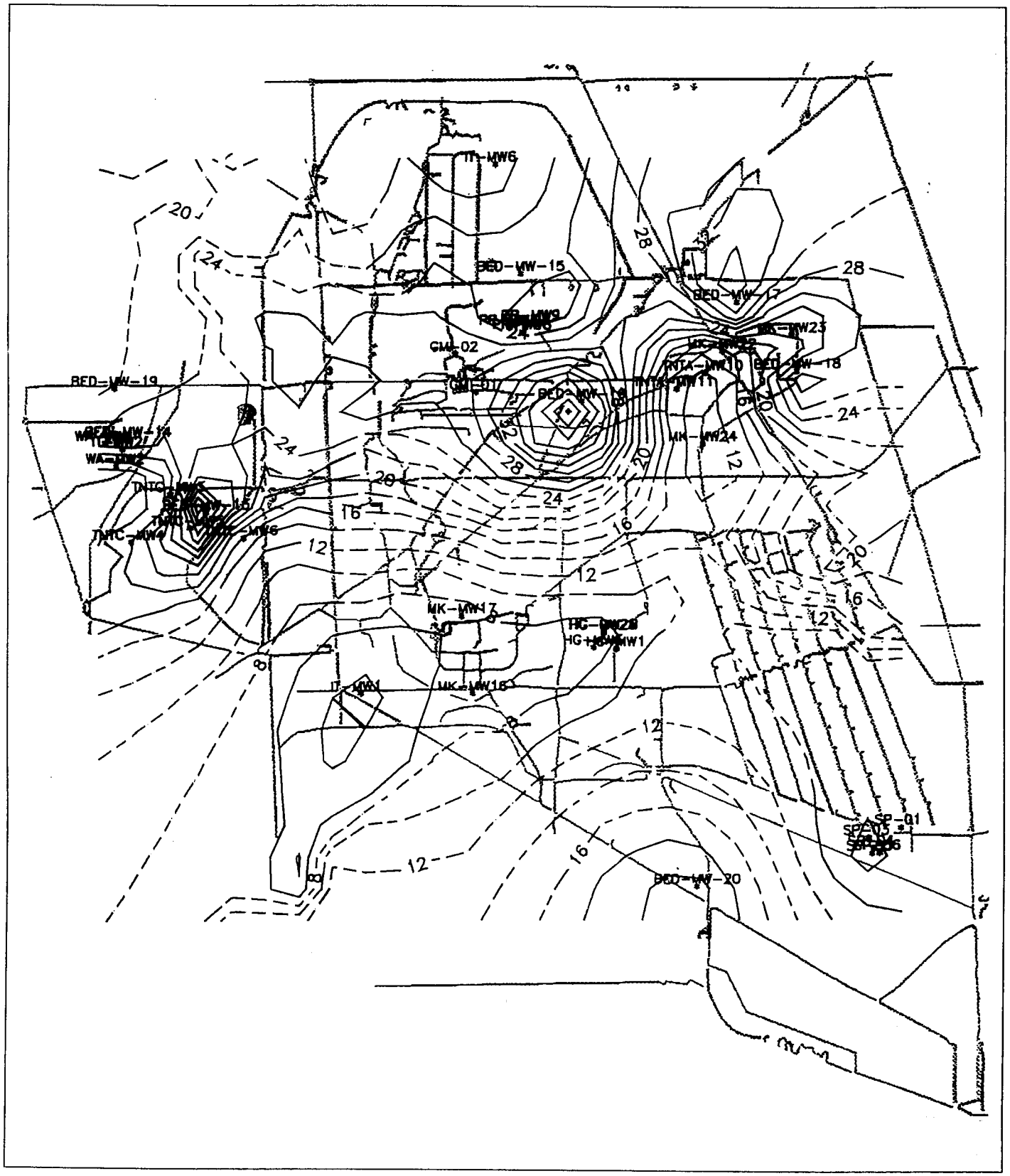
N

Figure 5-2

TOP OF BEDROCK ELEVATION CONTOUR MAP

Plum Brook Ordnance Works
Sandusky, Ohio

DAMES & MOORE



3000 1500 0 3000 6000 FEET

Approximate Scale

N

Figure 5-3

OVERBURDEN THICKNESS CONTOUR MAP

Plum Brook Ordnance Works
Sandusky, Ohio

DAMES & MOORE

Figure 5-3 shows a contour map of overburden thickness throughout the PBS site. This map is based on the 38 borings that went to bedrock. The patterns observed in the thickness of overburden map generally mirror the patterns noted in the top of bedrock elevations. In general, the overburden is thinnest in the southern portion of the site, and increases in thickness to the north.

Using information obtained during drilling of the background well, BED-MW20, the overburden thickness is 20 feet at the southeastern edge of the site. Immediately northwest and northeast of this well, however, overburden thicknesses are generally much thinner. The overburden is thinnest near the bedrock high southwest of TNT Area B, with a thickness of less than 3 feet in places. In this area, shale outcrops can be seen at the surface.

A line between TNT Area B and TNT Area A areas seems to mark a transition in overburden thickness. South and east of this line, the overburden is relatively thin, with a thickness of less than 10 feet. North and west of this line, overburden thickness increases dramatically. The areas where local top of bedrock lows are present show the greatest thickness of overburden materials, up to 45 feet at well BED-MW16. North of this wedge of thick overburden materials, overburden thickness is relatively constant at about 20 to 25 feet thick.

5.1.2 Groundwater Flow within the Overburden

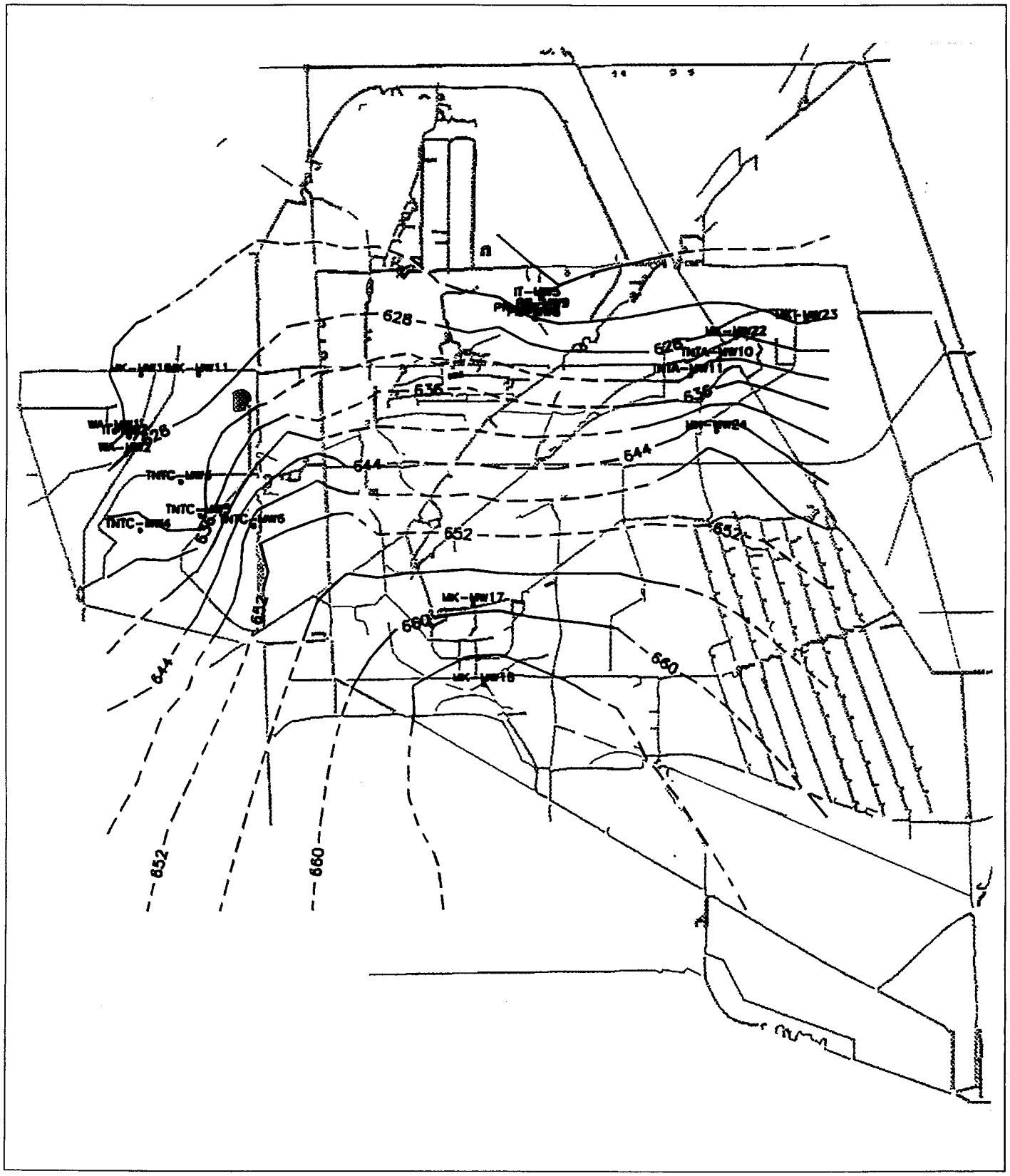
Two rounds of groundwater level measurements were taken in 19 overburden wells, one on December 5 to 9, 1994, and the second on March 14, 1995. The groundwater level measurements are summarized in Table 5-2.

Contour maps of the groundwater elevations in the overburden hydrostratigraphic unit were constructed for each of the measurement dates. Figure 5-4 is a contour map of the groundwater elevations in the overburden on December 5 to 9, 1994. Figure 5-5 is a contour map of the groundwater elevations in the overburden on March 14, 1995.

TABLE 5-2

SUMMARY OF OVERBURDEN GROUNDWATER WELL INFORMATION

Monitoring Well ID	Top of Casing Elevation (ft)	Ground Surface Elevation (ft)	Well Depth bgs (ft)	Depth to Groundwater Dec. 1994 (ft)	Depth to Groundwater Mar. 1995 (ft)	Groundwater Elevation Dec. 1994 (ft)	Groundwater Elevation Mar. 1995 (ft)		Easting	Northing
TNT-A Area										
TNTA-MW10	640.18	637.50	11.00	6.47	3.14	633.71	637.04	-3.33	27478.66	32093.12
TNTA-MW11	640.50	637.86	11.40	9.94	7.68	630.56	632.82	-2.26	26832.65	31731.51
MK-MW22	638.05	635.56	9.50	9.20	6.50	628.85	631.55	-2.70	27844.34	32580.36
MK-MW23	636.47	636.95	16.00	15.59	8.35	620.88	628.12	-7.24	29414.52	32934.09
MK-MW24	657.12	654.44	9.50	8.81	6.35	648.31	650.77	-2.46	27420.48	30494.71
TNT-B Area										
MK-MW16	674.32	671.33	8.00	7.18	4.96	667.14	669.36	-2.22	22260.12	24938.51
MK-MW17	664.64	660.97	6.00	5.06	3.54	659.58	661.10	-1.52	22019.82	26670.71
TNT-C Area										
TNTC-MW3	645.41	642.57	14.00	dry	6.21	< 628.57	639.20	> -10.63	15532.75	29408.88
TNTC-MW4	654.43	651.89	18.83	19.56	3.36	634.87	651.07	-16.20	14634.99	28332.11
TNTC-MW5	651.81	649.07	29.70	23.80	4.19	628.01	647.62	-19.61	15972.14	28645.94
TNTC-MW6	659.40	656.82	12.20	7.47	4.20	651.93	655.20	-3.27	17169.56	28413.03
West Area RWP										
WA-MW1	644.43	642.32	22.30	24.58	24.98	619.85	619.45	0.40	14060.58	30549.4
WA-MW2	633.65	631.16	12.00	4.06	1.74	629.59	631.91	-2.32	14301.25	30038.91
IT-MW2	639.63	636.69	15.00	12.31	5.88	627.32	633.75	-6.43	14379.83	30428.08
MK-MW10	640.89	638.06	14.00	14.23	Not Measured	626.66	Not Measured	Not Measured	14646.65	31784.09
MK-MW11	637.69	634.71	13.00	12.47	6.33	625.22	631.36	-6.14	15926.81	31782.65
Pentolite Road RWP										
PR-MW7	633.99	631.50	22.30	7.67	2.34	626.32	631.65	-5.33	23074.69	33122.14
PR-MW8	635.02	632.50	27.50	10.47	5.04	624.55	629.98	-5.43	23364.7	33022.17
PR-MW9	633.70	630.70	19.00	10.78	3.58	622.92	630.12	-7.20	23564.68	33227.19
IT-MW5	634.99	631.91		14.80	5.37	620.19	629.62	-9.43	23518.73	33481.14



3000 1500 0 3000 6000 FEET

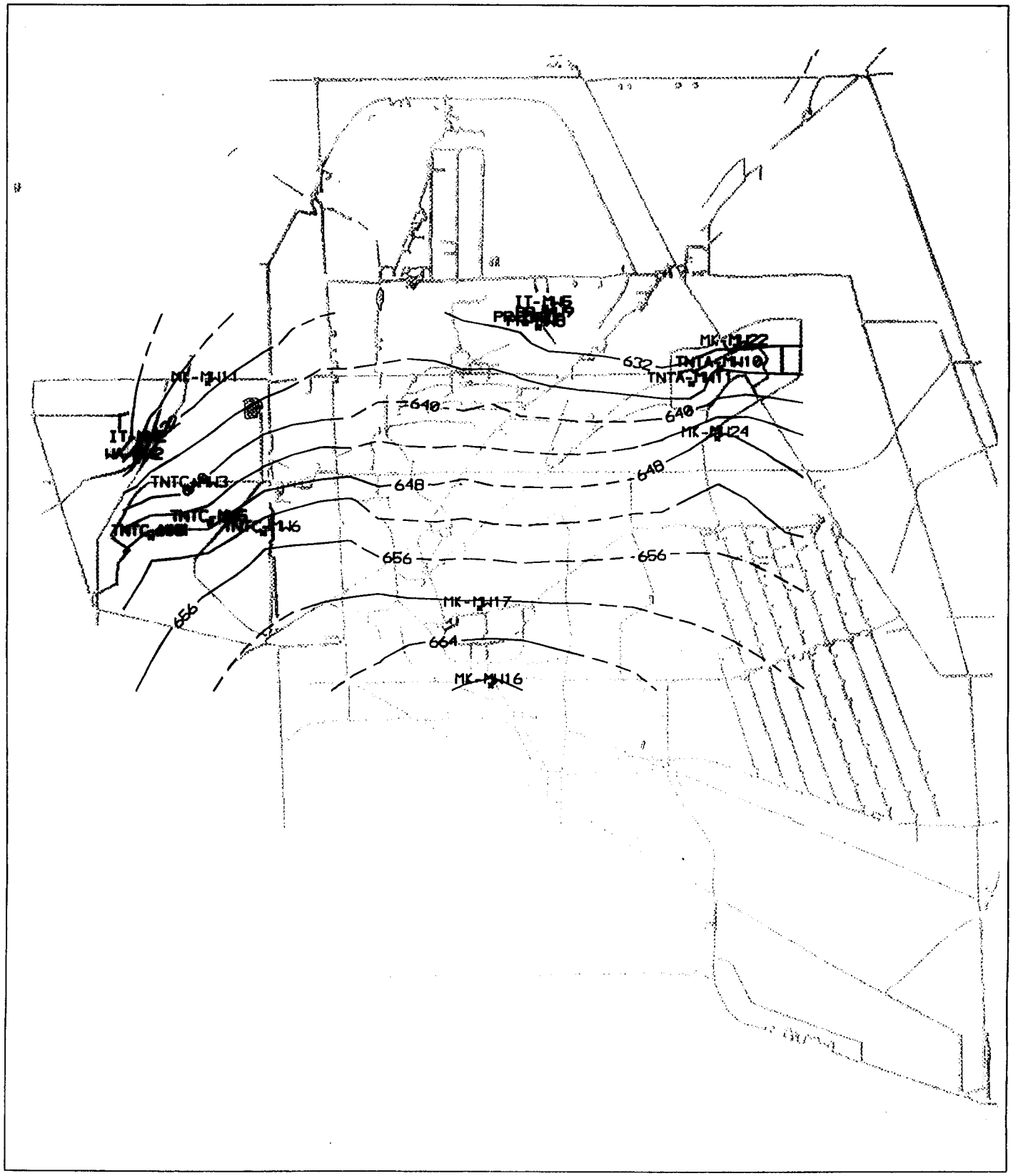
Approximate Scale

N

Figure 5-4

OVERBURDEN WATER TABLE ELEVATION CONTOUR MAP
December 1994
Plum Brook Ordnance Works
Sandusky, Ohio

DAMES & MOORE



3000 1500 0 3000 6000 FEET

Approximate Scale

N

Figure 5-5

OVERBURDEN WATER TABLE ELEVATION CONTOUR MAP

March 1995

Plum Brook Ordnance Works

Sandusky, Ohio

DAMES & MOORE

Before interpreting these contour maps, several important points must be noted. First, the data are clustered around the investigation areas, and large portions of the site have no data available. In particular, the entire southern section of the site, south of well MK-MW16, has no data available. The groundwater contour maps were constructed by kriging using the available data, and represent the best fit kriged surface to the data. Groundwater contours in areas with little or no data available should be considered speculative. Second, the overburden is highly heterogeneous both in thickness and hydraulic conductivity. There may be regions of relatively high hydraulic conductivity, leading to pathways of preferential flow which may not be in a direction perpendicular to groundwater contours. However, on a regional basis, the contour patterns depict the overall direction of groundwater flow.

Both maps show an overall groundwater gradient from south to north, with an average gradient of approximately 0.0045 ft/ft (25 ft/mile). Through the central and eastern portions of the site, the groundwater elevation contours trend east-west, indicating flow directly northward. On the western side of the site the groundwater contours indicate flow to the northwest. The December 1994 measurements indicate a stronger northwest component to the flow direction on the western side of the site than the March 1995 measurements. It is likely that the change in the direction of groundwater flow on the west side of the site is related to the change in bedrock type which occurs in this area. The contours indicate that the horizontal direction of flow is to the northwest toward the contact between the limestone and shale bedrock units. This contact trends southwest to northeast on the northwest side of the West Area Red Water Ponds.

The overburden groundwater elevation contour maps have a close relationship with the surface elevations, especially for the second round of measurements in March 1995. The second round of measurements were made during an unseasonably warm spell in March, after snowmelt occurred. Standing water was observed in the vicinity of 15 of the 19 wells. The groundwater elevations were within 3 feet of the ground surface in 13 of the 19 wells. During the December 1994 measurements, groundwater elevations were within 3 feet of the ground surface elevations in only two of the 19 wells measured.

The groundwater elevations during March 1995 are an average of 4 feet higher than the groundwater elevations during December 1994. In some locations, especially at TNT Area C, groundwater elevations during March 1995 are up to 19 feet higher than during December 1994. The greatest variations in groundwater elevations occur at TNT Area C, and the smallest variations occur at TNT Areas A and B. The West Area Red Water Ponds and the Pentolite Road Red Water Ponds areas had variations in groundwater elevations between 3 and 9 feet.

The pattern of groundwater flow in the overburden aquifer is similar for the December 1994 and March 1995 measurements. The major difference in groundwater flow patterns occurs on the western portion of the site. Based on the December 1994 map, groundwater in the overburden aquifer near TNT Area B moves toward both the north and the northwest, towards TNT Area C. Overburden groundwater in TNT Area C moves northwest towards the West Area Red Water Ponds. Based on the March 1995 map, groundwater in the overburden near TNT Area B no longer moves toward TNT Area C, but rather moves directly northward. Overburden groundwater at TNT Area C still moves northwest towards the West Area Red Water Ponds.

No apparent relationship exists between the overburden thickness contour map presented on Figure 5-3 and the groundwater elevation contour maps on a sitewide scale. The dramatic thickening of the overburden near well BED-MW16, north of TNT Area A and on the east side of TNT Area C, has no apparent effect on the groundwater table in these regions. The groundwater gradient does flatten slightly north of TNT Area A, perhaps in response to the thickening of the overburden in that area. However, over most of the site, the groundwater gradient is relatively constant, and is probably more correlated with surface elevations than the thickness of the overburden.

It is difficult to estimate the volume or rate of groundwater flow in the overburden flow regime because very little site specific hydraulic conductivity information is available. Even if it were available, there is probably significant variation in the hydraulic conductivity of the overburden materials, given the nature of the glacial deposits. IT performed a rising head slug test at well IT-MW2 near the West Area Red Water Ponds which resulted in a hydraulic conductivity value of 0.25 ft/day. Recharge in other wells

was too slow to perform hydraulic conductivity testing, indicating significantly lower hydraulic conductivity values.

5.1.3 Groundwater Flow in the Bedrock

Two rounds of groundwater level measurements were made in nine bedrock wells at the site, eight bedrock wells installed for this investigation and one PBS Reactor well. The measurements were made on December 5 to 9, 1994 and March 14, 1995. The results of the groundwater level measurements are summarized in Table 5-3.

Contour maps of the groundwater elevations in the bedrock hydrostratigraphic unit were constructed for December 1994 and March 1995. Figure 5-6 is a contour map of the groundwater elevations in the bedrock on December 5 to 9, 1994. Figure 5-7 is a contour map of the groundwater elevations in the bedrock on March 14, 1995. These contour maps were constructed using all of the bedrock wells except BED-MW-16, which showed anomalous water levels during both rounds of measurements. During the first round, the measured water level in well BED-MW16 was below the bottom of the casing, within the open hole interval. All other wells had measured water levels above the bottom of the casing. It is possible that the water level in well BED-MW16 had not recovered fully for the first sampling event. During the second sampling round, the measured water level in well BED-MW16 was at the ground surface. No other bedrock wells had measured water levels within 15 feet of the ground surface. Including well BED-MW16 for contouring water levels in the bedrock aquifer caused severe anomalies for both December 1994 and March 1995, and it was, therefore, not used in the maps presented in this report.

