RESULTS OF 1997-1998 SITE-WIDE GROUNDWATER MONITORING AT THE FORMER PLUM BROOK ORDNANCE WORKS

AS REPORTED IN THE DRAFT SUMMARY REPORT
SITE-WIDE GROUNDWATER INVESTIGATION

Presented to the Restoration Advisory Board

May 12, 1999

Purpose and Objectives

- Determine if hazardous substances are present in groundwater at concentrations that may constitute unacceptable risk to human health and the environment
- Refine Site Conceptual Model
- Determine current and future routes of exposure as part of a site conceptual exposure model

NOTE: Summary Report Site-Wide Groundwater Monitoring (1997-1998) issued as Draft in February 1999. Therefore, findings, recommendations, and conclusions presented herein are subject to revision.

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Scope of the Site-Wide GW Investigation

- Monitoring Well Installation
  - ➔ Install 3 overburden and 8 bedrock monitoring wells
  - ➔ One proposed overburden well was dry
- Groundwater Level Measurements
  - ➔ Quarterly measurements of 58 overburden wells and 19 bedrock wells
- Groundwater Sampling
  - ➔ Semi-annual sampling of 38 overburden and 17 bedrock monitoring wells (November 1997 & May 1998)

Groundwater Level Measurements

- Four Quarterly Measurement Events Completed
  - August & November 1997
  - February & May 1998

➔ Two Water-Bearing Zones Monitored
- Overburden Water-Bearing Zone
- Bedrock Water-Bearing Zone
  - Ohio Shale
  - Olentangy Shale
  - Delaware Limestone

Groundwater Level Measurements

- Bedrock Water Level Measurements
  - ➔ Groundwater flow is generally to the north-northeast with flow on the west side of the site toward a groundwater trough trending west to northeast
  - ➔ Groundwater fluctuations between wells completed in the Ohio Shale and Olentangy Shale are very similar; greater water level fluctuations were observed in wells completed in the Delaware Limestone
    - Fluctuations in the Delaware Limestone possibly attributed to groundwater extraction from sump wells in the Reactor Building and formation heterogeneity
  - ➔ Hydraulic conductivity ranges from 0.03 ft/day to 22.2 ft/day with a geometric mean of 0.35 ft/day in eight bedrock wells

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Bedrock Groundwater Elevation Contour Map

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Groundwater Level Measurements

- Overburden Water-Bearing Zone
  - ➔ Groundwater flow in the overburden generally mirrors surface topography with the predominant flow direction to the north-northeast
  - ➔ Groundwater fluctuations in the overburden wells are very similar possibly implying a certain degree of connectivity between site wells.

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Groundwater Level Measurements

- Overburden Water-Bearing Zone (continued)
  - ➔ Hydraulic conductivity ranges from 0.74 ft/day to 212 ft/day with a geometric mean of 8.75 ft/day.
  - ➔ Similar groundwater elevations in the overburden and bedrock water bearing zones were observed in the eastern and southern portions PBOW indicating a higher degree of connectivity between overburden and bedrock water bearing zones.

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Overburden Groundwater Elevation Contour Map

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Risk-Based Screening Concentrations (RBC)

- RBCs are a screening tool
  - ➔ Determine need for additional investigation/assessment
  - ➔ Identify Chemicals of Potential Concern for Risk Assessment
- PBOW RBCs adapted from published EPA Region 3 RBCs using lifetime excess cancer risk of 10^{-6} and hazard index (HI) of 0.1 (published RBCs use cancer risk of 10^{-6} and HI of 1.0)
- RBCs do not replace human health or ecological risk assessments
- Risk Based Screening Criteria derived from EPA Region IX Preliminary Remediation Goals currently proposed to replace RBCs.

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Groundwater Sampling Results

- **Sampled Areas**
  - → West Area Red Water Ponds Area (5 overburden / 1 bedrock)
  - → Pentolite Road Red Water Ponds Area (4 / 1)
  - → TNT Area A (5 / 2), TNT Area B (2 / 2), TNT Area C (6 / 1)
  - → Acid Area 1 (2 / 2), Acid Area 2 (3 / 2), Acid Area 3 (1 / 1)
  - → Burning Grounds (5 / 2)
  - → Upper Toluene Tank Area (1 / 1)
  - → Lower Toluene Tank Area (2/0)
  - → Reactor Facility (1 / 1)
  - → PB-BED-GW020 (0 / 1)
  - → IT-MW01 (1/0)

Site-Wide RBC Exceedances

Site	Water Bearing Zone	Number of Wells Exceeding RBCs/Total Number of Wells					
		VOCs	SVOCs	Nitroaromatic	Dissolved Metals	Cyanide	Nitrate
West Area Redwater Ponds	Overburden	0/5	**3/5**	**2/5**	**5/5**	**1/5**	**1/5**
	Bedrock	**1/1**	**1/1**	0/1	0/1	**1/1**	**1/1**
Pentolite Road Red Water Ponds	Overburden	**2/4**	**3/4**	**3/4**	**4/4**	**3/4**	**3/4**
	Bedrock	1/1	1/1	0/1	1/1	0/1	0/1
TNT Area A	Overburden	0/5	**1/5**	**1/5**	**5/5**	0/5	0/5
	Bedrock	**2/2**	0/2	**1/2**	**2/2**	0/2	0/2
TNT Area B	Overburden	0/2	0/2	1/2	2/2	0/2	0/2
	Bedrock	**1/2**	0/2	0/2	2/2	0/2	0/2
TNT Area C	Overburden	0/6	**2/6**	0/6	6/6	0/6	2/6
	Bedrock	**1/1**	**1/1**	0/1	**1/1**	0/1	0/1
Acid Areas	Overburden	**2/6**	**1/6**	0/6	**2/6**	0/6	0/6
	Bedrock	3/5	**3/5**	**3/5**	**5/5**	0/5	0/5
Burning Grounds Areas	Overburden	**1/5**	**1/5**	0/5	**5/