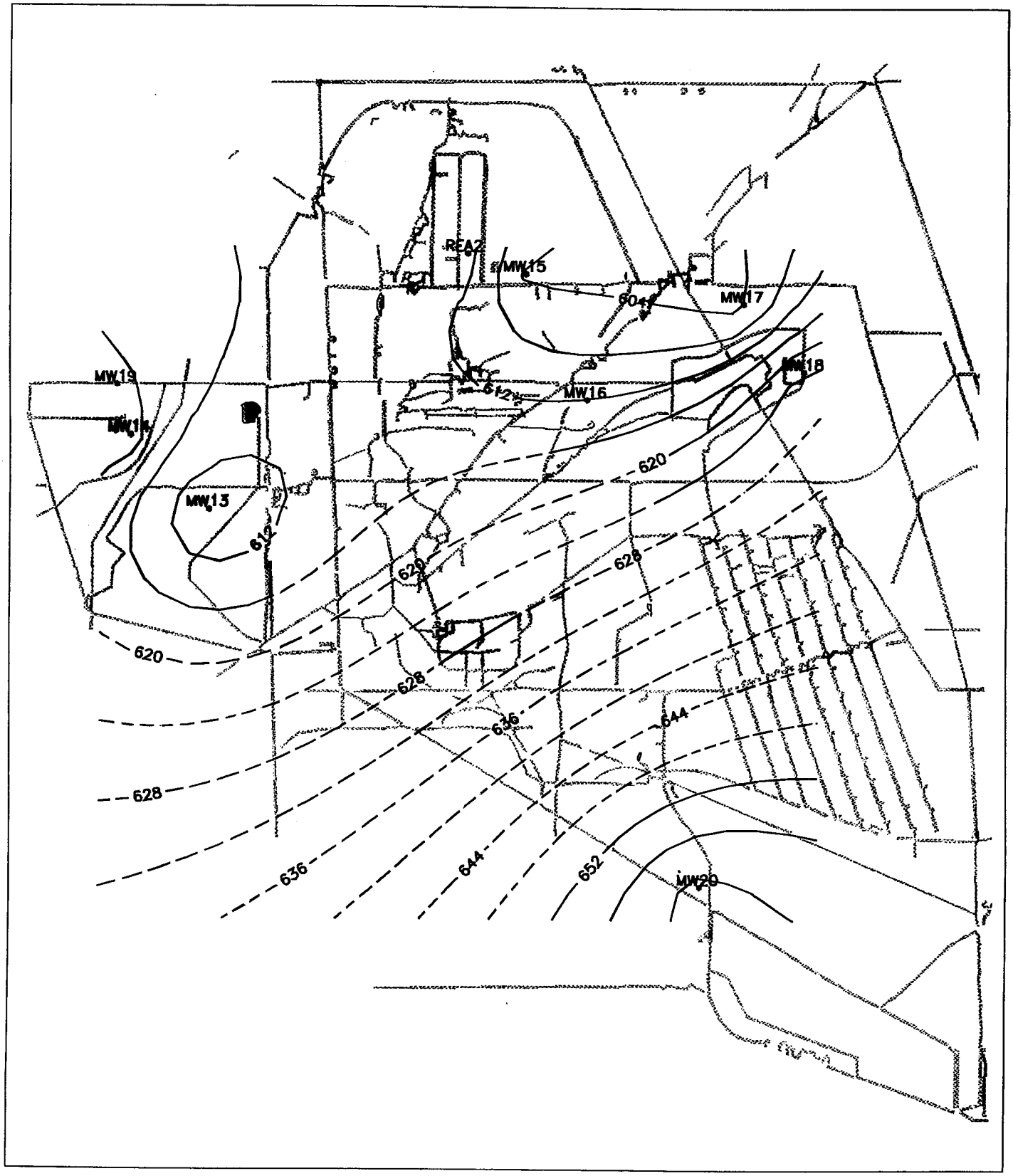
Several other wells showed anomalous results during one or both sets of measurements. Well BED-MW13 showed evidence in December 1994 of not having recovered fully after development. First, the contour map of the bedrock groundwater levels for the December 1994 (Figure 5-6) indicates a local sink in the area defined by well BED-MW13. By the March 1995 (Figure 5-7), this sink is no longer present. Second, with the obvious exception of well BED-MW16, well BED-MW13 showed the

TABLE 5-3

SUMMARY OF BEDROCK GROUNDWATER WELL INFORMATION

Monitoring Well ID	Top of Casing Elevation (ft)	Ground Surface Elevation (ft)	Well Depth bgs (ft)	Depth to Groundwater Dec. 1994 (ft)	Depth to Groundwater Mar. 1995 (ft)	Groundwater Elevation Dec. 1994 (ft)	Groundwater Elevation Mar. 1995 (ft)	Difference between GW elevations (ft)	Depth to Top of Rock (bgs)	Easting	Northing
BED-MW-13	648.27	645.81	75.5	40.42	28.98	607.85	619.29	-11.44	40.7	16324.84	29004.74
BED-MW-14	646.04	643.05	52.20	24.28	21.65	621.76	624.39	-2.63	24.5	14564.93	30640.67
BED-MW-15	631.64	629.08	74.40	28.10	32.73	603.54	598.91	4.63	24.3	23310.1	34311.28
BED-MW-16	636.02	633.68	74.00	64.64	2.34	571.38	633.68	-62.30	44.2	24688.03	31461.03
BED-MW-17	629.97	627.37	64.40	27.40	27.07	602.57	602.90	-0.33	37.3	28164.75	33667.92
BED-MW-18	651.50	648.83	75.40	26.45	31.11	625.05	620.39	4.66	30.8	29536	32128.05
BED-MW-19	643.07	640.51	49.50	22.00	19.55	621.07	623.52	-2.45	19.1	14256.32	31780.91
BED-MW-20	676.33	673.57	49.50	14.98	15.05	661.35	661.28	0.07	21.5	27305.63	20645.12
REACTOR-2	630.68	630.72		15.97	28.79	614.71	601.89	12.82		22017.22	34762.68

bgs = below ground surface



3000 1500 0 3000 6000 FEET

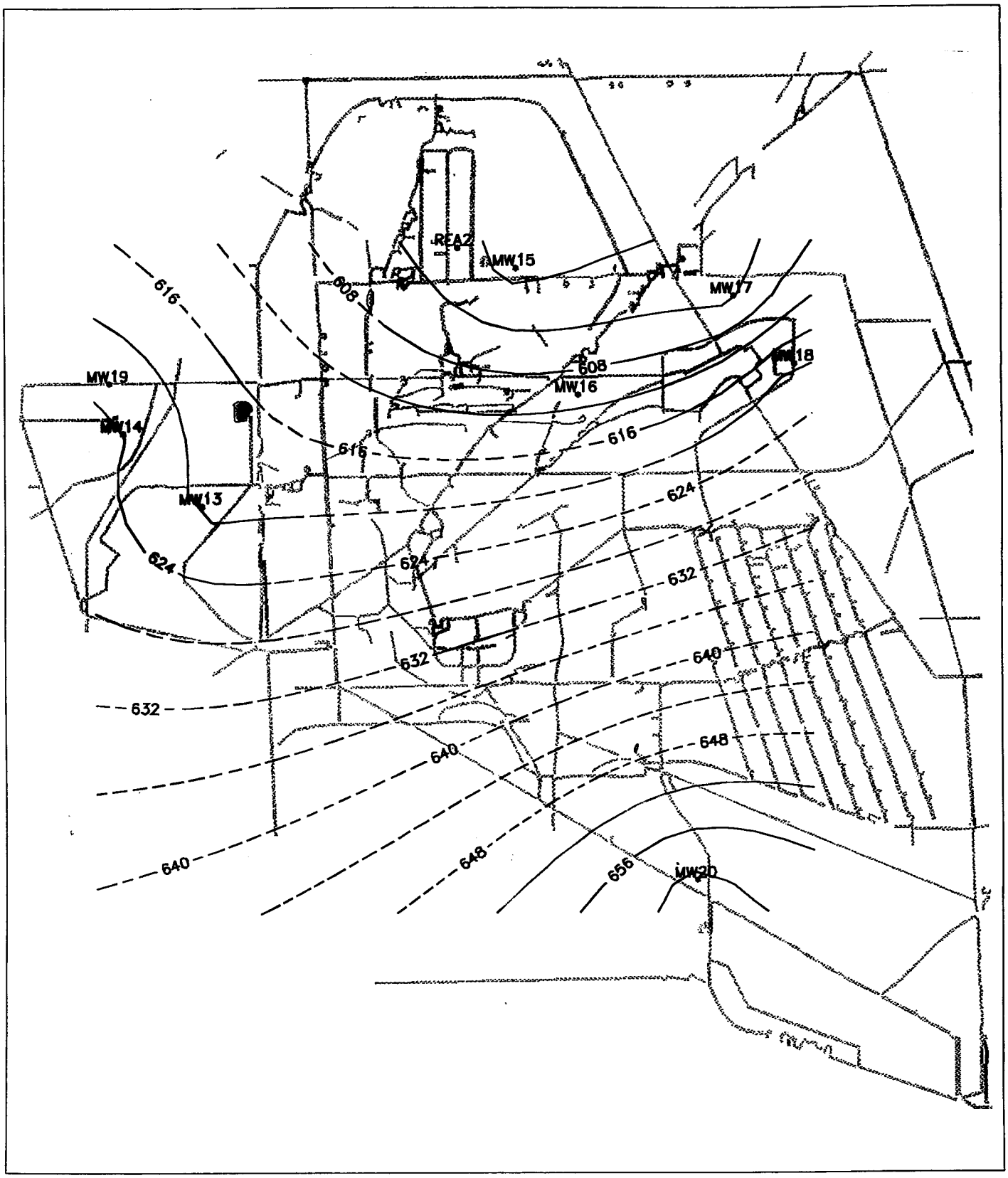
Approximate Scale

N

Figure 5-6

BEDROCK WATER TABLE ELEVATION CONTOUR MAP
December 1994
Plum Brook Ordnance Works
Sandusky, Ohio

DAMES & MOORE



3000 1500 0 3000 6000 FEET

Approximate Scale

N

Figure 5-7

BEDROCK WATER TABLE ELEVATION CONTOUR MAP
March 1995
Plum Brook Ordnance Works
Sandusky, Ohio

DAMES & MOORE

largest increase in measured groundwater level between the two measurement dates, with the water level being nearly 12 feet higher during March 1995.

Reactor Well 2 had a decrease in measured water level of nearly 13 feet between December 1994 and March 1995. Well BED-MW15, about 200 feet away, had a decrease in measured water level of only about 4 feet. It is not apparent why measured water levels in Reactor Well 2 should decrease so dramatically over a 4-month period.

Care must be taken in interpreting the contour maps of the bedrock flow regime. First, only nine data points are available throughout the site, most of them in the northern portion. Second, the bedrock may contain fractures or fracture zones in which preferential flow occurs. Many of the bedrock wells were situated in locations where fracture zones were suspected to exist. The direction of groundwater flow may not always be perpendicular to the equipotentials (contours of equal groundwater levels). There may be pathways of relatively high hydraulic conductivity, leading to pathways of preferential flow which may not be in a direction perpendicular to groundwater contours. Given only nine well locations, it is very difficult to delineate any pathways of preferential flow using the groundwater contour maps. As a first approximation, the direction of groundwater flow is assumed to be perpendicular to contours of equal groundwater elevation.

For both measurement events, the general bedrock groundwater flow direction is from south to north, with an average gradient of 0.0042 ft/ft (22 ft/mile). The map of the groundwater levels for December 1994 (Figure 5-6) shows a definite northwest trend to the groundwater flow direction across the central and southern portions of the site. However, the northwest trend may be an artifact of the anomalous reading at well BED-MW13. In the northwest portion of the site, the groundwater flow direction is toward the east-northeast, from the West Area Red Water Ponds towards the Reactor Area. In the northeast portion of the site, the groundwater flow direction is towards the north-northwest.

The map of groundwater levels from the March 1995 measurements (Figure 5-7) may be more representative of conditions at the site. All wells had time to recover from

drilling, development, and sampling activities. In the southern and eastern portions of the site (across TNT Areas A and B), groundwater contours indicate flow towards the north, with a slight northwesterly component. In the western portion of the site (across TNT Area C and West Area Red Water Ponds), groundwater contours indicate flow toward the northeast. Bedrock groundwater flow is indicated from the TNT Area C and the West Area Red Water Ponds toward the Pentolite Road Red Water Pond and Reactor Area.

The direction of groundwater flow in the bedrock may be correlated with the bedrock type. Figure 2-2 shows the location and orientation of the bedrock units underlying the PBS. The Delaware Limestone outcrops in the northwestern portion of the PBS. The assumed contact of the Delaware Limestone with the Plum Brook Shale trends northeast. Southeast of the contact between the Delaware Limestone and the Plum Brook Shale, the direction of groundwater flow in the bedrock is to the north-northwest. Where the Delaware Limestone is present, the direction of groundwater flow is toward the north-northeast. The bending in the groundwater contours correlates well with the assumed contact between the Delaware Limestone and the Plum Brook Shale.

5.1.4 Groundwater Flow Between the Overburden and Bedrock Hydrostratigraphic Units

The overburden hydrostratigraphic unit is directly on top of the bedrock in this area. The well boring logs showed no physical evidence of any flow barrier between the overburden and the bedrock. Groundwater flow occurs between the overburden and the bedrock. The rate of groundwater flux between the two units is controlled by the hydraulic gradient and the hydraulic conductivity contrast between the two hydrostratigraphic units.

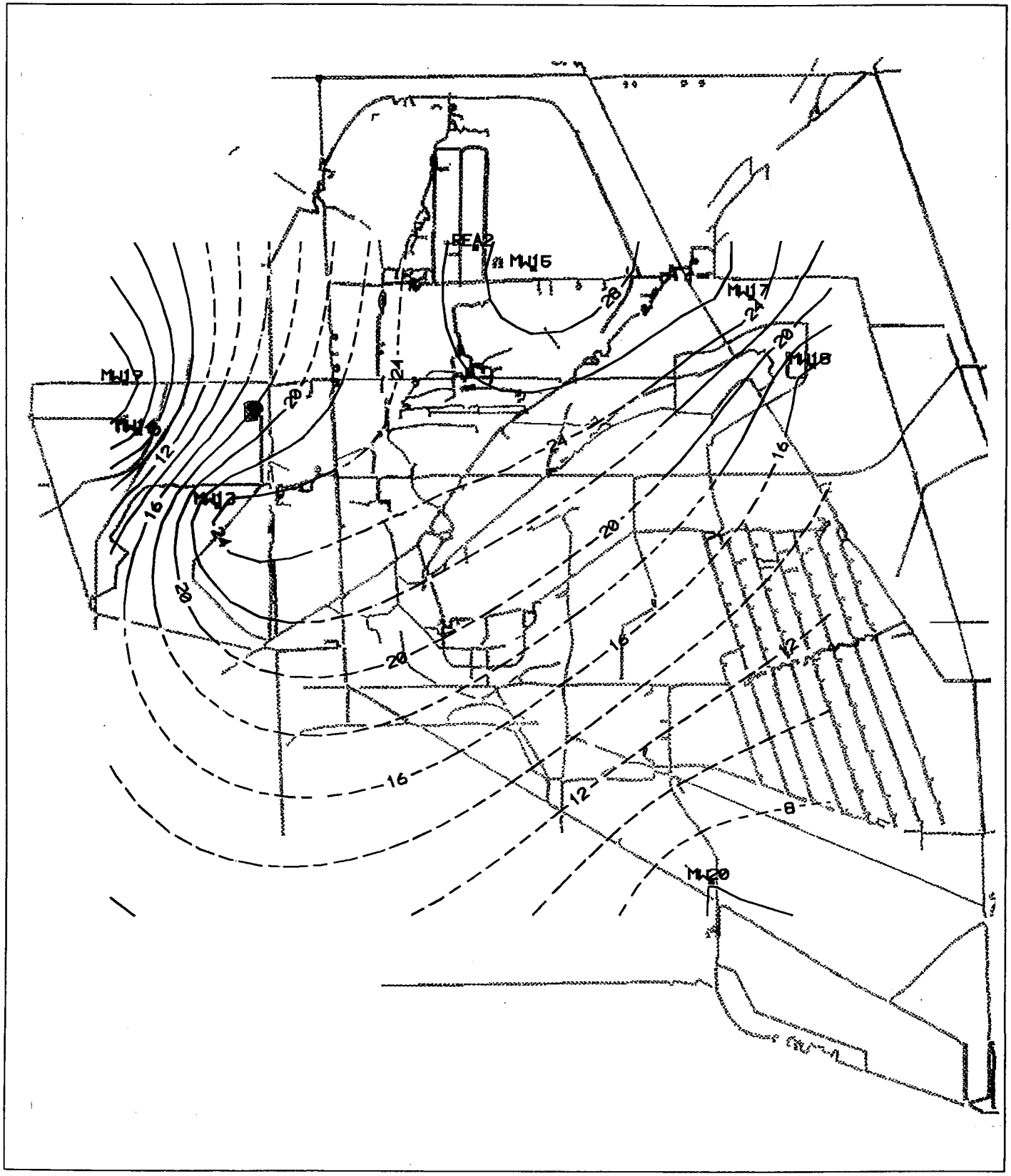
A cursory examination of the maps of the groundwater levels in both the overburden and the bedrock shows that groundwater levels in the overburden are consistently higher than groundwater levels in the bedrock. These differences in hydraulic heads

indicate that downward hydraulic gradients exist throughout the site, and groundwater flows from the overburden to the bedrock.

No well pairs were installed to evaluate the true vertical gradients present at the site. However, the vertical gradient distribution across the site can be approximated. Figure 5-8 is a map showing the approximate difference in hydraulic head between the overburden and bedrock wells in March 1995. This map was constructed by contouring the water levels in the overburden wells, and then noting the difference between the contoured water level and the measured water levels in the bedrock wells. This difference in water levels was then contoured to produce Figure 5-8. The data for March 1995 is presented, because the data for December 1994 appears to be biased due to the anomalous water level at well BED-MW13. It must be stressed that the head differences indicated by Figure 5-8 are approximate, and only represent one method of estimating the head differences in the absence of paired wells.

Figure 5-8 indicates that the smallest difference in hydraulic heads is in the south at well BED-MW20. This portion of the map may be inaccurate, because no overburden wells are present near this bedrock well. Small differences in hydraulic heads are also present near the West Area Red Water Ponds. The largest differences in hydraulic heads are at the Pentolite Road Red Water Pond, with head differences up to 30 feet. The northern part of TNT Area A and TNT Area C also have significant head differences, up to 25 feet. At the TNT Area B area the head differences are between 15 and 25 feet, though these values are interpolated, since no bedrock wells exist in the area.

To evaluate the approximate vertical hydraulic gradients, the difference in hydraulic heads between the overburden and bedrock wells must be established. Water enters the overburden wells over the length of the screened interval below the water table and enters the bedrock wells over the length of the open hole. The midpoint of the intervals over which water enters the well is assumed to be the measurement point for assessing vertical gradients. The overburden wells are generally screened throughout most of the overburden, with screen lengths between about 5 to 25 feet. The bedrock wells are cased from the surface to at least 5 feet into solid bedrock, and then are open to the bottom of the hole. The open interval ranges from about 15 to 30 feet. As



3000 1500 0 3000 6000 FEET

Approximate Scale

N

Figure 5-8

OVERBURDEN/BEDROCK HYDRAULIC HEAD DIFFERENCES CONTOUR MAP

March 1995

Plum Brook Ordnance Works

Sandusky, Ohio

DAMES & MOORE

a very rough estimate, the average vertical separation of the midpoint of the measurement interval between the overburden and bedrock wells is approximately 25 feet. If an average vertical separation of 25 feet is assumed between the overburden and bedrock wells throughout the site, the vertical gradients range from a low of 0.08 ft/ft up to 1.0 ft/ft. These vertical gradients are only approximate; however, they indicate the range of vertical gradients present at the site.

The indicated vertical gradients are much greater than the horizontal gradient within either hydrostratigraphic unit. The strong vertical gradients implies that groundwater within the overburden unit will tend to move downward into the bedrock rather than migrate horizontally within the overburden unit.

Given the strong vertical gradients, only a high hydraulic conductivity contrast would prevent downward migration of groundwater from the overburden unit into the bedrock. The high hydraulic conductivity contrast would require that the bedrock be significantly lower in hydraulic conductivity than the overburden. Since the hydraulic conductivity of neither unit is well known, it is difficult to estimate whether significant downward migration occurs.

5.2 AREA SPECIFIC GROUNDWATER FLOW CHARACTERIZATION

Groundwater flow patterns are characterized for each specific investigation area for the overburden hydrostratigraphic unit. These patterns are evaluated from the two rounds of groundwater level measurements. Where bedrock measurements are available near an investigation area, the relationship of groundwater flow between the overburden and the bedrock hydrostratigraphic units is examined.

5.2.1 TNT Area A

Five overburden and two bedrock wells are located near the TNT Area A. The water levels of these wells were measured in two rounds, and the results are included in

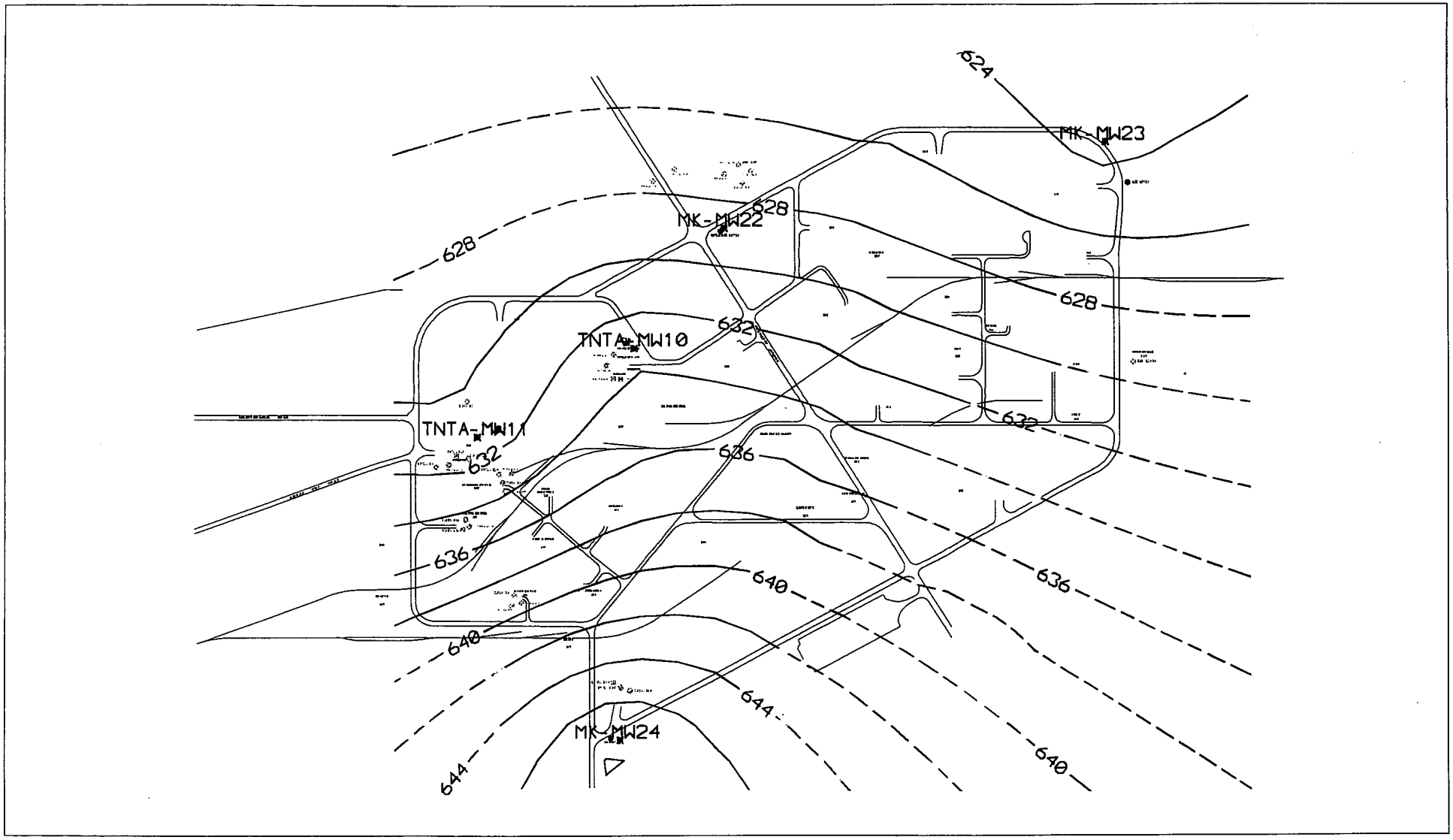
Tables 5-2 and 5-3. The depth to bedrock and overburden thickness are derived from the sitewide overburden thickness evaluation included in Section 5.1.1 above.

At TNT Area A, the top of bedrock (Figure 5-2) dips to the north and strikes nearly east-west, with elevations ranging from about 642 feet at the southern edge of the area (at well MK-MW24) to about 610 feet at the northern edge of the area. The top of bedrock trough lies just to the north of the TNT Area A. The thickness of the overburden (Figure 5-3) changes significantly over the TNT Area A, thickening to the north. Through the southern and central portions of the area, the overburden thickness averages about 12 feet. The overburden becomes significantly thicker in the top of bedrock trough to the north of the area, with a thickness of up to 32 feet in the top of bedrock trough. The overburden also thickens to the east of the site, up to 26 feet at well BED-MW18.

Figures 5-9 and 5-10 are contour maps of the groundwater elevations in the overburden for the first and second sets of measurements respectively (December 1994, and March 1995) across the TNT Area A. These maps are based primarily on the five overburden groundwater wells in the area, but information from other areas is also used to extrapolate the groundwater contours.

Both maps show an overall groundwater gradient from south to north, with an average gradient of approximately 0.008 ft/ft. This gradient is about twice the sitewide average gradient of 0.0045 ft/ft. Through the central and eastern portions of the area, the groundwater elevation contours trend east-west, indicating flow directly northward. On the western side of the site the groundwater contours indicate flow to the northwest. The transition between flow directly north and flow to the northwest occurs between wells TNTA-MW10 and TNTA-MW11. The groundwater gradients are slightly steeper in the southern portion of the area, and flatten out somewhat in the northern half of the area, particularly in the March 1995 measurements. The pattern of groundwater flow in the overburden aquifer indicated by the two sets of measurements is very similar.

The groundwater elevations in the overburden at the TNT Area A area were generally between 2 and 9 feet below the ground surface. The groundwater elevations during



700 350 0 700 1400 FEET

Approximate Scale

N

Figure 5-9

TNT AREA A OVERBURDEN WATER TABLE CONTOUR MAP
December 1994
Plum Brook Ordnance Works
Sandusky, Ohio

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the March 1995 sampling round are all higher than the groundwater elevations during December 1994. At well MK-MW23 on the northeastern edge of the area, the groundwater elevation during March 1995 was 7.24 feet higher than in December 1994. All other wells in the area had much smaller differences, between 2 and 3.5 feet higher in March 1995.

There is some correlation between the thickness of overburden and the groundwater flow patterns at the TNT Area A. First, the groundwater gradient is steepest in the thinnest overburden materials to the south, and flattens where the overburden is thicker to the north. Where the overburden is thin, the overall transmissivity of the hydrostratigraphic unit is relatively low. Where the overburden becomes thicker, the transmissivity of the unit increases. This increased transmissivity leads to flatter gradients. Second, the largest change in groundwater levels between the two sampling periods occurred in well MK-MW23, which was located in the thickest overburden materials.

Two bedrock wells are located in the vicinity of TNT Area A. Well BED-MW18 is located on the eastern edge of the area, and well BED-MW17 is located approximately 700 feet north of the area. The bedrock underneath the TNT Area A is shale. The groundwater elevation at well BED-MW18 was 625.05 feet during December 1994, and decreased to 620.39 feet in March 1995. The groundwater elevation at well BED-MW17 was approximately 603 feet for both measurement dates. The sitewide bedrock groundwater contour maps (Figures 5-6 and 5-7) indicate flow towards the north with a slight northwesterly component across the TNT Area A.

Downward hydraulic gradients exist within the TNT Area A, from the overburden to the bedrock. Though the true vertical gradients are unknown, since no well pairs were installed, it is possible to approximate the magnitude of this downward gradient. The magnitude of the downward gradient may be quite variable over time. At well BED-MW18, the approximate difference in hydraulic head between the overburden and the bedrock is only 5 feet for the first measurement round, but is over 15 feet for the second. At well BED-MW17, the approximate difference in hydraulic head is relatively constant at about 25 feet. Based on the well depths, these differences in hydraulic heads indicate approximate vertical gradients of between 0.1 to 1.0 ft/ft. These

vertical gradients are one to two orders of magnitude higher than the horizontal hydraulic gradients within the overburden in the area.

5.2.2 TNT Area B

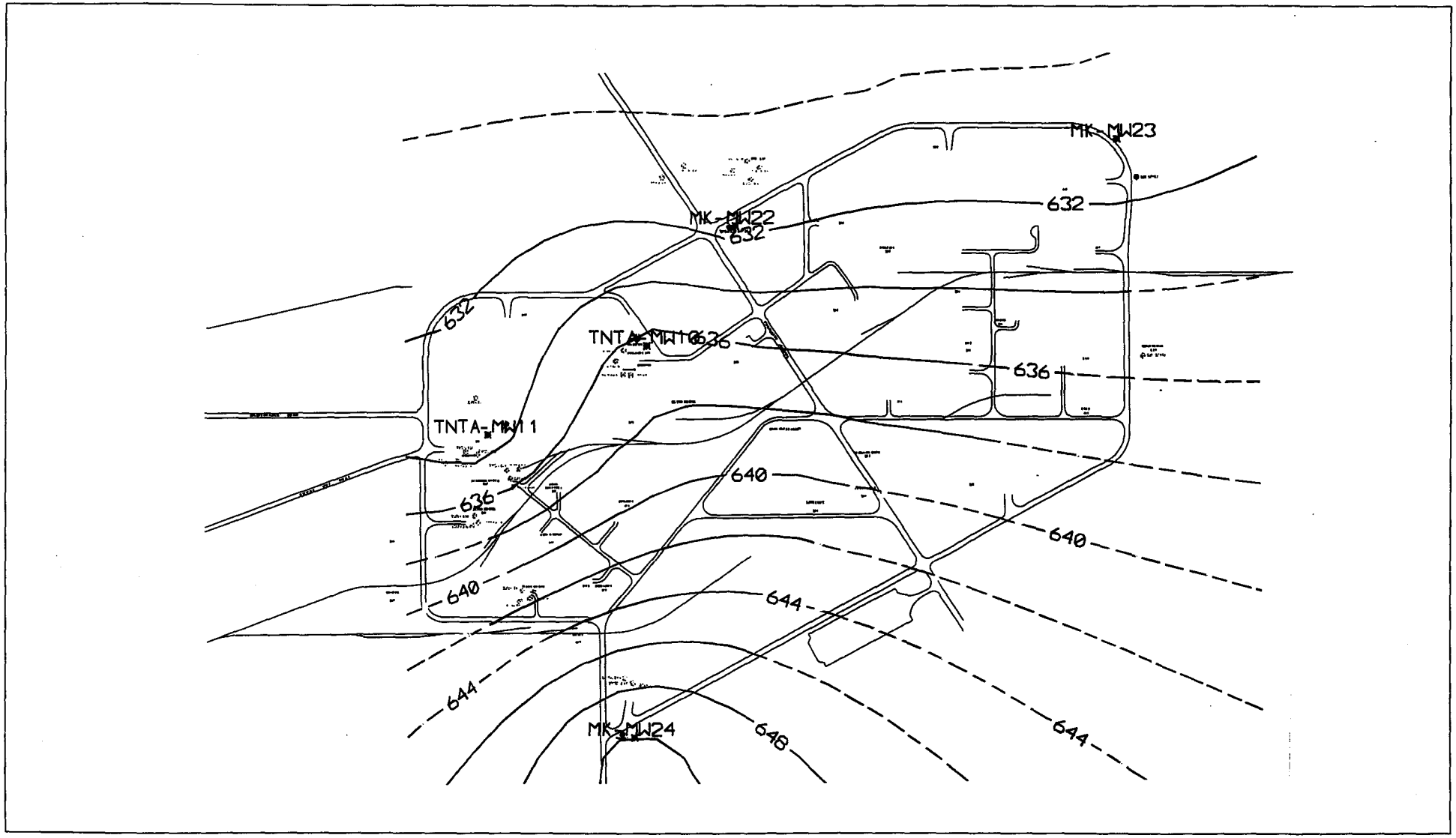
Only two overburden and no bedrock wells are located near the TNT Area B. The water levels of these two wells are included in Table 5-2. The depth to bedrock and overburden thickness are derived from the sitewide overburden thickness evaluation included in Section 5.1.1 above. Since groundwater flow cannot be characterized using only two wells, information from wells in other areas of the site (from the sitewide flow characterization presented previously) was used to assess groundwater flow in TNT Area B.

At the TNT Area B, the top of bedrock dips to the north and strikes nearly east-west, with elevations ranging from about 663 feet at Scheid Road south of the area (at well MK-MW16) to about 655 feet at the northern edge of the area (at well MK-MW17). The thickness of the overburden is relatively constant, ranging from 6 to 8 feet. The bedrock in this area is shale.

Figures 5-11 and 5-12 are contour maps of the groundwater elevations in the overburden for December 1994 and March 1995, respectively. These maps are based primarily on the two overburden groundwater wells in the area, but information from other areas is also used to extrapolate the groundwater contours.

Both maps show an overall groundwater gradient from south to north, with an average gradient of approximately 0.004 ft/ft, similar to the overall sitewide gradient. The groundwater elevation contours trend east-west, indicating flow directly northward. The pattern of groundwater flow in the overburden aquifer indicated by the two measurement rounds is very similar.

The groundwater elevations in the overburden at the TNT Area B were generally between 3 and 7 feet below the ground surface. The groundwater elevations during



700 350 0 700 1400 FEET

Approximate Scale

N

Figure 5-10

TNT AREA A OVERBURDEN WATER TABLE CONTOUR MAP
March 1995
Plum Brook Ordnance Works
Sandusky, Ohio

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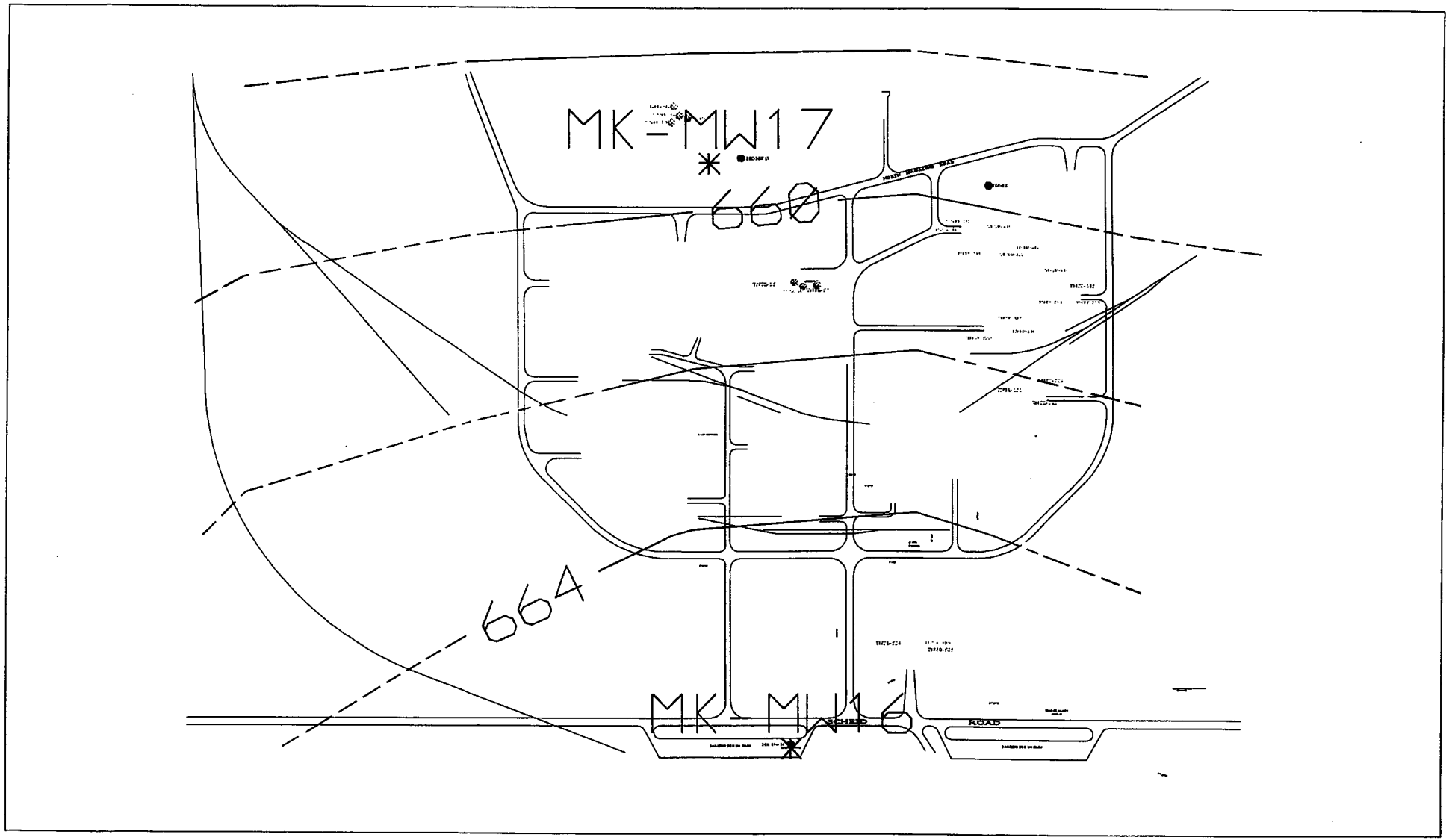


500 250 0 500 1000 FEET

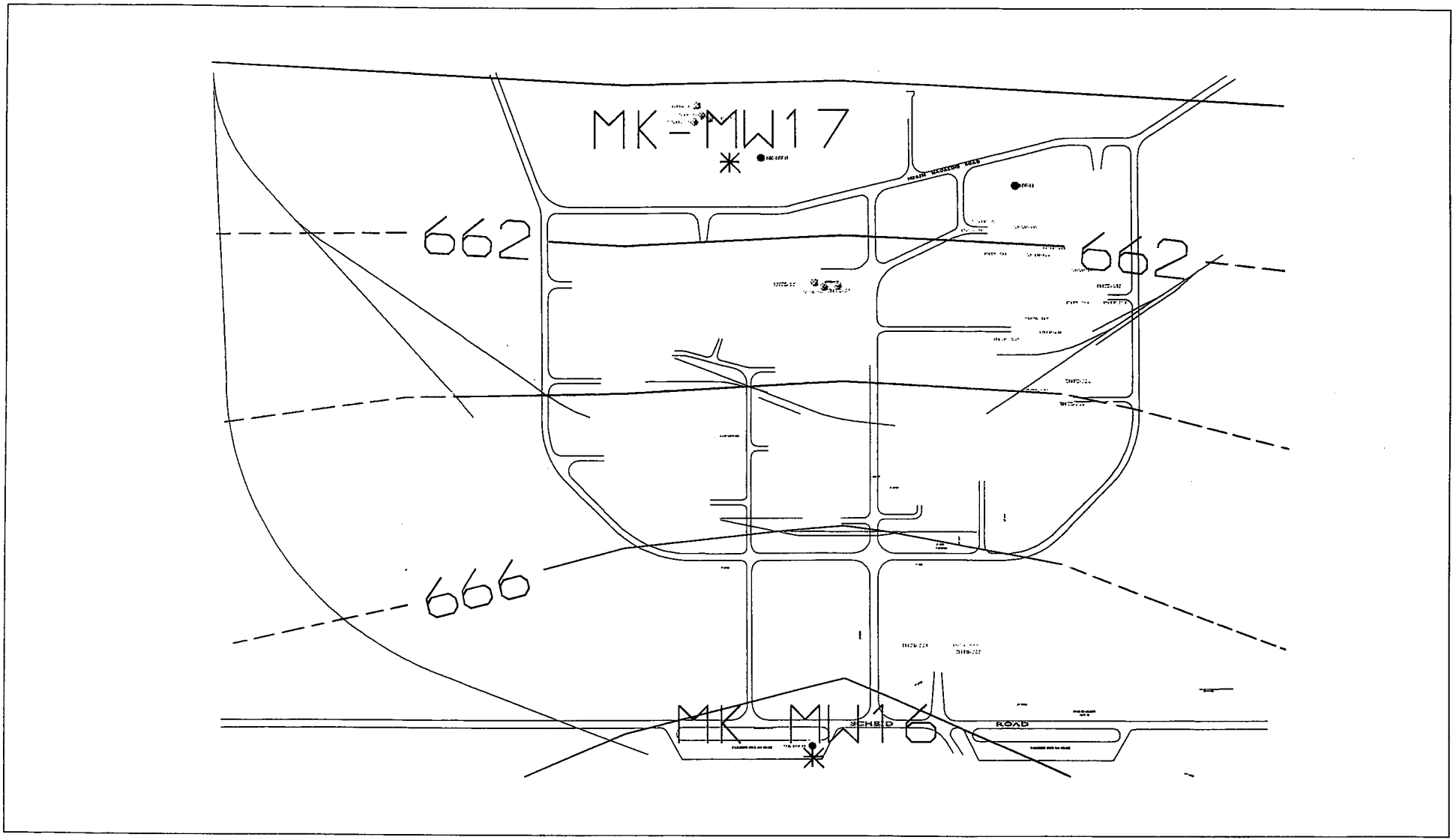
Approximate Scale

N

Figure 5-11

TNT AREA B OVERBURDEN
WATER TABLE CONTOUR MAP
December 1994
Plum Brook Ordnance Works
Sandusky, Ohio

DAMES & MOORE



500 250 0 500 1000 FEET

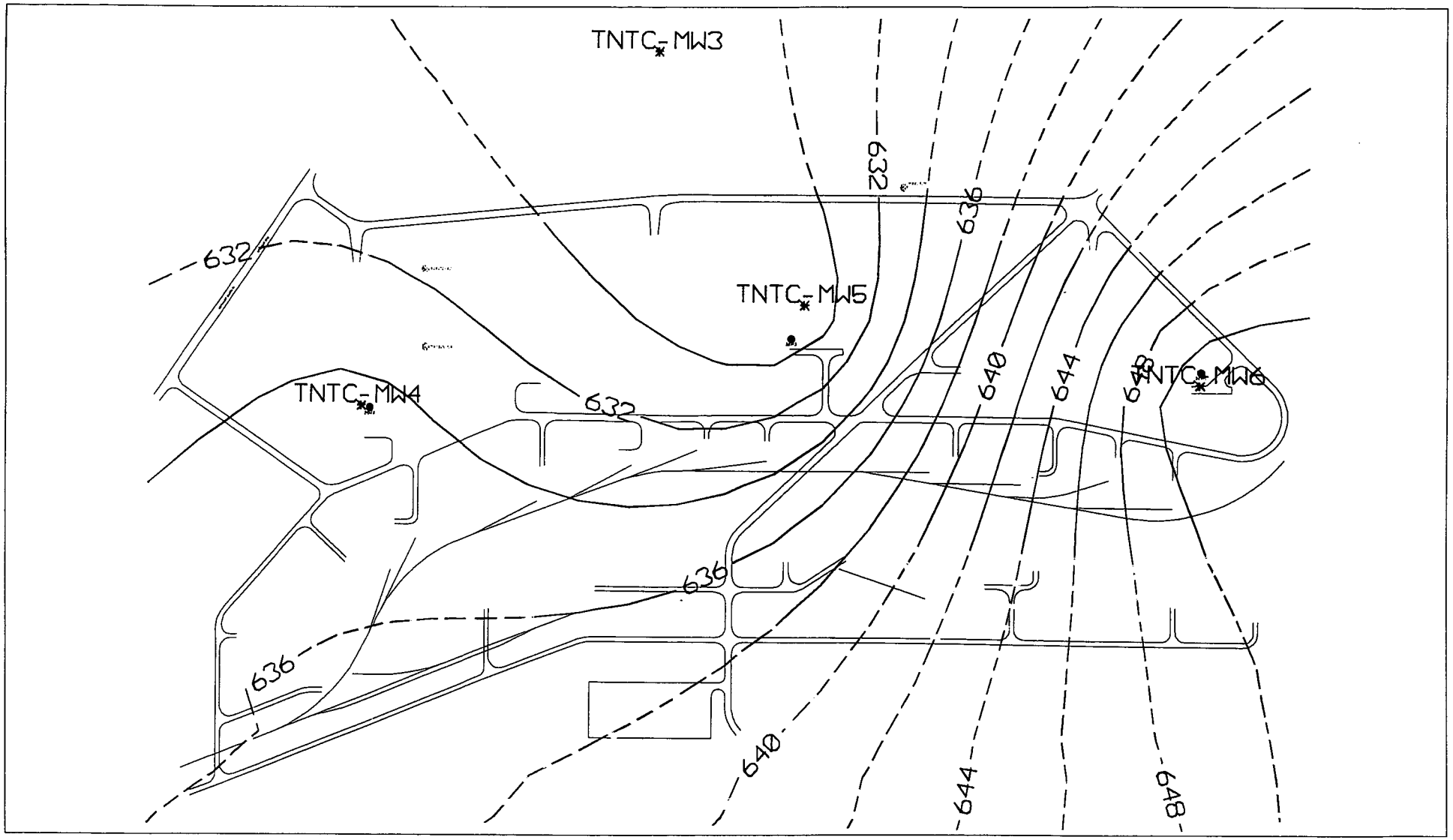
Approximate Scale

N

Figure 5-12

TNT AREA B OVERBURDEN
WATER TABLE CONTOUR MAP
March 1995
Plum Brook Ordnance Works
Sandusky, Ohio

DAMES & MOORE



500 250 0 500 1000 FEET

Approximate Scale

N

Figure 5-13

TNT AREA C OVERBURDEN
WATER TABLE CONTOUR MAP
December 1994
Plum Brook Ordnance Works
Sandusky, Ohio

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the second measurement round are both higher than the groundwater elevations during the first measurement round, by between 1.5 and 2.2 feet.

Since the overburden is relatively thin near the TNT Area B and the depth to the water table is generally several feet, the saturated thickness of the overburden is between 2 to 3 feet for December 1994. Significant horizontal groundwater flow is unlikely in such a thin saturated unit. Since no bedrock wells were located near the TNT Area B, it is not possible to extrapolate possible gradients between the overburden and the bedrock in this area. However, it is likely that vertical migration does occur, given the thin saturated overburden unit and low horizontal gradients.

5.2.3 TNT Area C

Four overburden and one bedrock wells are located near the TNT Area C. The water levels of these wells were measured twice and the results are included in Tables 5-2 and 5-3. The depth to bedrock and overburden thickness are derived from the sitewide overburden thickness evaluation included in Section 5.1.1 above.

The top of bedrock surface in the vicinity of the TNT Area C is very uneven. Based on the top of bedrock map (Figure 5-2), a significant depression in the top of bedrock surface is present in the center of the TNT Area C, in the region near wells BED-MW13 and TNTC-MW5. The elevation of the top of bedrock at well BED-MW13 is about 605 feet, and the elevation of the top of bedrock at well TNTC-MW5 is 619 feet. All the other wells in the area have top of bedrock elevations of over 628 feet. The sitewide pattern of a northward dip of the top of bedrock is superimposed over the large depression in the center of the TNT Area C. Shale bedrock was encountered at all wells in this area.

The overburden thickness at the TNT Area C reflects the unevenness in the top of bedrock elevations. A thick wedge of overburden materials is present in the bedrock depression, with thicknesses of up to 40 feet in well BED-MW13. At well TNTC-MW-5 the overburden is 29 feet thick. The overburden in all other wells is between 12 and 18 feet thick.

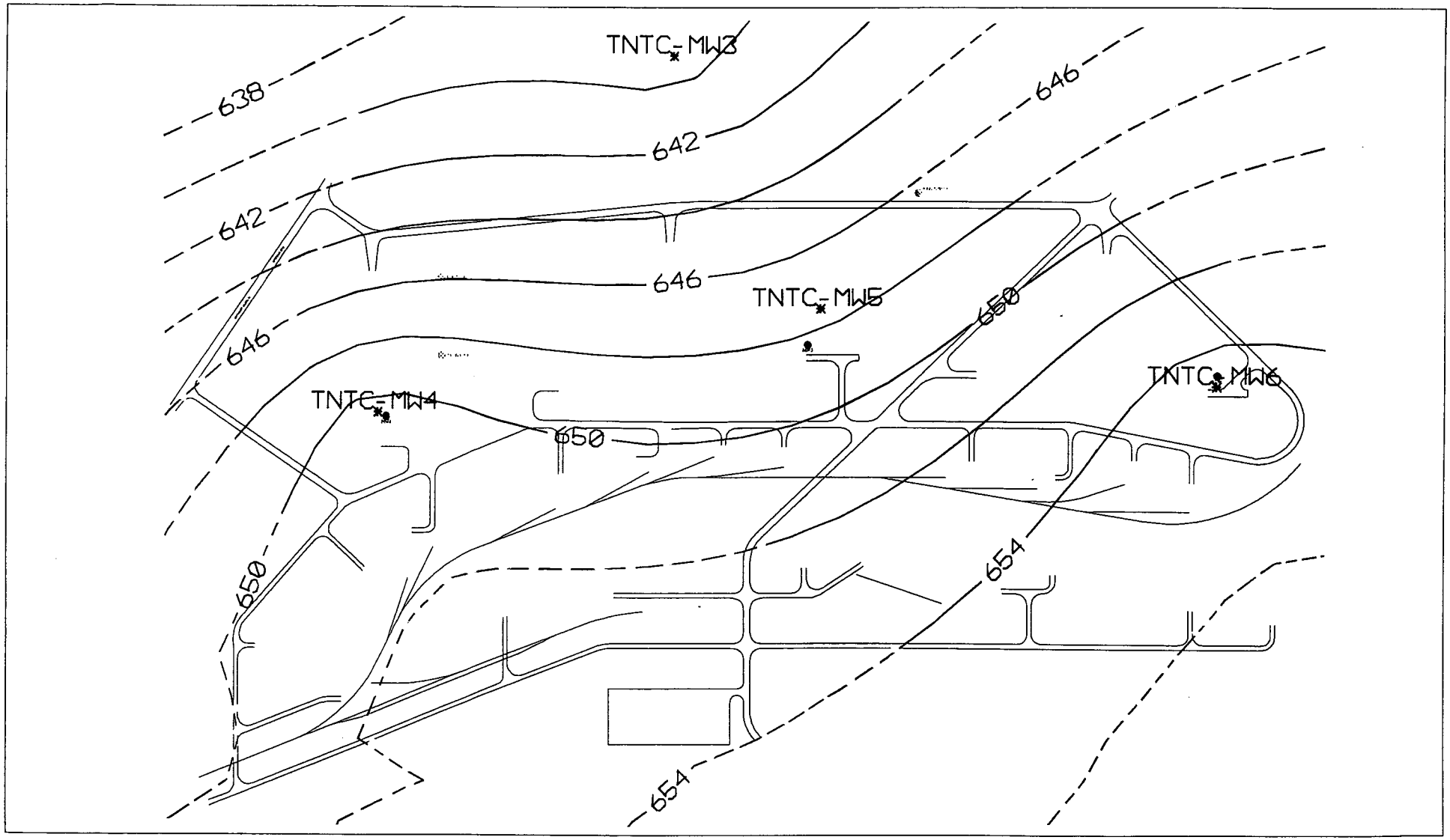
Figures 5-13 and 5-14 are contour maps of the groundwater elevations in the overburden for December 1994 and March 1995, respectively. These maps are based primarily on the four overburden groundwater wells in the area, but information from other areas is also used to extrapolate the groundwater contours.

The maps of the groundwater elevations for the two sampling periods show significantly different flow patterns. On both measurements dates, the overall groundwater flow direction is from southeast to northwest, but during December 1994 the westerly component of the flow direction is much more enhanced.

During December 1994 (Figure 5-13), the groundwater level at well TNTC-MW5 is 628.01 feet, creating a local groundwater depression in the vicinity of the well. Well TNTC-MW3 was dry, so the elevation of the bottom of the well, 628.57 ft, was used as an approximation of the groundwater level. The direction of groundwater flow in the eastern part of TNT Area C is to the west, and between wells TNTC-MW6 and TNTC-MW5 the gradient is approximately 0.02 ft/ft. In the western portion of the area the direction of flow is to the north, and the gradient is much less steep. North of well TNTC-MW5 the gradient is much less steep, but since well TNTC-MW3 was dry, the direction of flow and gradient is unknown.

During March 1995 (Figure 5-14), all the wells in the overburden had groundwater present, and the flow pattern was significantly different. The groundwater depression at well TNTC-MW5 was no longer present. The direction of groundwater flow across the area was from southeast to northwest, with an average gradient of 0.005 ft/ft. The groundwater contours do curve somewhat, with a hinge axis along a line connecting wells TNTC-MW3 and TNTC-MW5. However, this curve is not nearly as pronounced as the groundwater depression that was present during December 1994.

The groundwater elevations in the overburden at TNT Area C were relatively deep below the ground surface in December 1994 with depths ranging from 7.47 feet up to 23.8 feet. During March 1995, the groundwater depths were much smaller, between 3 and 7 feet. With the exception of well TNTC-MW6, the groundwater elevations during March 1995 are over 10 feet higher than during December 1994.



500 250 0 500 1000 FEET

Approximate Scale

N

Figure 5-14

TNT AREA C OVERBURDEN WATER TABLE CONTOUR MAP
March 1995
Plum Brook Ordnance Works
Sandusky, Ohio

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TNT Area C had much larger differences in groundwater elevations than any other area.

There is some correlation between the thickness of overburden and the changes in groundwater levels at TNT Area C for the two measurement periods. The largest change in groundwater levels occurred in well TNTC-MW5, in which the March 1995 groundwater level was 19.61 feet higher than the December 1994 level. The second largest change in groundwater levels occurred in well TNTC-MW4, in which the March 1995 groundwater level was 16.20 feet higher than the December 1994 level. These two wells had the greatest thickness of overburden, with well TNTC-MW5 at 29 feet thick and well TNTC-MW4 at 18 feet thick, respectively. The smallest change in groundwater levels between the two periods occurred in well TNTC-MW6, in which the March 1995 groundwater level was only 3.27 feet higher than the December 1995 level. This well had the smallest thickness of overburden materials, approximately 12 feet.

Only one bedrock well is located in the vicinity of TNT Area C, well BED-MW13. The December measurement of this well may have been taken before the well had completely recovered from sampling. The March 1995 water level was 619.29 feet, nearly 27 feet lower than the overburden water level in that area. Significant downward gradients are probable at the TNT Area C, with approximate gradients of 0.5 ft/ft.

5.2.4 West Area Red Water Ponds

Six overburden and two bedrock wells are located near the West Area Red Water Ponds, including well TNTC-MW3. The water levels of all wells except MK-MW10 were measured in two rounds, and the results are included in Tables 5-2 and 5-3. The depth to bedrock and overburden thickness are derived from the sitewide overburden thickness evaluation included in Section 5.1.1 above.

The top of bedrock surface in the vicinity of the West Area Red Water Ponds is very flat. In the center of the area, the elevations of the top of bedrock are all between 618

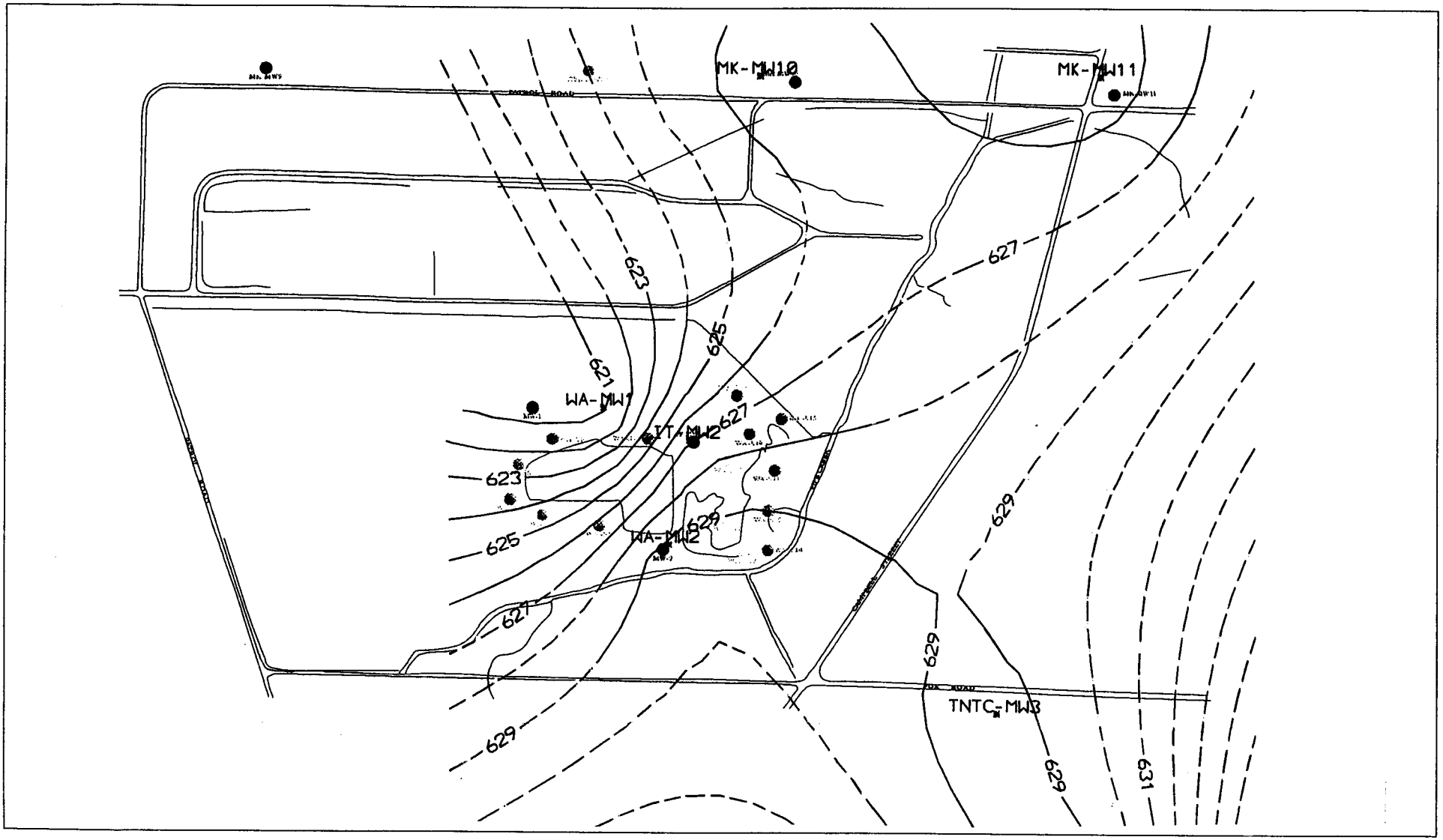
and 620 feet. To the north, the top of bedrock was not encountered in wells MK-MW11 or MK-MW12, but the bedrock well BED-MW19 had a top of bedrock elevation of 621 feet. To the south, the elevation of the top of bedrock at well TNTC-MW3 is 628 feet.

The overburden thickness at the West Area Red Water Ponds reaches a maximum of 22 feet on the north side of the ponds, and decreases in thickness to both the north and the south. To the north, the overburden thickness decreases slightly to 19 feet at well BED-MW19. The overburden thickness on the south side of the pond is only 12 feet at well WA-MW2, but this thickness may be biased due to the location of the well near the dike between the two ponds and Pipe Creek. Further south, the overburden thickness at well TNTC-MW3 is 14 feet.

Figures 5-15 and 5-16 are contour maps of the groundwater elevations in the overburden for the first and second measurement rounds respectively (December 1994 and March 1995) across the area surrounding the West Area Red Water Ponds. These maps are based primarily on the six overburden groundwater wells in the area, but information from other areas is also used to extrapolate the groundwater contours.

The maps of the groundwater elevations for the two measurement periods show similar directions of groundwater flow, but the groundwater gradients and elevations are somewhat different. In both, the groundwater flow direction across the area is from southeast to northwest, but during December 1994 the gradient is significantly lower. Both show the steepest gradients in the immediate vicinity of the pond, with flatter gradients to both the south and the north.

During December 1994 (Figure 5-15), the groundwater table surface has a steep gradient across the pond, with an elevation drop of approximately 10 feet from well WA-MW2 on the southeast corner of the pond to well WA-MW1 on the northwest corner of the pond. However, east of the pond, the slope in the groundwater table surface is much less steep, with an elevation drop of approximately 3 ft from well TNTC-MW3 south of the area to well MK-MW11 north of the area. During March 1995 (Figure 5-16), the gradient across the pond is significantly steeper, with an elevation drop of over 12 feet from well WA-MW2 to well WA-MW1, and an elevation drop of



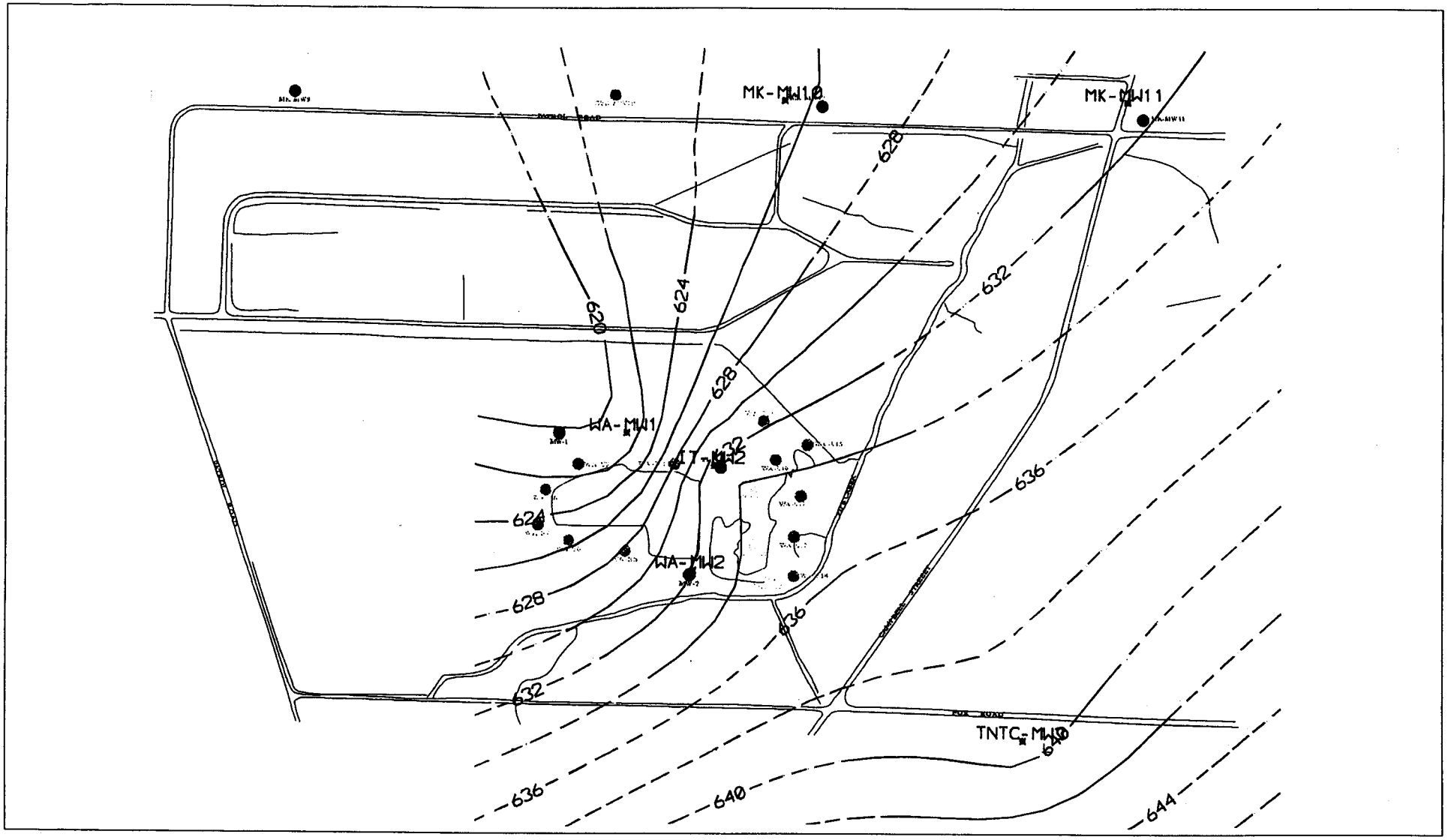
650 325 0 650 1300 FEET

Approximate Scale

N

Figure 5-15
WEST AREA
RED WATER PONDS OVERBURDEN
WATER TABLE CONTOUR MAP
December 1994
Plum Brook Ordnance Works
Sandusky, Ohio

DAMES & MOORE



650 325 0 650 1300 FEET

Approximate Scale

N

Figure 5-16
WEST AREA
RED WATER PONDS OVERBURDEN
WATER TABLE CONTOUR MAP
March 1995
Plum Brook Ordnance Works
Sandusky, Ohio

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about 14 feet from well IT-MW2 to well WA-MW1. East of the pond, the slope in the groundwater table surface is less steep than across the pond, but steeper than during the December 1994. The elevation drop between well TNTC-MW3 and well MK-MW11 is approximately 8 feet. Well MK-MW10 was not measured during March 1995, so the contours in that region of the map are interpolated.

Well WA-MW1 had the deepest measured water level below ground surface for any overburden well within the PBS, approximately 25 feet deep for both measurement periods. It was also the only overburden well at the site that showed a decrease in water level from December 1994 to March 1995. All other wells in the area had depths to groundwater between 4 to 14 feet during the December sampling period. The increase in groundwater levels between the two measurement dates ranged from 2 to 7 feet.

Based on the steep groundwater gradient across the pond, it appears that the West Area Red Water Pond is poorly connected hydraulically to the overburden aquifer. If a hydraulic connection did exist, the groundwater elevations near the pond would be influenced by the surface water elevation in the pond, and the groundwater gradient would be relatively flat across the pond.

No apparent correlation exists between the thickness of overburden and groundwater levels or pattern of groundwater flow at the West Area Red Water Ponds.

Two bedrock wells are located in the vicinity of West Area Red Water Ponds, well BED-MW14 near the pond and well BED-MW19 to the north of the area. The bedrock in this area is mainly limestone to the northwest, and shale to the southeast. The contact between the shale and limestone is located near the southeast corner of the pond.

The groundwater elevation at BED-MW14 was 621.76 feet in December 1994, and increased to 624.39 feet in March 1995. The groundwater elevation at well BED-MW-19 also increased from 621.07 feet in December 1994 to 623.53 feet in March 1995. The sitewide bedrock groundwater contour maps (Figures 5-6 and 5-7) indicate bedrock groundwater flow toward the northeast across the West Area Red

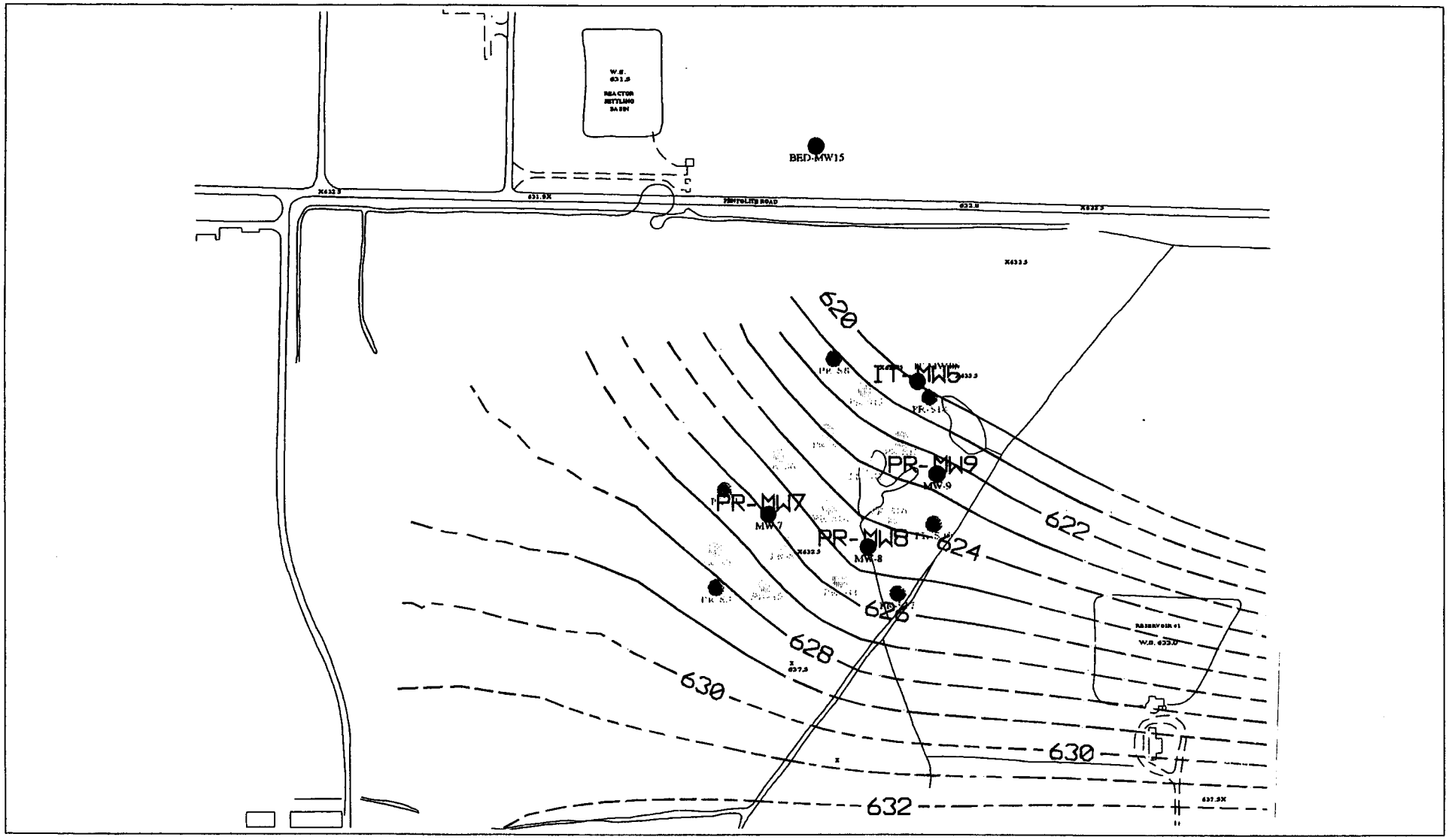
Water Ponds region. As in the other areas of the site, downward gradients exist from the overburden to the bedrock, with approximate groundwater elevation differences of between 2 and 8 feet. These groundwater elevation differences are smaller than in other areas, indicating larger downward gradients. It is possible that the larger downward gradients are due to the presence of more permeable limestone bedrock. The more permeable limestone bedrock may allow a greater degree of hydraulic connection between the overburden and bedrock hydrostratigraphic units. Additional evidence of a greater degree of hydraulic connection is the fact that both bedrock wells experienced an increase in groundwater elevations from December 1994 to March 1995, reflecting the behavior of the overburden wells.

5.2.5 Pentolite Road Red Water Ponds

Four overburden and two bedrock wells are located near the Pentolite Road Red Water Ponds, including Reactor Well 2. The water levels of all wells were measured in two rounds, and the results are included in Tables 5-2 and 5-3. The depth to bedrock and overburden thickness are derived from the sitewide overburden thickness evaluation included in Section 5.1.1 above.

The top of bedrock surface in the vicinity of the Pentolite Road Red Water Ponds is relatively flat, with top of bedrock elevations between 605 and 611 feet throughout the area. South of the area, the top of bedrock trough is present. North of the area no data is available to evaluate the top of bedrock elevations. The bedrock in this area is shale. The overburden thickness near the Pentolite Road Red Water Ponds is also relatively constant, with a thickness of between 19 and 27 feet. No general pattern is apparent in the distribution of the overburden thickness in the vicinity of the Pentolite Road Red Water Ponds.

Figures 5-17 and 5-18 are contour maps of the groundwater elevations in the overburden for the first and second measurement rounds, respectively (December 1994 and March 1995) across the area surrounding the Pentolite Road Red Water Ponds. These maps are based primarily on the four overburden groundwater wells in



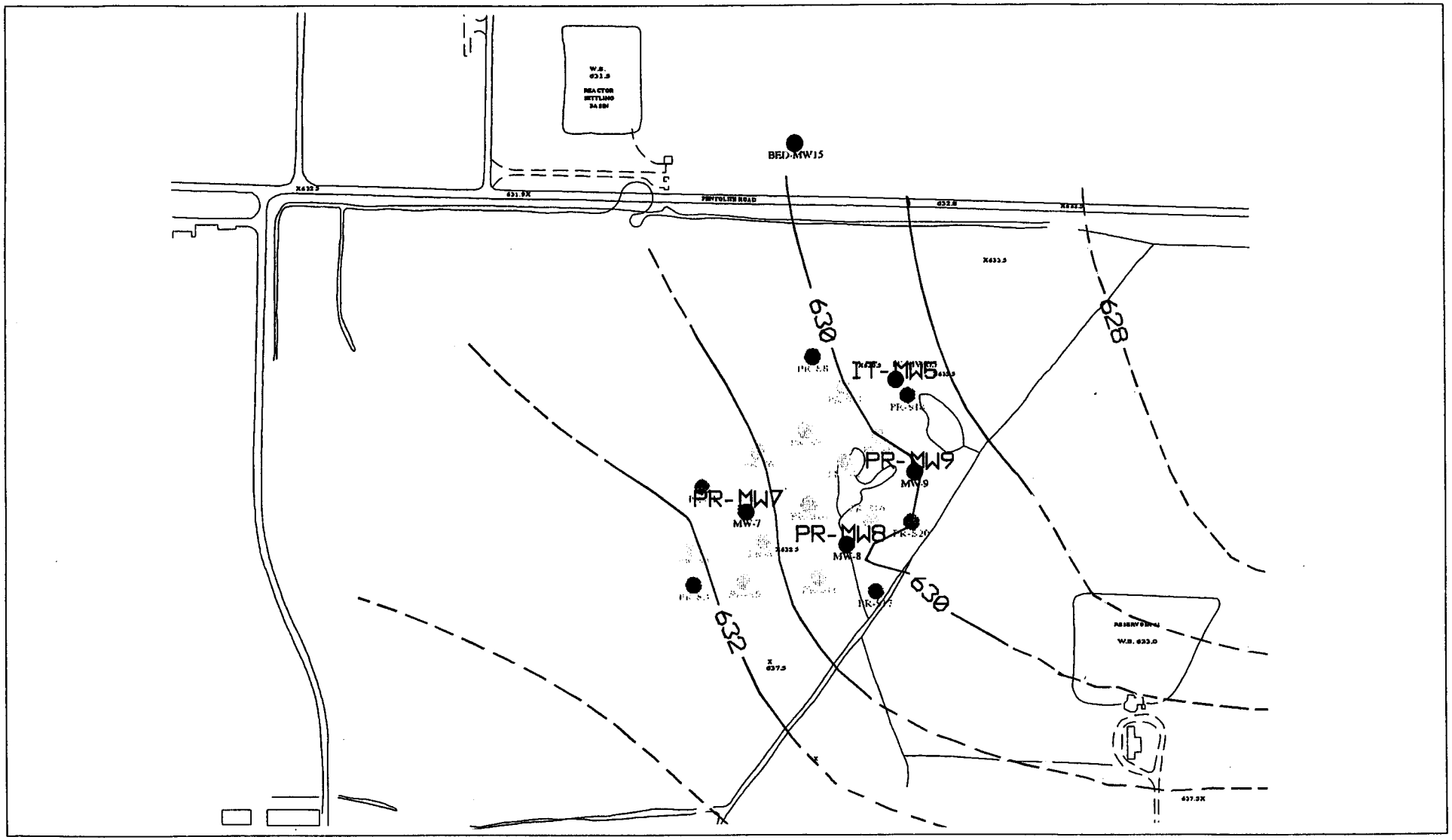
500 250 0 500 1000 FEET

Approximate Scale

N

Figure 5-17
PENTOLITE ROAD
RED WATER PONDS OVERBURDEN
WATER TABLE CONTOUR MAP
December 1994
Plum Brook Ordnance Works
Sandusky, Ohio

DAMES & MOORE



500 250 0 500 1000 FEET

Approximate Scale

N

Figure 5-18
PENTOLITE ROAD
RED WATER PONDS OVERBURDEN
WATER TABLE CONTOUR MAP
March 1995
Plum Brook Ordnance Works
Sandusky, Ohio

DAMES & MOORE

the area, but information from other areas is also used to extrapolate the groundwater contours.

The maps of the groundwater elevations for the two measurement dates show similar directions of groundwater flow, but different gradients. The groundwater flow direction across the area is mainly from southwest to northeast, with the March 1995 measurements showing a more pronounced easterly component of groundwater flow. In December 1994, the groundwater levels reflect a significantly steeper groundwater gradient across the area than in March 1995.

During December 1994 (Figure 5-17), the groundwater table surface has a relatively steep gradient in the vicinity of the former ponds, with an elevation drop of approximately 6 feet from well PR-MW7 to well IT-MW5. During March 1995 (Figure 5-18), the gradient across the former ponds is less steep, with an elevation drop of only about 2 feet.

The depth to groundwater ranged from 7 to 15 feet for the wells in the area during December 1994, and ranged from 2 to 5 feet during March 1995. All overburden wells showed an increase in water levels in March 1995, with an average increase of nearly 7 feet. No apparent correlation exists between the thickness of overburden and groundwater levels or pattern of groundwater flow at the Pentolite Road Red Water Ponds.

Water levels were measured in two bedrock wells located in the vicinity of Pentolite Road Red Water Ponds, well BED-MW15 and the Reactor Well 2. Both wells are located north of the area. The bedrock is shale. Both bedrock wells experienced a decrease in measured groundwater levels between the two measurement dates, with well BED-MW15 decreasing about 5 feet and Reactor Well 2 decreasing nearly 13 feet.

The sitewide bedrock groundwater contour maps (Figures 5-6 and 5-7) indicate bedrock groundwater flow toward the northeast across the Pentolite Road Red Water Ponds region. The groundwater elevation differences between the overburden and the bedrock are the largest on the site, ranging between 28 and 30 feet. It is possible that very little hydraulic connection between the bedrock and overburden exists in this area,

based on two lines of evidence. First, the high head differences between the overburden and bedrock show a significant barrier to flow between the two hydrostratigraphic units. Second, the overburden wells increased in hydraulic head by an average of 7 feet during the same period that the bedrock wells both showed decreases in head.

5.2.6 General Conclusions

Several patterns emerge from the area specific groundwater flow analysis.

Correlation between the overburden thickness variation and the changes in overburden groundwater levels were observed at two areas. At both TNT Area A and TNT Area C, the largest variations in overburden groundwater levels were observed in the thickest overburden materials. At other areas, the variation in overburden thickness was not significant, and this correlation was not observed. Also, at TNT Area A, the magnitude of the horizontal gradients could be correlated with the thickness of the overburden.

Most of the areas had similar groundwater flow patterns during both measurement periods. TNT Area C showed the largest variation in both local groundwater flow patterns and gradients between December 1994 and March 1995. This area also had a significant local variation in overburden thickness, which may account for the variation in flow patterns and gradients. All areas had higher overburden groundwater levels during March 1995. The largest increase in groundwater levels occurred at TNT Area C, and the smallest increase at TNT Area B.

All areas also showed significantly higher groundwater levels in the overburden than the underlying bedrock. The greatest differences occurred at the Pentolite Road Red Water Ponds, and the smallest differences occurred at the West Area Red Water Ponds. The West Area Red Water Ponds area is the only area located in limestone bedrock, which may account for the close hydraulic connection between the overburden and bedrock in this area.

Local overburden groundwater gradients range from a low of 0.004 ft/ft at TNT Area B to a high of 0.02 ft/ft at TNT Area C. The vertical gradients ranged from 0.1 to 1.0 ft/ft in most areas. The vertical gradients are up to two orders of magnitude higher than the horizontal gradients in all areas.

6.0 GROUNDWATER QUALITY

Groundwater samples were collected from 16 wells completed in the overburden hydrostratigraphic unit and nine wells completed in the bedrock. Samples from all 25 wells were analyzed for explosives residues, nitrates, and total and dissolved concentrations of 14 metals, the 13 priority pollutant metals plus manganese. Samples from the nine bedrock wells were also analyzed for VOCs and SVOCs. The analysis of the laboratory results and data evaluation, including the establishment of a PQL for explosives residues compounds, were previously discussed in Section 4.0. Copies of the laboratory reports, which list explosives residues concentrations detected above the MDL but below the PQL, are included in Appendix I.

The analytical results for explosives residues, nitrates, metals, VOCs, and SVOCs are discussed in Sections 6.1, 6.2, 6.3, 6.4, and 6.5, respectively. Measurements of pH, specific conductance, and temperature were gathered during sample collection. These measurements are discussed in Section 6.6. A summary of the groundwater quality is provided in Section 6.7.

6.1 EXPLOSIVES RESIDUES

Explosives residues were detected at concentrations above the PQL in eight of the 16 overburden wells and six of the nine bedrock wells. Nitroaromatics concentrations above the PQL are listed in Table 6-1 and illustrated on Figure 6-1.

By far the highest concentrations of explosives residues were detected in the groundwater in the overburden hydrostratigraphic unit at the two former red water ponds areas. Nine nitroaromatics, 2,4,6-TNT, 1,3,5-TNB, 2,4-DNT, 2,6-DNT, 4-Am-2-NT, 3,4-DNT, 4-Am-DNT, 2-Am-DNT, and 1,3-DNB, were each detected in at least one well at each of the former red water ponds areas. Concentrations of 1,3,5-TNB, 2,4-DNT, 4-Am-2-NT, and 1,3-DNB at the Pentolite Road Red Water Ponds were significantly higher than at the West Area Red Water Ponds. Concentrations of the other five compounds were comparable in both areas.

TABLE 6-1
EXPLOSIVES RESIDUES CONCENTRATIONS
GROUNDWATER MONITORING WELLS

	Sample ID	2,4,6-TNT	1,3,5-TNB	NB	2,4-DNT	2,6-DNT	4-Am-2-NT	3,4-DNT	4-Am-DNT	2-Am-DNT	2-NT	3-NT	4-NT	2-Am-4-NT	1,3-DNB
West Area Red Water Ponds	DM-MW2	34	550		320	12		75		5.7					470
	IT-MW02		390		340	24	14		5.1						340
	MK-MW11														
	WA-S16-P*		20,000		9,200	850	190	1,500	370	63			110	22	7,200
Pentolite Road Red Water Ponds	DM-MW07	30	5,700		980	17	66	11							3,000
	DM-MW08	64	1,300		440	33	37	41	10	11					790
	DM-MW09				9.5										49
	IT-MW05														
TNT Area A Overburden Wells	DM-MW10	10			11				8.7	31					
	DM-MW11														
	MK-MW22														
	MK-MW23											13			
	MK-MW24														
TNT Area B Overburden Wells	MK-MW16														
	MK-MW17	6.5										5.3			

Concentrations are listed in μg/L or ppb.

The sample IDs used in this table are abbreviated. For overburden wells, the ID is composed of two parts: the investigation for which the well was installed (e.g., DM = Dames & Moore, MK = MK Ferguson, IT = IT Corporation); and the well number (e.g. MW10). Bedrock wells are designated by "BED" and the well number.

All samples listed in the Sample ID column (column 2) were analyzed for all 14 nitroaromatic compounds listed across the top row of the table. Only concentrations above the Practical Quantitation Limit (PQL) are listed on the table. Concentrations corresponding to the blank boxes were either below the laboratory detection limit (BDL) or above BDL but less than the PQL.

G:\WP\C\COE\PLUM-BRO.OK\GROUND.WTR\TAB6-1.WPD

QC sample DM-MW22 is duplicate of DM-MW2.
QC sample DM-MW23 is duplicate of DM-MW10.
* Sample WA-S16-P at the West Area Red Water Ponds was a sample of groundwater collected from a test pit excavated on the north bank of the west pond.

TABLE 6-1
(Continued)

	Sample ID	2,4,6-TNT	1,3,5-TNB	NB	2,4-DNT	2,6-DNT	4-Am-2-NT	3,4-DNT	4-Am-DNT	2-Am-DNT	2-NT	3-NT	4-NT	2-Am-4-NT	1,3-DNB
TNT Area C Overburden Wells	DM-MW05														
	DM-MW06														
Bedrock Wells	BED-MW13											11			
	BED-MW14													11	
	BED-MW15														
	BED-MW16	7.8	22			7.0						18			
	BED-MW17														
	BED-MW18														
	BED-MW19											8.1			
	BED-MW20											53			
	Reactor Well 2							13				23			
QA Samples	DM-MW21														
	DM-MW22	26	570		250	10				5.2					400
	DM-MW23	10			10				7.9	29					
	Drill Water		13												

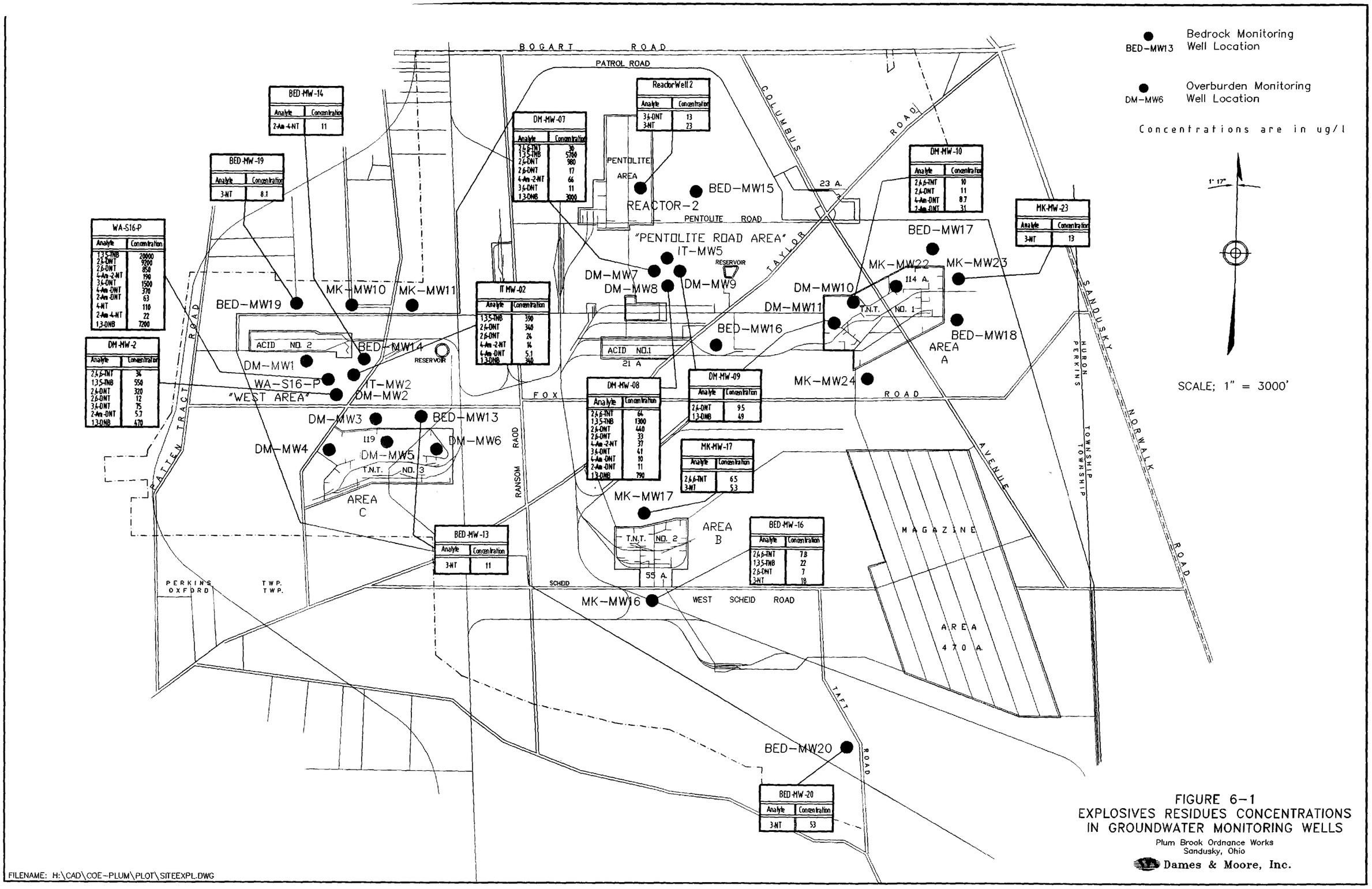
Concentrations are listed in $\mu g/L$ or ppb.

The sample IDs used in this table are abbreviated. For overburden wells, the ID is composed of two parts: the investigation for which the well was installed (e.g., DM = Dames & Moore, MK = MK Ferguson, IT = IT Corporation); and the well number (e.g. MW10). Bedrock wells are designated by "BED" and the well number.

All samples listed in the Sample ID column (column 2) were analyzed for all 14 nitroaromatic compounds listed across the top row of the table. Only concentrations above the Practical Quantitation Limit (PQL) are listed on the table. Concentrations corresponding to the blank boxes were either below the laboratory detection limit (BDL) or above BDL but less than the PQL.

G:\WP\C\COE\PLUM-BRO.OK\GROUND.WTR\TAB6-1.WPD

QC sample BED-MW21 is a duplicate of BED-MW18.
QC sample DM-MW22 is a duplicate of DM-MW2.
QC sample DM-MW23 is a duplicate of DM-MW10.



BED-MW-14	
Analyte	Concentration
2-Am-4-NT	11

BED-MW-19	
Analyte	Concentration
3-NT	8.1

WA-S16-P	
Analyte	Concentration
1,3,5-TNB	20000
2,4-DNT	9200
2,6-DNT	850
4-Am-2-NT	190
3,4-DNT	1500
4-Am-DNT	370
2-Am-DNT	63
4-NT	110
2-Am-4-NT	22
1,3-DNB	7200

DM-MW-2	
Analyte	Concentration
2,4,6-TNT	34
1,3,5-TNB	550
2,4-DNT	320
2,6-DNT	12
3,4-DNT	75
2-Am-DNT	5.7
1,3-DNB	470

DM-MW-07	
Analyte	Concentration
2,4,6-TNT	30
1,3,5-TNB	5700
2,4-DNT	980
2,6-DNT	17
4-Am-2-NT	66
3,4-DNT	11
1,3-DNB	3000

Reactor Well 2	
Analyte	Concentration
3,4-DNT	13
3-NT	23

IT MW-02	
Analyte	Concentration
1,3,5-TNB	390
2,4-DNT	340
2,6-DNT	24
4-Am-2-NT	14
4-Am-DNT	5.1
1,3-DNB	340

DM-MW-08	
Analyte	Concentration
2,4,6-TNT	64
1,3,5-TNB	1300
2,4-DNT	440
2,6-DNT	33
4-Am-2-NT	37
3,4-DNT	41
4-Am-DNT	10
2-Am-DNT	11
1,3-DNB	790

DM-MW-09	
Analyte	Concentration
2,4-DNT	95
1,3-DNB	49

MK-MW-17	
Analyte	Concentration
2,4,6-TNT	65
3-NT	53

BED-MW-13	
Analyte	Concentration
3-NT	11

BED-MW-16	
Analyte	Concentration
2,4,6-TNT	7.8
1,3,5-TNB	22
2,6-DNT	7
3-NT	18

DM-MW-10	
Analyte	Concentration
2,4,6-TNT	10
2,4-DNT	11
4-Am-DNT	8.7
2-Am-DNT	31

MK-MW-23	
Analyte	Concentration
3-NT	13

BED-MW-20	
Analyte	Concentration
3-NT	53

FIGURE 6-1
EXPLOSIVES RESIDUES CONCENTRATIONS
IN GROUNDWATER MONITORING WELLS
Plum Brook Ordnance Works
Sandusky, Ohio
Dames & Moore, Inc.

H:\C COE-PLUM\PLOT\SITEEXPL Thu Apr 03 22:19:03 1997 Dame: Moore - Atlanta, GA

6.1.1 Pentolite Road Red Water Ponds

The highest concentrations of explosives residues detected were in samples collected from the Pentolite Road Red Water Ponds wells DM-MW7 and DM-MW8. Explosives residues were also detected in one of the two other overburden wells, DM-MW9, and in one of the two bedrock wells, Reactor Well 2.

Seven explosives residues were detected in well DM-MW7. Of these, three were present at much higher concentrations than the others. 1,3,5-TNB, 1,3-DNB, and 2,4-DNT were reported at concentrations of 5,700 μg/L, 3,000 μg/L, and 980 μg/L, respectively. These three nitroaromatics are among the compounds removed from TNT in the washing process that generates the "red water." 4-Am-2-NT, a product plant mediated biotransformation of 2,4-DNT was present at a concentration of 66 μg/L. The other three nitroaromatics, 2,4,6-TNT, 2,6-DNT, and 3,4-DNT were each present at concentrations of 30 μg/L or less.

Groundwater monitoring well DM-MW7 was installed coincident with soil boring PR-S4 in the southern portion of the western pond. Soil samples were collected from the upper 10 feet of the boring. Relatively low levels of explosives residues were detected. However, red water was noted in the split spoon samples retrieved as the boring was advanced below 10 feet.

Significant levels of nitroaromatics were also detected in well DM-MW8, which was installed in soil boring PR-S14. The purge and sample water bailed from well DM-MW8 during the sampling process was red. The highest levels of explosives residues detected in the soils at the Pentolite Road Red Water Ponds were present in this boring. As with well DM-MW7, the nitroaromatics reported at the highest levels were 1,3,5-TNB, 1,3-DNB, and 2,4-DNT. The concentrations were 1,300 μg/L, 790 μg/L, and 440 μg/L, respectively. 2,4,6-TNT, which was detected at very high levels in the soil samples collected from 3 to 10 feet in the boring for this well, was detected in the groundwater sample at a concentration of 64 μg/L. Two other components of red water, 2,6-DNT and 3,4-DNT, were detected at concentrations of 33 μg/L and 41 μg/L, respectively. Also, three biotransformation products were detected. 4-Am-2-NT

was detected at a concentration of 37 μg/L. 4-Am-DNT and 2-Am-DNT, microbially mediated biotransformation products of TNT, were also detected.

Only two nitroaromatics were detected in the sample collected from overburden well DM-MW9. 1,3-DNB and 2,4-DNT were detected at concentrations of 49 μg/L and 9.5 μg/L, respectively. This well is located on the eastern boundary of the Pentolite Road Red Water Ponds and, based on a 1956 aerial photograph, is just outside the pond perimeter. However, as stated in Section 5, it is possible that the pond configuration was larger during plant operation and that this location was at one time within the pond area.

No explosives residues were detected in the sample collected from overburden well IT-MW5, which is located on the downgradient side of the Pentolite Road Red Water Ponds.

No explosives residues were detected in the sample collected from bedrock well BED-MW15, which is located downgradient of the former pond area. However, low levels of two nitroaromatics were detected in Reactor Well 2 which is also located on the north, or downgradient, side of the former pond area. 3-NT and 3,4-DNT were detected at concentrations of 23 μg/L and 13 μg/L, respectively.

6.1.2 West Area Red Water Ponds

Explosives residues were detected at concentrations above the PQL in two of the three overburden wells and both of the bedrock wells at the former West Area Red Water Ponds. Nitroaromatics were also detected in a groundwater sample collected from a test pit excavated on the north side of the western pond.

The nitroaromatics concentrations detected in the groundwater in the overburden at the West Area Red Water Ponds were significantly lower than those detected in the samples from wells DM-MW7 and DM-MW8 at the Pentolite Road Red Water Ponds. However, in both areas the highest concentrations were detected for 1,3,5-TNB, 1,3-DNB, and 2,4-DNT. 1,3,5-TNB was detected in wells DM-MW2 and IT-MW2, at

concentrations of 560 μg/L (average of two duplicate samples) and 390 μg/L, respectively. 1,3-DNB and 2,4-DNT were detected at slightly lower levels in each well. 2,4,6-TNT was detected only in the sample collected from well DM-MW2 at a concentration of 30 μg/L (average of two duplicate samples). Biotransformation products were present in both wells.

No explosives residues were detected in the sample collected from the third overburden well MK-MW11.

It is noteworthy that the highest concentrations of explosives residues in a groundwater sample from the West Area Red Water Ponds were reported in a sample of water retrieved from the bottom of a test pit excavated on the north side of the west pond. NASA excavated a pit where soil boring WA-S16 had been installed approximately 5 feet from the north bank of the west pond. Total depth of the pit was estimated as approximately 10 feet. Red water collected in the bottom of the pit immediately following excavation. A sample of the water was collected for laboratory analysis. Nine of the 14 explosives residues analytes were detected in this sample, some at significant concentrations noted on Table 6-1. 1,3,5-TNB was present at a concentration of 20,000 μg/L and 1,3-DNB was present at a concentration of 7,200 μg/L. Other components of red water that were also present in this sample were: 2,4-DNT at a concentration of 9,200 μg/L; 2,6-DNT at a concentration of 850 μg/L; 3,4-DNT at a concentration of 1,500 μg/L; and 4-NT at a concentration of 110 μg/L. Four biotransformation products were also present in this sample: 4-Am-2-NT at a concentration of 190 μg/L; 2-Am-4-NT at a concentration of 22 μg/L; 4-Am-DNT at a concentration of 370 μg/L; and 2-Am-DNT at a concentration of 63 μg/L. These nitroaromatics concentrations are significantly higher than the concentration detected in the groundwater monitoring wells at the West Area Red Water Ponds and indicate that red water contamination is present in the immediate vicinity of the west pond at concentrations comparable to those observed at the Pentolite Road Red Water Ponds.

QC sample DM-MW22 was a duplicate of sample DM-MW2. Six nitroaromatics were detected in each of the duplicate samples at comparable concentrations. 3,4-DNT was

detected at a concentration of 75 μg/L in one sample, but was not detected in the other sample.

Low levels of nitroaromatics were detected in each of the bedrock wells at the West Area Red Water Ponds. Only one compound was detected per well. 2-Am-4-NT, a biotransformation product of DNT was detected at a concentration of 11 μg/L in well BED-MW14 which was installed near overburden well IT-MW2. 3-NT was reported at a concentration of 8.1 μg/L in well BED-MW19 which is located along the northern property boundary.

6.1.3 TNT Area A

Explosives residues were detected at concentrations above the PQL in two of the five overburden wells. No explosives residues were detected in either of the two bedrock wells installed in TNT Area A.

The sample from well DM-MW10 contained four explosives residues. The average concentrations detected in the two duplicate samples were: 10.0 μg/L of 2,4,6-TNT, 10.5 μg/L of 2,4-DNT, 8.3 μg/L of 4-Am-DNT, and 30 μg/L of 2-Am-DNT. This well is located immediately downgradient of the Wash House for manufacturing line 3. Two of these same compounds, 2,4,6-TNT and 2-Am-DNT were also detected in a soil sample from boring TNTA-S5 which was installed closest to the location of Well DM-MW10. The presence of two biodegradation products in this sample, 4-Am-DNT and 2-Am-DNT, indicates that natural degradation of the nitroaromatics is occurring in this area.

3-NT was the only explosives residue detected in overburden well MK-MW23. It was present at a concentration of 13 μg/L. This well is located northwest of the Wash House for line 1. Well MK-MW23 had been installed and sampled for explosives residues by MK Ferguson in their 1993 investigation. No explosives residues were detected in that investigation. However, the analytical laboratory method for detecting low levels of explosives residues has been refined since 1993.

No explosives residues were detected above the PQL in the three other overburden wells, DM-MW11, MK-MW22, or MK-MW24, in TNT Area A or in either of the two bedrock wells, BED-MW17 and BED-MW18. Explosives residues were also not detected in wells MK-MW22 or MK-MW24 in the 1993 MK Ferguson investigation.

QC sample DM-MW23 was a duplicate of sample DM-MW10. The same four explosives residues compounds were found in both samples at very consistent concentrations. Additionally, QC sample BED-MW21 was a duplicate of sample BED-MW18. No explosives residues compounds were detected at concentrations above the PQL in either sample.

6.1.4 TNT Area B

Explosives residues were detected at concentrations above the PQL in overburden well MK-MW17, the well which is installed on the downgradient side of TNT Area B east of the Waste Water Settling Basins. 2,4,6-TNT and 3-NT were detected at concentrations of 6.5 μg/L and 5.3 μg/L, respectively. No explosives residues were detected in the sample from well MK-MW16 which is located on the upgradient side of TNT Area B.

The presence of explosives residues in the groundwater in the overburden at TNT Area B is not surprising. Explosives residues are ubiquitous in the thin soil layer overlying bedrock in this area and the groundwater is very shallow. Therefore, migration of explosives residues into the groundwater in the overburden would be expected.

No explosives residues were detected in either of these two wells during the 1993 MK Ferguson investigation.

6.1.5 TNT Area C

No explosives residues were detected at concentrations above the PQL in either of the two overburden wells sampled at TNT Area C in December 1994. 3-NT was detected at a concentration of 11 μg/L in bedrock well BED-MW13.

6.1.6 Other Areas

Two bedrock wells were installed at locations away from the TNT manufacturing areas and red water ponds areas.

Well BED-MW16 was installed near the central set of toluene storage tanks on the east side of Taylor Road. Four explosives residues were detected in this well. 1,3,5-TNB, 3-NT, 2,4,6-TNT, and 2,6-DNT, were detected at concentrations of 22 μg/L, 18 μg/L, 7.8 μg/L, and 7.0 μg/L, respectively.

The background bedrock well was installed on the south side of the site west of Taft Road in an area thought to be uninfluenced by PBOW operations. However, the highest single concentration of explosives residues in the bedrock aquifer was detected in this well. 3-NT was reported at a concentration of 53 μg/L. No other nitroaromatics were detected in the sample collected from this well.

6.2 NITRATES

Nitrate levels are considered significant at the former PBOW when they exceed the EPA established Maximum Contaminant Level (MCL) of 10 milligrams per liter (mg/L). As the nitrate data on Table 6-2 indicates, nitrate concentrations exceeded 10 mg/L in only five of the 25 wells samples. In all cases, the elevated nitrate levels correspond to elevated levels of explosives residues.

The highest nitrate levels were detected in the three Pentolite Road Red Water Ponds overburden wells in which high levels of explosives residues were detected. In wells

TABLE 6-2

NITRATE CONCENTRATIONS IN GROUNDWATER

	Sample ID	Nitrates (mg/L)
West Area Red Water Ponds Overburden Wells	DM-MW2	15
	IT-MW2	12
	MK-MW11	0.2
Pentolite Road Red Water Ponds Overburden Wells	DM-MW7	80
	DM-MW8	650
	DM-MW9	50
	IT-MW5	0.1
TNT Area A Overburden Wells	DM-MW10	0.3
	DM-MW11	0.2
	MK-MW22	0.3
	MK-MW23	0.3
	MK-MW24	0.5
TNT Area B Overburden Wells	MK-MW16	0.2
	MK-MW17	0.2
TNT Area C Overburden Wells	DM-MW5	0.2
	DM-MW6	1.4
Bedrock Wells	BED-MW13	BDL
	BED-MW14	3.3
	BED-MW15	0.5
	BED-MW16	BDL
	BED-MW17	0.2

BDL = Below Detection Limit

mg/L = milligrams per liter or ppm

The sample IDs used in this table are abbreviated. For overburden wells, the ID is composed of two parts: the investigation for which the well was installed (e.g., DM = Dames & Moore, MK = MK Ferguson, IT = IT Corporation); and the well number (e.g. MW10). Bedrock wells are designated by "BED" and the well number.

TABLE 6-2
(Continued)

	Sample ID	Nitrates (mg/L)
Bedrock Wells (Continued)	BED-MW18	0.2
	BED-MW19	0.2
	BED-MW20	0.2
	Reactor Well 2	0.2
QC Samples	BED-MW21	0.4
	DM-MW22	16
	DM-MW23	0.3
	Drill Water	0.3

QC sample BED-MW21 is a duplicate of BED-MW18.
QC sample DM-MW22 is a duplicate of DM-MW2.
QC sample DM-MW23 is a duplicate of DM-MW10.

BDL = Below Detection Limit

mg/L = milligrams per liter or ppm

The sample IDs used in this table are abbreviated. For overburden wells, the ID is composed of two parts: the investigation for which the well was installed (e.g., DM = Dames & Moore, MK = MK Ferguson, IT = IT Corporation); and the well number (e.g. MW10). Bedrock wells are designated by "BED" and the well number.

DM-MW7, DM-MW8, and DM-MW9, the nitrate concentrations were 80 mg/L, 650 mg/L, and 50 mg/L, respectively.

Nitrates were present at levels above the MCL in two of the three overburden wells at the West Area Red Water Ponds. Concentrations in wells DM-MW2 and IT-MW2 were 15 mg/L and 12 mg/L, respectively. Elevated levels of nitroaromatics were present in both of these wells.

The nitrate concentrations in duplicate samples DM-MW10 and DM-MW23 were both 0.3 mg/L. Additionally, the nitrate concentrations in duplicate samples BED-MW18 and BED-MW21 of 0.2 mg/L and 0.4 mg/L, respectively, compare favorably.

6.3 METALS

Groundwater samples from all wells were analyzed for total (unfiltered) and dissolved (filtered) concentrations of 14 metals, the 13 priority pollutant metals and manganese. The reported concentrations are listed on Table 6-3 and are illustrated on Figure 6-2.

Mercury, selenium, and silver were not detected in any of the groundwater samples. Concentrations of the 11 metals that were detected are discussed below.

6.3.1 Antimony

Antimony was detected in eight wells, three completed in the overburden and five completed in bedrock. In seven of the eight wells, antimony was detected only in the filtered sample. As stated in Section 4, antimony was detected in the filtered equipment blank sample. It is probable that the antimony concentrations in the filtered samples are related to the sample collection process and are not representative of groundwater conditions at the site.

The three overburden wells in which antimony was detected are located in the former TNT manufacturing areas. Antimony was reported in one overburden well in each

TABLE 6-3

METALS CONCENTRATIONS
GROUNDWATER MONITORING WELLS

	Sample ID	Antimony	Arsenic	Beryllium	Cadmium	Chromium	Copper	Lead	Manganese	Mercury	Nickel	Selenium	Silver	Thallium	Zinc
West Area Red Water Ponds Overburden Wells	DM-MW2-U					14	38	10	1,600		63				88
	DM-MW2-F						20		1,000		60				
	IT-MW2-U						140		2,300		120				34
	IT-MW2-F						130		2,500		130				
	MK-MW11-U								160						30
	MK-MW11-F								180						
Pentolite Road Red Water Ponds Overburden Wells	DM-MW7-U					36	1,400		12,000		2,000			0.9	94
	DM-MW7-F					21	1,100		10,000		1,800			0.7	44
	DM-MW8-U					52	1,600		8,000		2,500				52
	DM-MW8-F					38	1,400		7,000		2,100				50
	DM-MW9-U						770		1,800		1,500				60
	DM-MW9-F						760		1,800		1,600				70
	IT-MW5-U								100						27
	IT-MW5-F								100						
TNT Area A Overburden Wells	DM-MW10-U							7	980						110

Concentrations are listed in µg/L or ppb.

All samples listed in the Sample ID Column (column 2) were analyzed for all 14 metals listed across the top row of the table. Only concentrations above the detection limit are listed on the table. Concentrations corresponding to the blank boxes were below the laboratory detection limit.

The sample IDs used in this table are abbreviated. For overburden wells, the ID is composed of two parts: the investigation for which the well was installed (e.g., DM = Dames & Moore, MK = MK Ferguson, IT = IT Corporation); and the well number (e.g. MW10). Bedrock wells are designated by "BED" and the well number.

Sample DM-MW2 is a duplicate of QC sample DM-MW22.
Sample DM-MW10 is a duplicate of QC sample DM-MW23.

TABLE 6-3
(Continued)

	Sample ID	Antimony	Arsenic	Beryllium	Cadmium	Chromium	Copper	Lead	Manganese	Mercury	Nickel	Selenium	Silver	Thallium	Zinc
TNT Area A Overburden Wells (Continued)	DM-MW10-F								960						
	DM-MW11-U		10			29	21	14	1,300		46				74
	DM-MW11-F	5							710						
	MK-MW22-U								280						20
	MK-MW22-F								190						
	MK-MW23-U								460		47				53
	MK-MW23-F								240		30				20
	MK-MW24-U								310						21
	MK-MW24-F								220						
TNT Area B Overburden Wells	MK-MW16-U			2			35	6	14,000		150			2.3	160
	MK-MW16-F			2					17,000		180			2.6	140
	MK-MW17-U		13		2		37	9	2,200		320			0.9	250
	MK-MW17-F	2							2,300		320				200
TNT Area C Overburden Wells	DM-MW5-U							13	570						52
	DM-MW5-F	8							460						
	DM-MW6-U							5	1,400		29				34
	DM-MW6-F								1,600		20				

Concentrations are listed in $\mu g/L$ or ppb.

All samples listed in the Sample ID Column (column 2) were analyzed for all 14 metals listed across the top row of the table. Only concentrations above the detection limit are listed on the table. Concentrations corresponding to the blank boxes were below the laboratory detection limit.

The sample IDs used in this table are abbreviated. For overburden wells, the ID is composed of two parts: the investigation for which the well was installed (e.g., DM = Dames & Moore, MK = MK Ferguson, IT = IT Corporation); and the well number (e.g. MW10). Bedrock wells are designated by "BED" and the well number.

Sample DM-MW10 is a duplicate of QC sample DM-MW23.

TABLE 6-3
(Continued)

	Sample ID	Antimony	Arsenic	Beryllium	Cadmium	Chromium	Copper	Lead	Manganese	Mercury	Nickel	Selenium	Silver	Thallium	Zinc
Bedrock Wells	BED-MW13-U														23
	BED-MW13-F	14													
	BED-MW14-U													0.5	28
	BED-MW14-F														
	BED-MW15-U						40							0.6	22
	BED-MW15-F	18													
	BED-MW16-U	3							280						30
	BED-MW16-F														34
	BED-MW17-U		18												
	BED-MW17-F	7	15												
	BED-MW18-U						36		89						20
	BED-MW18-F								80						
	BED-MW19-U						22							0.6	24
	BED-MW19-F	8													
	BED-MW20-U						54		140						24
	BED-MW20-F								140						
	Reactor Well 2-U						20	9.6	470		70				90
	Reactor Well 2-F						20		120						

Concentrations are listed in µg/L or ppb.

All samples listed in the Sample ID Column (column 2) were analyzed for all 14 metals listed across the top row of the table. Only concentrations above the detection limit are listed on the table. Concentrations corresponding to the blank boxes were below the laboratory detection limit.

The sample IDs used in this table are abbreviated. For overburden wells, the ID is composed of two parts: the investigation for which the well was installed (e.g., DM = Dames & Moore, MK = MK Ferguson, IT = IT Corporation); and the well number (e.g. MW10). Bedrock wells are designated by "BED" and the well number.

Sample BED-MW18 is a duplicate of QC sample BED-MW21.

TABLE 6-3
(Continued)

	Sample ID	Antimony	Arsenic	Beryllium	Cadmium	Chromium	Copper	Lead	Manganese	Mercury	Nickel	Selenium	Silver	Thallium	Zinc
QC Samples	BED-MW21-U						36		90						27
	BED-MW21-F								80						20
	DM-MW22-U						32	4	1,800		47			0.5	63
	DM-MW22-F						20		970		60				
	DM-MW23-U							7	880						34
	DM-MW23-F								830						
	Drill Water-U						20	3.1							110
	Drill Water-F	10													240

QC sample BED-MW21 is a duplicate of BED-MW-18.
QC sample DM-MW22 is a duplicate of DM-MW2.
QC sample DM-MW23 is a duplicate of DM-MW10.

Concentrations are listed in µg/L or ppb.

All samples listed in the Sample ID Column (column 2) were analyzed for all 14 metals listed across the top row of the table. Only concentrations above the detection limit are listed on the table. Concentrations corresponding to the blank boxes were below the laboratory detection limit.

The sample IDs used in this table are abbreviated. For overburden wells, the ID is composed of two parts: the investigation for which the well was installed (e.g., DM = Dames & Moore, MK = MK Ferguson, IT = IT Corporation); and the well number (e.g. MW10). Bedrock wells are designated by "BED" and the well number.

G:\WP\C\COE\PLUM-BRO.OK\GROUND.WTR\TAB6-3

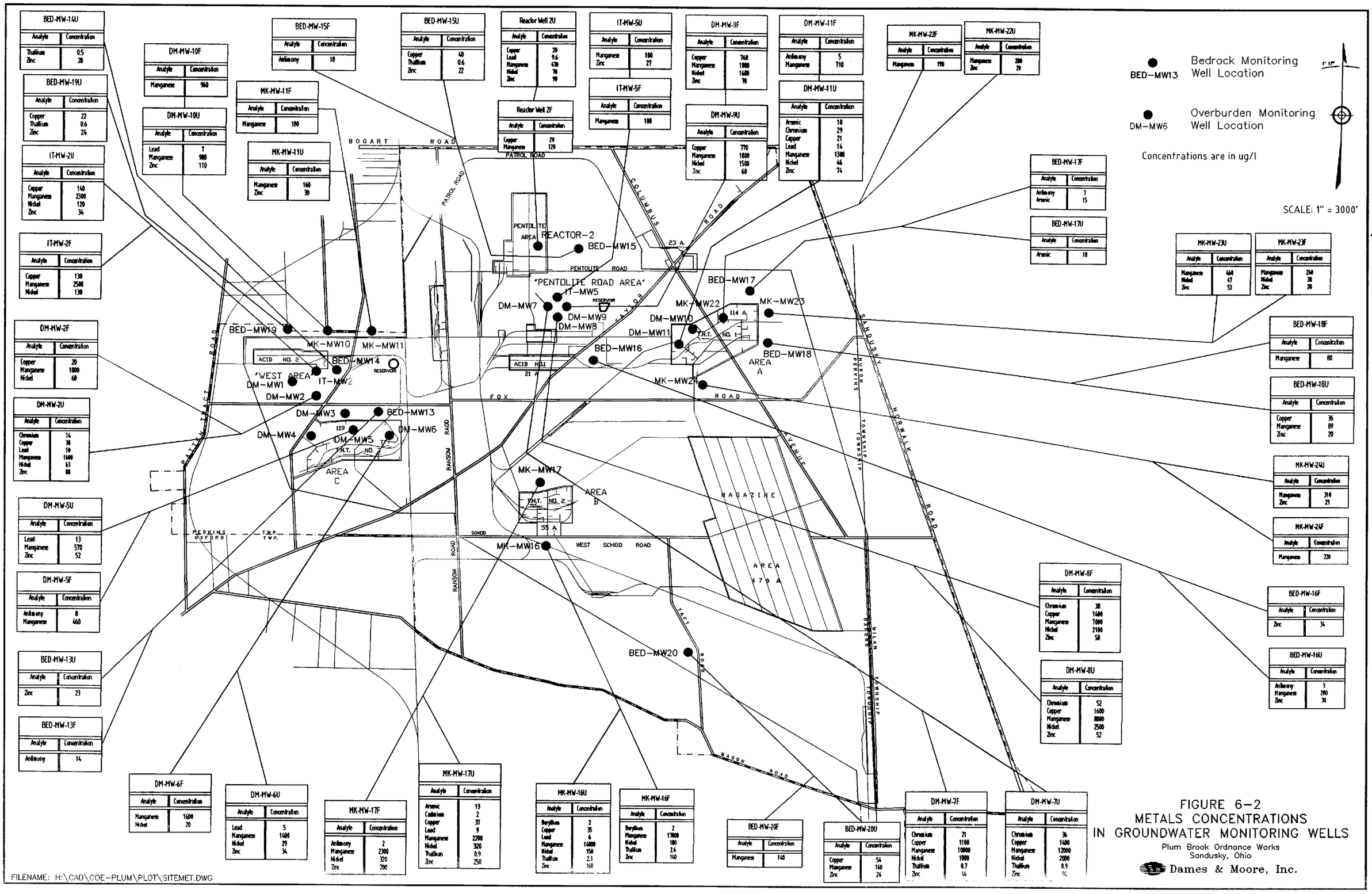


FIGURE 6-2
METALS CONCENTRATIONS
IN GROUNDWATER MONITORING WELLS

Plum Brook Ordnance Works
Sandusky, Ohio

Dames & Moore, Inc.

FILENAME: H:\CAD\COE-PLUM\PLOT\SITEMET.DWG

H:\CAD\COE-PLUM\PLOT\SITEMET Thu Apr 03 22:22:53 1997 Dames & Moore - Atlanta, GA

area. In TNT Area A, antimony was detected in the filtered sample from overburden well DM-MW11 at a concentration of 5 μg/L. In TNT Area B, antimony was detected only in the filtered sample collected from well MK-MW17 at a concentration of 2 μg/L. In overburden well DM-MW5, located in TNT Area C, the antimony concentration in the filtered sample was 8 μg/L.

Antimony was detected in five bedrock wells. In four wells, BED-MW13, BED-MW15, BED-MW17, and BED-MW19, the antimony concentrations were 14 μg/L, 18 μg/L, 7 μg/L, and 8 μg/L, respectively, in the filtered samples. Wells BED-MW13 and BED-MW17 are located at TNT Areas C and A, respectively. Wells BED-MW15 and BED-MW19 are located at the Pentolite Road Red Water Ponds and West Area Red Water Ponds, respectively. Only in well BED-MW16, located near the central toluene storage tanks, was antimony detected in the unfiltered sample at a concentration of 3 μg/L.

In five of the eight wells in which antimony was detected, DM-MW5, BED-MW13, BED-MW15, BED-MW17, and BED-MW19, the antimony concentration exceeded the MCL of 6 μg/L. However, all of these results are for suspect filtered samples. The only antimony result for an unfiltered sample, in well BED-MW16, was below the MCL.

6.3.2 Arsenic

Arsenic was detected in three wells, two completed in the overburden and one in bedrock. All three wells are located in former TNT areas. Arsenic was detected in overburden well DM-MW11, located at TNT Area A, and overburden well MK-MW17, located at TNT Area B. Concentrations were 10 μg/L and 13 μg/L, respectively. In both cases, arsenic was detected only in the unfiltered samples. Based on the fact that arsenic was not detected in the filtered samples in either overburden well, it appears that the arsenic in the samples from the overburden wells are related to particulate matter in the samples.

In bedrock well BED-MW17, located in TNT Area A, arsenic was detected in both the unfiltered and filtered samples at concentrations of 18 μg/L and 15 μg/L, respectively.

Because arsenic was detected in both the filtered and unfiltered samples, it is likely that arsenic is present in the bedrock aquifer in this area in the dissolved phase.

All arsenic concentrations are below the MCL of 50 μg/L.

6.3.3 Beryllium

Beryllium was detected in only one groundwater sample, collected from well MK-MW16 in TNT Area B. The concentrations in both the unfiltered and filtered samples were 2 μg/L. This concentration is below the MCL of 4 μg/L.

Because beryllium was detected in both the filtered and unfiltered samples, it is likely that it is present in the dissolved phase in well MK-MW16. Additionally, because beryllium was detected in several of the soil samples collected from TNT Area B, it is probably naturally occurring.

6.3.4 Cadmium

Cadmium was detected only in the unfiltered sample from well MK-MW17, located at former TNT Area B. The concentration of 2 μg/L is below the MCL of 5 μg/L.

As cadmium was not detected in the filtered sample from well MK-MW17, it is possible that its presence is related to particulate matter suspended in the groundwater.

6.3.5 Chromium

Chromium was detected in four overburden wells, two located at the Pentolite Road Red Water Ponds, one at the West Area Red Water Ponds, and one at former TNT Area A. Chromium was not detected in any of the bedrock wells.

The highest chromium concentrations were reported for overburden wells DM-MW7 and DM-MW8 at the Pentolite Road Red Water Ponds. These are the two wells in which the highest nitroaromatics concentrations were detected. Chromium was detected in both the filtered and unfiltered samples. In both cases, the concentration in the unfiltered sample was about 50 percent higher than in the filtered samples. The concentrations in the unfiltered samples were 36 μg/L and 52 μg/L, respectively for wells DM-MW7 and DM-MW8. The corresponding concentrations in the filtered samples were 21 μg/L and 38 μg/L, respectively. Therefore, it is likely that some of the chromium in the unfiltered samples is related to particulate matter, but chromium does appear to be present in the dissolved phase in the groundwater in this area.

In the other two wells in which chromium was detected, well DM-MW11 at TNT Area A and well DM-MW2 at the West Area Red Water Ponds, chromium was detected only in the unfiltered samples. The concentrations in wells DM-MW11 and DM-MW2 were 29 μg/L and 14 μg/L, respectively. As chromium was not detected in the filtered samples from either well, it is likely that the concentrations in the unfiltered samples are related to presence of particulate matter. This is supported by the fact that chromium was not reported in the duplicate unfiltered sample from well DM-MW2.

All chromium concentrations detected are below the MCL of 100 μg/L.

6.3.6 Copper

Copper was detected in eight overburden wells and five bedrock wells. By far the highest concentrations of copper were detected in the overburden wells at the two red water ponds areas. The highest copper concentrations were in the wells with the highest levels of explosives residues.

Copper was detected in three of the four overburden wells, DM-MW7, DM-MW8, and DM-MW9 at the Pentolite Road Red Water Ponds and in two of the three overburden wells, DM-MW2 and IT-MW2, at the West Area Red Water Ponds.

The highest concentrations, 1,400 μg/L and 1,600 μg/L, were detected in the Pentolite Road Red Water Ponds wells DM-MW7 and DM-MW8, respectively. As noted above for chromium, these are the two wells in which red water has been observed. Much lower levels of explosives residues from red water were detected in well DM-MW9. The copper levels in the sample from this well, 770 μg/L in the unfiltered sample and 760 μg/L in the filtered sample, were half the levels detected in wells DM-MW7 and DM-MW8. Copper was not detected in overburden well IT-MW5. Also, no explosives residues were detected in well IT-MW5.

Copper concentrations at the West Area Red Water Ponds were significantly lower than at the Pentolite Road Red Water Ponds. This same pattern was observed for the explosives residues. The concentrations in well IT-MW2,140 μg/L and 130 μg/L in the unfiltered and filtered samples, respectively, were an order of magnitude higher than in well DM-MW2. In well DM-MW2 the concentrations in the unfiltered and filtered samples were 38 μg/L and 20 μg/L, respectively.

Copper was present in both the filtered and unfiltered samples from each of the five red water ponds areas overburden wells where it was detected. The concentrations in the unfiltered samples were slightly higher than in the filtered samples in all cases. This indicates that copper is probably present in the groundwater in these areas in the dissolved phase.

In the TNT areas, copper was present in only three of nine overburden wells. In each well, it was detected only in the unfiltered samples. Concentrations in wells DM-MW11, MK-MW16, and MK-MW17 were 21 μg/L, 35 μg/L, and 37 μg/L, respectively. As copper was not detected in the filtered samples, it is likely that the concentrations in the unfiltered samples are related to presence of particulate matter.

Copper was detected in five of the nine bedrock wells. In four of the five cases, it was detected in the unfiltered samples only indicating that it is likely not present in the dissolved phase. The concentrations in the unfiltered samples from wells BED-MW15, BED-MW18, BED-MW19, and BED-MW20 were 40 μg/L, 36 μg/L, 22 μg/L, and 54 μg/L, respectively. Copper was detected in both the filtered and unfiltered samples from Reactor Well 2 at concentrations of 20 μg/L.

The concentrations in all samples from overburden wells DM-MW7 and DM-MW8 were above the MCL of 1,300 μg/L. All other copper concentrations were below the MCL and the Secondary Maximum Contaminant Level (SMCL) of 1,000 μg/L.

6.3.7 Lead

Lead was detected at relatively low levels in about a third of the wells (eight of 25).

Interestingly, lead was not detected in any samples collected from the Pentolite Road Red Water Ponds overburden wells. At the West Area Red Water Ponds, lead was detected in only one groundwater sample. The concentration in the unfiltered sample collected from well DM-MW2 was 7 μg/L (average of two duplicate samples). No lead was present in either of the corresponding duplicate filtered samples.

Lead was detected in six of the nine samples collected from overburden wells in the former TNT areas. In each case, lead was detected only in the unfiltered sample. In wells DM-MW10 and DM-MW11 in TNT Area A, the concentrations were 7 μg/L and 14 μg/L, respectively. At TNT Area B, lead was detected in the unfiltered samples from wells MK-MW16 and MK-MW17 at concentrations of 6 μg/L and 9 μg/L, respectively. In wells DM-MW5 and DM-MW6 in TNT Area C, the concentrations were 13 μg/L and 5 μg/L, respectively.

Reactor Well 2, located north of the Pentolite Road Red Water Ponds, was the only bedrock well in which lead was detected. The concentration in the unfiltered samples was 9.6 μg/L.

Lead was only detected in unfiltered samples indicating it is probably related to particulate matter in the sample and is not dissolved in the groundwater. In any event, all reported lead concentrations are below the lead Action Level (AL) of 15 μg/L.

6.3.8 Manganese

Manganese was detected in all of the filtered and unfiltered groundwater samples collected from overburden wells. The highest concentrations were reported in TNT Area B in well MK-MW16. In this well, the concentrations in the unfiltered and filtered samples were 14,000 μg/L and 17,000 μg/L, respectively. In well MK-MW17, the concentrations were much lower, 2,200 μg/L and 2,300 μg/L, respectively, for the unfiltered and filtered samples.

Manganese concentrations were also very elevated in the samples from the Pentolite Road Red Water Ponds area. The highest concentrations, 12,000 μg/L in the unfiltered sample and 10,000 μg/L in the filtered sample, were reported in well DM-MW7. The manganese levels in well DM-MW8, 8,000 μg/L in the unfiltered sample and 7,000 μg/L in the filtered sample, were not substantially lower. Concentrations in well DM-MW9 were 1,800 μg/L in both the filtered and unfiltered samples. Nitroaromatics were detected in each of these three wells. The manganese concentrations of 100 μg/L in both the unfiltered and filtered samples from well IT-MW5 were an order of magnitude lower than those in wells DM-MW8 and DM-MW9 and two orders of magnitude lower than in well DM-MW7.

At the West Areas Red Water Ponds, manganese was detected at relatively high concentrations in two of the three overburden well samples. In wells IT-MW2 and MK-MW11, the manganese concentration in the filtered sample was slightly higher than in the unfiltered sample. Manganese levels were an order of magnitude lower in well MK-MW11, the well located north of the West Area Red Water Ponds along Patrol Road. In the two wells in or immediately adjacent to the ponds area, wells DM-MW2 and IT-MW2, the manganese concentrations were all 1,000 μg/L or more.

Manganese was also detected in both groundwater samples collected from overburden wells in TNT Area C. In each case, manganese was reported in both the filtered and unfiltered samples. The manganese concentration in the unfiltered sample from well DM-MW5 of 570 μg/L was higher than the concentration of 460 μg/L in the filtered sample. Conversely, the concentration in the filtered sample from well DM-MW6 of

1,600 μg/L was higher in the filtered sample than the concentration of 1,400 μg/L in the unfiltered sample.

In TNT Area A, manganese concentrations ranged from a low of 190 μg/L in the filtered sample from well MK-MW22 to a high of 1,300 μg/L in the sample collected from overburden well DM-MW11.

Manganese concentrations in the soils at the PBS were sampled in connection with the TNT Site Investigation and the Red Water Ponds Focused Remedial Investigation. The results of the analysis showed elevated levels of manganese in the soils in the investigation areas in relation to concentrations in soils collected from background areas. Elevated manganese levels are also apparent in the groundwater. No statistical relationship was established between the presence of explosives residues and manganese. However, the elevated manganese levels do appear to be coincident with elevated concentrations of other metals and explosives residues, particularly at the two red water ponds areas. At the former red water ponds areas, the samples in which the highest manganese concentrations were reported are also the samples containing elevated concentrations of copper, nickel, and zinc and explosives residues.

Manganese was not as ubiquitous in the bedrock groundwater. It was detected in only four of the nine wells. Concentrations in the unfiltered samples ranged from a low of 89.5 μg/L (average of two duplicate samples) in the sample collected from bedrock well BED-MW18 to a high of 470 in Reactor Well 2. In the filtered samples, concentrations ranged from 80 μg/L in well BED-MW18 to 140 μg/L in the background well BED-MW20.

Manganese values in all samples in which it was detected exceeded the SMCL of 50 μg/L. In some samples, particularly in TNT Area B and the Pentolite Road Red Water Ponds, the concentrations exceeded the SMCL by three orders of magnitude.

6.3.9 Nickel

Nickel was detected in ten of the fifteen overburden wells but in only one of the nine bedrock wells. By far the highest nickel concentrations were detected in the overburden wells at the Pentolite Road Red Water Ponds. Again, as with copper and manganese, the highest concentrations were in the wells with the highest levels of explosives residues. In overburden wells DM-MW7, DM-MW8, and DM-MW9, nickel concentrations ranged from 1,500 μg/L to 2,500 μg/L. All of these values exceed the MCL of 100 μg/L by an order of magnitude. Concentrations in the unfiltered samples from well DM-MW7 and DM-MW8 slightly exceeded the concentrations in the filtered samples. However, in well DM-MW9, the concentration of 1,600 μg/L in the filtered sample slightly exceeded the concentration of 1,500 μg/L in the unfiltered sample. Nickel was not detected in overburden well IT-MW5. Also, no explosives residues were detected in well IT-MW5.

Nickel concentrations at the West Area Red Water Ponds were significantly lower than at the Pentolite Road Red Water Ponds. Nickel was detected only in the two overburden wells installed immediately adjacent to the ponds area, wells IT-MW2 and DM-MW2. Concentrations in well IT-MW2 (120 μg/L for the unfiltered sample and 130 μg/L for the filtered sample) were about double concentrations in well DM-MW2 (55 μg/L for the unfiltered sample and 60 μg/L for the filtered sample averaged for two duplicate samples). In both wells, the concentration in the filtered samples was slightly higher than in the unfiltered samples. Also, the explosives residues concentrations in well IT-MW2 were an order of magnitude higher than in well DM-MW2. No nickel or explosives residues were reported in well MK-MW11.

In the TNT areas, nickel was present in five of nine overburden wells. In TNT Area A, nickel was detected at a concentrations of 47 μg/L and 30 μg/L in the unfiltered and filtered samples from well MK-MW23 and in the unfiltered sample from well DM-MW11 at a concentration of 46 μg/L. In TNT Area B, the nickel concentrations in the filtered samples were equal to or greater than the concentrations in the unfiltered samples. In well MK-MW16, the nickel concentrations in the unfiltered and filtered samples were 150 μg/L and 180 μg/L, respectively. Concentrations in the both samples from well MK-MW17 were 320 μg/L. Nickel was detected in only one of the

two wells at TNT Area C. The concentrations were 29 μg/L and 20 μg/L in the unfiltered and filtered samples, respectively, from well DM-MW6.

Nickel was detected in only one bedrock well. In the unfiltered sample from Reactor Well 2 the nickel concentration was 70 μg/L. It was not reported in the corresponding filtered sample.

The nickel concentrations in both wells at TNT Area B, in all three wells where it was detected at the Pentolite Road Red Water Ponds, and in well IT-MW2 at the West Area Red Water Ponds were above the MCL of 100 μg/L.

6.3.10 Thallium

Thallium was detected in three of the overburden well groundwater samples and three of the bedrock well samples. The highest concentrations, in well MK-MW16 in TNT Area B, were 2.6 μg/L in the filtered sample and 2.3 μg/L in the unfiltered sample. Both of these concentrations are above the MCL of 2 μg/L. In well MK-MW17, also located in TNT Area B, thallium was only detected in the unfiltered sample at a concentration of 0.9 μg/L.

Thallium was also detected at low levels in overburden well DM-MW7 at the Pentolite Road Red Water Ponds. Concentrations of 0.9 μg/L and 0.7 μg/L were reported in the unfiltered and filtered samples, respectively. In overburden well DM-MW2 at the West Area Red Water Ponds, thallium was detected at a concentration of 0.5 μg/L in one of two duplicate unfiltered samples. Thallium was not detected in the other duplicate unfiltered sample, in either of the duplicate filtered samples, or in any of the samples from either of the other overburden wells.

In the bedrock aquifer, thallium was detected in the unfiltered samples from three wells. The concentrations in wells BED-MW14 and BED-MW19, both at the West Area Red Water Ponds, were 0.5 μg/L and 0.6 μg/L, respectively. In well BED-MW15, located at the Pentolite Road Red Water Ponds, thallium was detected at a concentration of 0.6 μg/L in the unfiltered sample.

6.3.11 Zinc

Zinc was detected in all of the unfiltered samples collected from the overburden wells. In both wells in TNT Area B and in three of the four wells at the Pentolite Road Red Water Ponds, zinc was also detected in the filtered samples. On a sitewide basis, in the overburden wells, zinc concentrations in the unfiltered samples ranged from 20 μg/L in well MK-MW22 in TNT Area A to 250 μg/L in well MK-MW17 near the Waste Water Settling Basins in TNT Area B. In the filtered samples, concentrations ranged from 44 μg/L in well DM-MW7 at the Pentolite Road Red Water Ponds to 200 μg/L in well MK-MW17.

Zinc was also detected in the unfiltered samples from eight of the nine bedrock wells. It was only detected in the filtered sample from one well, BED-MW16. In this well, the concentration in the filtered sample, 34 μg/L, was slightly higher than the concentration in the unfiltered sample of 30 μg/L. Values in the filtered samples in the bedrock aquifer ranged from 20 μg/L in well BED-MW18 to 90 μg/L in the sample from Reactor Well 2.

Zinc values were all well below the SMCL of 5,000 μg/L.

6.4 VOCs

VOCs were analyzed only for the samples collected from the nine bedrock wells. Concentrations are listed on Table 6-4 and illustrated on Figure 6-3. Seven VOCs, acetone, benzene, 2-butanone, carbon disulfide, ethylbenzene, toluene, and xylenes, were detected in the bedrock wells. As is discussed below, low levels of three hydrocarbons were reported in the sample from the background well, BED-MW20. The other four VOCs were not detected in the background well.

QC sample BED-MW21 was a duplicate of sample BED-MW18. The same five VOCs, benzene, carbon disulfide, ethylbenzene, toluene, and xylenes, were detected in both samples at relatively similar concentrations.

TABLE 6-4

VOC AND SVOC CONCENTRATIONS IN BEDROCK WELLS

		VOCs							SVOCs		
	Sample ID	Acetone	Benzene	2-Butanone	Carbon Disulfide	Ethyl-benzene	Toluene	Xylenes	2,4-Dimethyl-phenol	2-Methyl-naphthalene	Naphthalene
Bedrock Wells	BED-MW13		50			82	190	720	10	24	28
	BED-MW14					1.6	3	14			
	BED-MW15	660	830		1,500	180	540	1,300		70	60
	BED-MW16	550	2,000	150		230	730	1,400		160	90
	BED-MW17	150	33			98	160	420		20	21
	BED-MW18		14		160	79	72	350	19		17
	BED-MW19	59	5		26	3	5	26			
	BED-MW20		8				4	3			
	Reactor Well 2		1.8			1.2		8			
QC Samples	BED-MW21		16		90	120	93	520	17		15
	Drill Water										

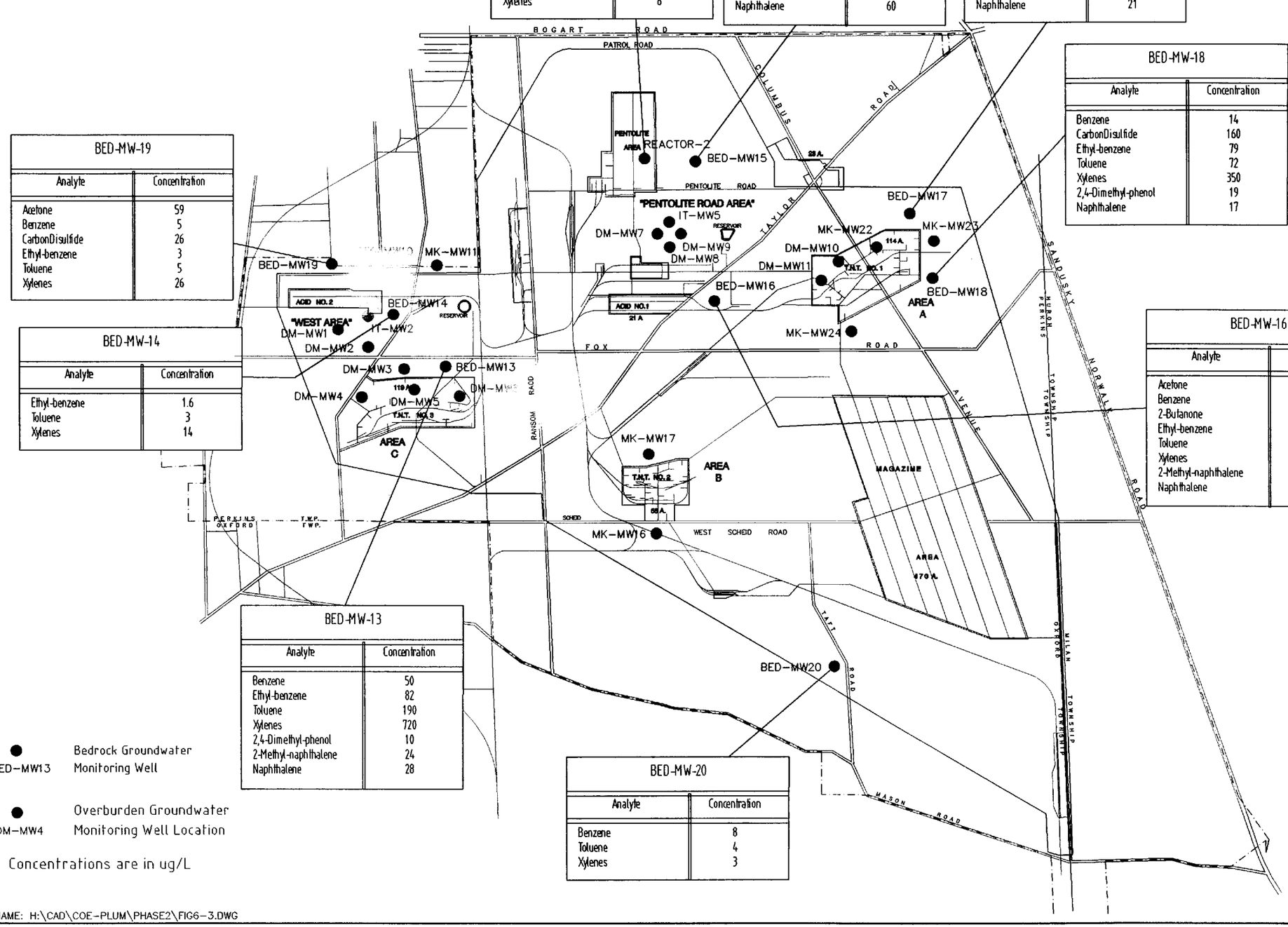
VOCs = volatile organic compounds
SVOCs = semivolatile organic compounds

QC sample BED-MW21 is a duplicate of BED-MW18.

Concentrations are listed in $\mu g/L$ or ppb.

The sample IDs used in this table are abbreviated. "BED" indicates a well completed in the bedrock. The well number is designated by MW (e.g., MW13).

All samples listed in the Sample ID column (column 2) were analyzed for all analytes on the VOC and SVOC method analysis lists. Only concentrations above the detection limit are listed on the table. Concentration corresponding to the blank boxes were below the laboratory limit.



BED-MW-15	
Analyte	Concentration
Acetone	660
Benzene	830
CarbonDisulfide	1500
Ethyl-benzene	180
Toluene	540
Xylenes	1300
2-Methyl-naphthalene	70
Naphthalene	60

Reactor Well 2	
Analyte	Concentration
Benzene	1.8
Ethyl-benzene	1.2
Xylenes	8

BED-MW-17	
Analyte	Concentration
Acetone	150
Benzene	33
Ethyl-benzene	98
Toluene	160
Xylenes	420
2-Methyl-naphthalene	20
Naphthalene	21

BED-MW-18	
Analyte	Concentration
Benzene	14
CarbonDisulfide	160
Ethyl-benzene	79
Toluene	72
Xylenes	350
2,4-Dimethyl-phenol	19
Naphthalene	17

BED-MW-19	
Analyte	Concentration
Acetone	59
Benzene	5
CarbonDisulfide	26
Ethyl-benzene	3
Toluene	5
Xylenes	26

BED-MW-14	
Analyte	Concentration
Ethyl-benzene	1.6
Toluene	3
Xylenes	14

BED-MW-16	
Analyte	Concentration
Acetone	550
Benzene	2000
2-Butanone	150
Ethyl-benzene	230
Toluene	730
Xylenes	1400
2-Methyl-naphthalene	160
Naphthalene	90

BED-MW-13	
Analyte	Concentration
Benzene	50
Ethyl-benzene	82
Toluene	190
Xylenes	720
2,4-Dimethyl-phenol	10
2-Methyl-naphthalene	24
Naphthalene	28

BED-MW-20	
Analyte	Concentration
Benzene	8
Toluene	4
Xylenes	3

● Bedrock Groundwater
BED-MW13 Monitoring Well

● Overburden Groundwater
DM-MW4 Monitoring Well Location

Concentrations are in ug/L

FIGURE 6-3
VOC AND SVOC CONCENTRATIONS
IN GROUNDWATER MONITORING WELLS

Plum Brook Ordnance Works
Sandusky, Ohio

Dames & Moore, Inc.

FILENAME: H:\CAD\COE-PLUM\PHASE2\FIG6-3.DWG

6.4.1 BTEX Compounds

One or more of the hydrocarbon compounds benzene, ethylbenzene, toluene, and xylenes (BTEX) were detected in all of the bedrock wells, including the background well. Previous investigations have indicated that low levels of BTEX compounds are ubiquitous in the soil and groundwater at the site. Low levels of benzene, toluene, and xylenes were detected in the groundwater sample from the background well, BED-MW20. The total BTEX concentration in background well BED-MW20 was 11 μg/L. The benzene concentration of 8 μg/L in this well was above the MCL of 5 μg/L.

The highest hydrocarbon levels, 2,850 μg/L total BTEX and 4,360 μg/L total BTEX, respectively, were detected in wells BED-MW15 and BED-MW16. These wells are both located in the north central portion of the site. Well BED-MW16 is installed near the central toluene tanks. An oily liquid was present in well BED-MW16. Well BED-MW15 is located downgradient of well BED-MW16, on the north side of Pentolite Road. The benzene concentrations in wells BED-MW15 and BED-MW16 of 830 μg/L and 2,000 μg/L, respectively, were both significantly above the MCL of 5 μg/L.

The total BTEX concentration in well BED-MW13 was 1,042 μg/L. This well is located along what is called "the EPA Road." Previously, this area was used for vehicle testing which may account for the high BTEX levels. The benzene concentration in well BED-MW13 of 50 μg/L is an order of magnitude above the MCL.

Significant levels of BTEX constituents were also present in the two bedrock wells located in the vicinity of former TNT Area A. Total BTEX concentrations in wells BED-MW17 and BED-MW18 were 711 μg/L and 632 μg/L (average of two duplicate samples), respectively. In both wells, the benzene concentrations, 33 μg/L in well BED-MW17 and 14 μg/L in well BED-MW18, were above the MCL.

Lower levels of BTEX were detected in the two West Area Red Water Ponds bedrock wells, BED-MW14 and BED-MW19. Three of the four BTEX compounds (ethylbenzene, toluene, and xylenes) were detected in both wells. Benzene was detected only in well BED-MW19 at a concentration of 5 μg/L, equal to the MCL. The total BTEX

concentration in well BED-MW19 was 39 μg/L. The total BTEX concentration in well BED-MW14 was only 18.6 μg/L.

Three of the four BTEX compounds, benzene, ethylbenzene, and xylenes, were detected in Reactor Well 2 at very low levels. The total BTEX concentration was 11 μg/L. This is the only bedrock well in which benzene was detected that the concentration was not above the MCL.

6.4.2 Acetone

Acetone was detected in four of the nine bedrock wells. It was not detected in the background bedrock well, BED-MW20. Acetone is a common solvent with a wide variety of common industrial uses. Acetone is also used in the manufacture of pentolite, one of the products of the PBOW.

The highest acetone concentration, 660 μg/L, was reported in Well BED-MW15. As discussed above, this is also one of the two wells with the highest levels of BTEX compounds.

The second highest concentration of acetone, 550 μg/L, was detected in the well with the highest BTEX concentration, well BED-MW16.

Acetone was also detected at somewhat lower levels in Wells BED-MW17, located at the former TNT Area A, and well BED-MW19, located north of Patrol Road north of the West Area Red Water Ponds. The concentrations in wells BED-MW17 and BED-MW19 were 150 μg/L and 59 μg/L, respectively.

6.4.3 2-Butanone

2-Butanone, or methyl ethyl ketone, was detected in only one well, BED-MW16. This well contained the highest concentration of BTEX compounds and an unidentified oily

liquid. This compound is a common additive in fuels and may be related to the hydrocarbons detected in this well.

6.4.4 Carbon Disulfide

Carbon disulfide, a VOC often related to petroleum hydrocarbons, coal tars, and crude hydrocarbons, was detected in three wells. The highest concentration, 1,500 μg/L, was reported in well BED-MW15, one of the two wells north of the former toluene storage tanks.

Carbon disulfide was also detected at significantly lower concentrations in two other wells. The concentration in well BED-MW18 was 125 μg/L (average of two duplicate samples). In well BED-MW19, the reported concentration was 26 μg/L.

6.5 SVOCs

SVOCs were also analyzed only for the samples collected from the nine bedrock wells. Table 6-4 lists the concentrations detected in each well. Three SVOCs, 2,4-dimethylphenol, 2-methylnaphthalene, and naphthalene, were detected in the bedrock wells.

No SVOCs were detected in the sample from the bedrock background well BED-MW20.

QC sample BED-MW21 was a duplicate of sample BED-MW18. The same two SVOCs, 2,4-dimethylphenol and naphthalene, were detected in both samples at almost identical concentrations.

6.5.1 2,4-Dimethylphenol

2,4-dimethylphenol was detected in only two wells, BED-MW13 and BED-MW18. The reported concentrations were 10 μg/L and 18 μg/L (average of two duplicate samples), respectively. 2,4-dimethylphenol is a naturally occurring, substituted phenol derived from the cresol fraction of petroleum or coal tars. It is also an additive to lubricants and gasolines. Its presence corresponds with two wells where elevated levels of BTEX were detected.

6.5.2 2-Methylnaphthalene

2-methylnaphthalene, a polyaromatic hydrocarbon related to naphthalene, occurs in nature in association with coal, coal tars, and oil deposits. As a trace constituent of oils, it is also often found with petroleum hydrocarbons released into the environment by man. 2-methylnaphthalene was detected in four of the nine bedrock wells. Petroleum hydrocarbons were also detected in all four wells. The highest concentrations, 160 μg/L and 70 μg/L, were detected in wells BED-MW16 and BED-MW15, respectively. The highest BTEX concentrations were also present in these two wells. The other two wells in which 2-methylnaphthalene was detected, wells BED-MW13 and BED-MW17, contained the third and fourth highest concentrations of BTEX respectively.

6.5.3 Naphthalene

Naphthalene is the single most common constituent of coal tar and, like 2-methylnaphthalene, is found in association with naturally occurring oils and hydrocarbons. It is insoluble in water, but readily soluble in benzene, toluene, or carbon disulfide. It is a constituent of several additives for lubricants and motor fuels.

Naphthalene was detected in five of the nine bedrock wells, the five wells with the five highest total BTEX concentrations. The highest concentrations, 90 μg/L and 60 μg/L, were detected in wells BED-MW16 and BED-MW15, respectively. Not surprisingly,

these are the two wells with the highest BTEX concentrations. The other three wells in which naphthalene was detected each contained a total BTEX concentration of 500 μg/L or more. The naphthalene concentrations in these five wells corresponded directly from highest to lowest with the total BTEX concentrations in each well.

6.6 pH AND CONDUCTIVITY

pH, specific conductance, and temperature measurements made during the sample collection in December 1994 are listed in Table 6-5.

The normal range of pH in groundwater is 6.0 to 8.5. The pH of all samples except two were within this range. The pH in well MK-MW17 in TNT Area B was 5.5, somewhat below the normal range. The pH in well MK-MW24 in TNT Area A was 5.9, only slightly below the normal range.

pH values in all of the other overburden wells ranged from 6.0 in several wells to 6.82 in two wells at the Pentolite Road Red Water Ponds. pH values in the bedrock well were slightly higher ranging from 6.0 in the background bedrock well and well BED-MW14 to 8.0 in wells BED-MW17 and BED-MW13 in TNT Areas A and C, respectively.

Specific conductance is the ability of a fluid like water to conduct a current. Values above 1,000 microhoms per centimeter (umhos/cm) are considered elevated. Specific conductance in all overburden wells except IT-MW5 (931 umhos/cm) and MK-MW22 (700 umhos/cm), and bedrock Reactor Well 2 (700 umhos/cm) were elevated. The highest specific conductance values measured were in the three overburden wells at the Pentolite Road Red Water ponds, wells DM-MW7, DM-MW8, and DM-MW9, which had high levels of explosives residues.

As is noted on Table 6-5, a hydrogen sulfide odor was obvious in a number of the bedrock wells. The source of the gas is not known, but was widespread in the bedrock wells. It correlated with high specific conductance measurements, although it was not noted in all wells with very elevated specific conductance values.

TABLE 6-5

GROUNDWATER SAMPLING FIELD MEASUREMENTS

	Well Identification	pH	Temperature (°F)	Conductivity (µmhos/cm)	Remarks
West Area Red Water Ponds	DM-MW2	6.5	48	>1990	
	IT-MW2	6.0	51	>1990	
	MK-MW11	6.7	54	1080	
	BED-MW14	6.0	47	1580	
	BED-MW19	7.0	50	>1990	
Pentolite Road Red Water Ponds	DM-MW7	6.75	52	18,060	
	DM-MW8	6.82	53	26,400	Water is red
	DM-MW9	6.82	53	11,520	
	IT-MW5	6.61	52	931	
	BED-15	7.5	50	>1990	
	Reactor Well 2	6.5	52	700	
TNT Area A	DM-MW10	6.75	48	1300	Water cloudy with fines
	DM-MW11	6.0	51	1570	Water cloudy with fines
	MK-MW22	6.5	51	700	Water mostly clear

µmhos/cm - microhoms per centimeter

The sample IDs used in this table are abbreviated. For overburden wells, the ID is composed of two parts: the investigation for which the well was installed (e.g., DM = Dames & Moore, MK = MK Ferguson, IT = IT Corporation); and the well number (e.g. MW10). Bedrock wells are designated by "BED" and the well number.

TABLE 6-5
(Continued)

	Well Identification	pH	Temperature (°F)	Conductivity (µmhos/cm)	Remarks
TNT Area A	MK-MW23	6.5	54	1370	Water mostly clear
	MK-MW24	5.9	53	1294	Water mostly clear
	BED-MW17	8.0	50	>1990	Strong H_2S odor. Possible hazardous environment from CGI monitoring.
	BED-MW18	7.5	47	>1990	H_2S odor
TNT Area B	MK-MW16	6.0	49	1350	
	MK-MW17	5.5	43	1520	
TNT Area C	DM-MW5	6.5	49	1060	Water cloudy with fines
	DM-MW6	6.75	51	1470	Water cloudy with fines
	BED-MW13	8.0	51	>1990	Strong H_2S odor to H_2S bubbling into well as water draws down. Slight oil film.
Central Toluene Tanks	BED-MW16	---	---	---	Petroleum oil on water. Cloudy water with fines.
Background	BED-MW20	6.0	51	>1990	

µmhos/cm - microhoms per centimeter

The sample IDs used in this table are abbreviated. For overburden wells, the ID is composed of two parts: the investigation for which the well was installed (e.g., DM = Dames & Moore, MK = MK Ferguson, IT = IT Corporation); and the well number (e.g. MW10). Bedrock wells are designated by "BED" and the well number.

6.7 SUMMARY OF GROUNDWATER QUALITY

The results of the groundwater quality investigation indicate that significant levels of explosives residues are present in the groundwater in the overburden aquifer in immediate vicinity of both former Red Water Ponds areas. With increasing distance from the ponds, even in the downgradient direction of horizontal flow, levels of explosives residues decrease in the overburden aquifer.

6.7.1 Pentolite Road Red Water Ponds

Explosives residues were detected at concentrations above the PQL in three of the four overburden wells at the Pentolite Road Red Water Ponds, wells DM-MW7, DM-MW8, and DM-MW9. Each of these wells is located within or immediately adjacent to the boundary of (well DM-MW) the former ponds. Nine of the 14 nitroaromatics analytes were detected in these three wells. The highest concentrations were present in well DM-MW7 and DM-MW8 which are definitely located within the perimeter of the former ponds. The most elevated concentrations (in excess of 500 μg/L) were detected for 1,3,5-TNB, 1,3-DNB, and 2,4-DNT.

Explosives residues were not detected in well IT-MW5 which is located a short distance downgradient of the ponds. Thus, the chemical data for this investigation supports the conclusion of the groundwater flow investigation with regard to the predominance of vertical flow in the overburden hydrostratigraphic unit. Even after 50 years, nitroaromatics have not migrated horizontally the short distance to well IT-MW5.

Low levels of explosives residues were detected in one of the two bedrock wells installed downgradient from the Pentolite Road Red Water Ponds. 3,NT and 3,4-DNT were detected at concentrations of 23 μg/L and 13 μg/L, respectively, in Reactor Well 2.

Nitrate levels in these same three wells, DM-MW7, DM-MW8, and DM-MW9, were also elevated. In each well, the nitrate concentration exceeded the MCL of 10 mg/L.

Several VOCs and SVOCs were detected in the two bedrock, generally hydrocarbons and associated compounds. The benzene concentration in bedrock well BED-MW15 was two orders of magnitude above the MCL.

Eight metals (antimony, chromium, copper, lead, manganese, nickel, thallium, and zinc) were detected in the groundwater samples collected at the Pentolite Road Red Water Ponds.

Very elevated levels of copper, manganese, and nickel were detected in each of the three wells in which high explosives residues were detected, wells, DM-MW7, DM-MW8, and DM-MW9. Chromium and zinc were also detected in the overburden wells, but at concentrations consistent with those detected in other site wells. Thallium was detected only in well DM-MW7, coincidentally the well with the highest explosives residues concentrations.

The antimony concentration in the filtered sample from bedrock well BED-MW15 is suspect and was the only antimony concentration detected at the Pentolite Road Red Water Ponds. Lead was detected in the Reactor Well 2 sample at a concentration below the AL. Copper, manganese, nickel, thallium, and zinc were also detected in the bedrock aquifer in this area.

Copper concentrations were above the MCL in two of the three overburden wells, and above the SMCL in all three of the overburden wells in which it was detected. Manganese concentrations were above the SMCL, sometimes by several order of magnitude, in all of the wells in which it was detected. Nickel values exceeded the MCL in all three overburden wells in which it was detected.

6.7.2 West Area Red Water Ponds

Explosives residues were also detected in two of the overburden wells at the West Area Red Water Ponds. The explosives residues concentrations in the two overburden wells at the West Area Red Water Ponds were considerably lower than the concentrations detected in the overburden wells installed within the pond perimeter at the Pentolite Road Red Water Ponds. However, the concentrations of explosives residues detected in the sample of reddish-tinted groundwater from the pit excavated on the north bank of the west pond were significantly higher than any concentrations detected at the Pentolite Road Red Water Ponds. Again, the presence of red water and high explosives residues concentrations near the current pond boundary and probably within the boundary of the pond during operation of the PBOW, supports the conclusion of the groundwater flow assessment. The dominant direction of groundwater flow in the overburden is apparently vertically downward.

Low levels of nitroaromatics were also detected in both of the bedrock wells at the West Area Red Water Ponds.

Nitrates were detected at concentrations above the MCL in both of the overburden wells in which explosives residues were also detected. However, concentrations were not as elevated as those at the Pentolite Road Red Water Ponds.

VOCs and SVOCs were detected in both bedrock wells at the West Area Red Water Ponds. The compounds detected were generally hydrocarbons and associated compounds. The benzene concentration in well BED-MW19 was 5 μg/L, equal to the MCL.

Eight metals (antimony, chromium, copper, lead, manganese, nickel, thallium, and zinc) were detected in the groundwater samples collected from the West Area Red Water Ponds.

Copper, manganese, and nickel were detected at relatively high concentrations in the two wells in which explosives residues were also detected. Again, the concentrations were significantly lower than those detected in the Pentolite Road Red Water Ponds

samples. Chromium, lead, and zinc were also detected in unfiltered samples collected from the West Area Red Water Ponds overburden wells.

Low levels of thallium and zinc were detected in the unfiltered sample from bedrock well BED-MW14 and low levels of copper, thallium, and zinc were detected in bedrock well BED-MW19 also only in the unfiltered sample.

The antimony concentration in the filtered sample from bedrock well BED-MW19 is suspect and was the only antimony concentration detected in the West Area Red Water Ponds.

Nickel concentrations in overburden well IT-MW2 exceeded the MCL. Manganese concentrations in all samples in which it was detected exceeded the SMCL.

6.7.3 TNT Area A

Groundwater samples were collected from five overburden and two bedrock wells located at TNT Area A. Explosives residues were detected in one of the overburden wells, DM-MW10, located downgradient from the Wash House for TNT manufacturing line 3. Several VOCs and SVOCs were detected in the bedrock aquifer, generally hydrocarbons and related compounds.

Seven priority pollutant metals, antimony, arsenic, chromium, copper, lead, nickel, and zinc, were present in the area groundwater. Groundwater at the site is not used for potable drinking water; however, it is noted that none of the concentrations of priority pollutant metals exceeded regulatory action levels. An eighth metal, manganese was detected in filtered and unfiltered samples from six of the seven groundwater monitoring wells at TNT Area A. All concentrations exceeded the SMCL.

6.7.4 TNT Area B

Groundwater samples were collected from two overburden wells located at TNT Area B. Explosives residues were detected in one of the two overburden wells, MK-MW17, located on the downgradient side of the area.

Nine priority pollutant metals, antimony, arsenic, beryllium, cadmium, copper, lead, nickel, thallium, and zinc, plus manganese were present in the area groundwater. Nickel, manganese, and thallium were detected in concentrations which exceed regulatory action levels. Manganese concentrations are two to three orders of magnitude over the SMCL.

6.7.5 TNT Area C

Groundwater samples were collected from two overburden wells and one bedrock well located at TNT Area C. One explosives residues compound was detected in the bedrock well, BED-MW13 located downgradient of the former TNT Area C. Several VOCs and SVOCs were detected in the bedrock aquifer, again generally hydrocarbons and related compounds.

Four priority pollutant metals, antimony, lead, nickel, and zinc, were present in the area groundwater. Antimony in the filtered samples from wells DM-MW5 and BED-MW13 exceeded the regulatory action level, but its presence in the samples is suspect. Manganese was detected in filtered and unfiltered samples from both overburden wells at TNT Area C. All concentrations exceeded the SMCL.

7.0 CONCLUSIONS

7.1 GROUNDWATER FLOW REGIME

The results of the groundwater investigation indicate that generally groundwater flow is to the north, eventually toward Lake Erie, as would be expected for this site. However, it is likely that with the shallow bedrock and thin veneer of overburden materials overlying the bedrock, the downward flow of groundwater from the overburden into the bedrock predominates over horizontal flow in the overburden. This flow pattern, if accurate, would facilitate migration of contaminants from the overburden soils and groundwater into the bedrock aquifer.

At the Pentolite Road Red Water Ponds, the direction of groundwater flow indicated by contouring water levels is from the southwest to the northeast. The direction of groundwater flow in the overburden at the West Area Red Water Ponds is from the southeast to the northwest. The investigation indicates that there is apparently not a significant hydrologic connection between the west pond and the groundwater in the overburden.

Groundwater in the overburden at TNT Area A generally flows south to north; however, on the western side of the site, there is a northwestern component to the flow direction. Contouring of groundwater levels at TNT Area B indicates a groundwater flow direction in the overburden from south to north. However, because of the very shallow bedrock in this area, the dominant direction of flow is probably vertical from the overburden to the bedrock. Groundwater flow in the overburden in the vicinity of TNT Area C is generally from southeast to northwest. However, the presence of groundwater in the overburden materials in this area, and the resulting groundwater flow pattern, is apparently seasonal.

In the bedrock, the direction of groundwater flow in generally from south to north. In the northwest portion of the site, the only part of the site underlain by limestone, the groundwater flow direction is east-northeast from the West Area Red Water Ponds toward the Reactor Area. In the northeast part of the site, groundwater flow in the bedrock is north-northwest.

The presence of groundwater in the overburden hydrostratigraphic unit at the site is apparently very seasonal. During the early winter when groundwater samples were collected for this investigation, several of the overburden monitoring wells were dry. However, after abundant winter precipitation, in early spring groundwater was present in all of the previously dry wells.

7.2 GROUNDWATER QUALITY

The results of the groundwater quality investigation indicate that significant levels of explosives residues are present in the groundwater in the overburden aquifer in immediate vicinity of both former Red Water Ponds areas. With increasing distance from the ponds, even in the downgradient direction of horizontal flow, levels of explosives residues decrease in the overburden aquifer. Low levels of explosives residues were detected in the overburden wells at two of the three TNT areas and in the bedrock wells.

Nitrates were also detected at elevated levels in some overburden wells at the two red water Ponds areas.

Several VOCs and SVOCs were detected in the bedrock wells. These were generally hydrocarbons and associated compounds. Benzene was reported at concentrations equal to or exceeding the MCL in seven of the nine bedrock wells sampled.

Eleven metals (antimony, arsenic, beryllium, cadmium, chromium, copper, lead, manganese, nickel, thallium, and zinc) were detected in the groundwater. The highest concentrations were of copper, manganese, and nickel in the wells at the Red Water Ponds that also contained elevated levels of explosives residues and nitrates. Copper, nickel, manganese, and thallium were detected at concentrations above their regulatory action levels.

7.2.1 Pentolite Road Red Water Ponds

Four overburden wells and two bedrock wells were sampled at the Pentolite Road Red Water Ponds. Explosives residues were detected at concentrations above the PQL in three of the four overburden wells at the Pentolite Road Red Water Ponds, wells DM-MW7, DM-MW8, and DM-MW9. Each of these wells is located within or immediately adjacent to the boundary of (well DM-MW) the former ponds.

Explosives residues were not detected in well IT-MW5 which is located a short distance downgradient of the ponds. Thus, the chemical data for this investigation supports the conclusion of the groundwater flow investigation with regard to the predominance of vertical flow in the overburden hydrostratigraphic unit. Even after 50 years, nitroaromatics have not migrated horizontally in the overburden the short distance to well IT-MW5.

Low levels of explosives residues were detected in one of the two bedrock wells installed downgradient from the Pentolite Road Red Water Ponds.

Nitrate levels in wells DM-MW7, DM-MW8, and DM-MW9 were also elevated. In each well, the nitrate concentration exceeded the MCL of 10 mg/L.

Six VOCs and two SVOCs, generally hydrocarbons and associated compounds, were detected in the two bedrock wells. The benzene concentration in bedrock well BED-MW15 was two orders of magnitude above the MCL.

Eight metals (antimony, chromium, copper, lead, manganese, nickel, thallium, and zinc) were detected in the groundwater samples collected at the Pentolite Road Red Water Ponds.

Very elevated levels of copper, manganese, and nickel were detected in each of the three wells in which high explosives residues were detected, wells DM-MW7, DM-MW8, and DM-MW9.

Copper concentrations were above the MCL in two of the three overburden wells, and above the SMCL in all three of the overburden wells in which it was detected. Manganese concentrations were above the SMCL, sometimes by several orders of magnitude, in all of the wells in which it was detected. Nickel values exceeded the MCL in all three overburden wells in which it was detected.

7.2.2 West Area Red Water Ponds

Three overburden and two bedrock wells were sampled at the West Area Red Water Ponds. Explosives residues were also detected in two of the overburden wells at the West Area Red Water Ponds. The explosives residues concentrations in the two overburden wells at the West Area Red Water Ponds were considerably lower than the concentrations detected in the overburden wells installed within the pond perimeter at the Pentolite Road Red Water Ponds. However, the concentrations of explosives residues detected in the sample of reddish-tinted groundwater from the pit excavated on the north bank of the west pond were significantly higher than concentrations detected at the Pentolite Road Red Water Ponds. Again, the presence of red water and high explosives residues concentrations near the current pond boundary (and probably within the boundary of the pond during operation of the PBOW) supports the conclusion of the groundwater flow assessment. The dominant direction of groundwater flow in the overburden is apparently vertically downward.

Low levels of nitroaromatics were detected in both of the bedrock wells at the West Area Red Water Ponds.

Nitrates were detected at concentrations above the MCL in both of the overburden wells in which explosives residues were also detected. However, concentrations were not as elevated as those at the Pentolite Road Red Water Ponds.

Five VOCs were detected in bedrock wells at the West Area Red Water Ponds. The compounds detected were generally hydrocarbons and associated compounds. The benzene concentration in well BED-MW19 was 5 μg/L, equal to the MCL.

Eight metals (antimony, chromium, copper, lead, manganese, nickel, thallium, and zinc) were detected in the groundwater samples collected from the West Area Red Water Ponds.

Copper, manganese, and nickel were detected at relatively high concentrations in the two wells in which explosives residues were also detected. Again, the concentrations were significantly lower than those detected in the Pentolite Road Red Water Ponds samples.

Nickel concentrations in overburden well IT-MW2 exceeded the MCL. Manganese concentrations in all samples in which it was detected exceeded the SMCL.

7.2.3 TNT Area A

Groundwater samples were collected from five overburden and two bedrock wells located at TNT Area A. Explosives residues were detected in one of the overburden wells, DM-MW10, located downgradient from the Wash House for TNT manufacturing line 3.

Nitrate concentrations were all well below the MCL.

Six VOCs and two SVOCs were detected in the bedrock. The TNT Area A bedrock wells had the third and fourth highest concentrations of BTEX compounds. Benzene exceeded the MCL in both bedrock wells.

Eight metals (antimony, arsenic, chromium, copper, lead, manganese, nickel, and zinc) were present in the area groundwater. All manganese concentrations exceeded the SMCL.

7.2.4 TNT Area B

Groundwater samples were collected from two overburden wells located at TNT Area B. Explosives residues were detected in one of the two overburden wells, MK-MW17, located on the downgradient side of the area.

Nitrate concentrations were all well below the MCL.

Ten metals (antimony, arsenic, beryllium, cadmium, copper, lead, manganese, nickel, thallium, and zinc) were present in the area groundwater. Nickel, manganese, and thallium were detected in concentrations which exceed regulatory action levels. Manganese concentrations are two to three orders of magnitude over the SMCL.

7.2.5 TNT Area C

Groundwater samples were collected from two overburden wells and one bedrock well located at TNT Area C. One explosives residues compound was detected in the bedrock well, BED-MW13 located downgradient of the former TNT Area C.

Nitrate concentrations were all well below the MCL.

Four VOCs and two SVOCs, generally hydrocarbons and related compounds, were detected in the bedrock well. The benzene concentration exceeded the MCL.

Five metals (antimony, lead, manganese, nickel, and zinc) were present in the area groundwater. Antimony in the filtered samples from wells DM-MW5 and BED-MW13 exceeded the regulatory action level. All manganese concentrations exceeded the SMCL.

7.2.6 Other Areas

Low levels of explosives residues were detected in two additional wells installed in the bedrock, one at the central toluene storage tanks and the background well located in the southern portion of the site.

The highest levels of VOCs and SVOCs were detected in bedrock well BED-MW16 installed near the central set of toluene storage tanks. The benzene concentration was 2,000 μg/L, 400 times the MCL. An oily substance was present in this well. Analysis of the substance for Diesel Range Hydrocarbons did not provide any data useful in identifying it.

Low levels of hydrocarbons were also present in the background bedrock well. However, no SVOCs were detected in the sample collected from the background well.

7.3 LIMITATIONS

The observations, findings, and conclusions included in this report are professional opinions based upon performance of a Sitewide Groundwater Investigation for the former PBOW in Sandusky, Ohio. They are intended exclusively for the use of the Nashville and Huntington Districts of the USACE for the purposes outline herein. Any use or reuse of this document or the comments, findings, conclusions, and recommendations represented herein is at the sole risk of said user.

The observations and conclusions presented herein apply only to the investigation of the groundwater at the former PBOW; the site conditions existing at the time of the investigation; and the review of historical information that could reasonably and accurately be obtained during the course of the investigation and as specified in the Scope of Work for the Sitewide Groundwater Investigation. They cannot apply to

subsequent changes in site conditions of which Dames & Moore is not aware and to conditions which were inaccurately portrayed to Dames & Moore by other parties.

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Charles T. Allen, P.E.
Principal

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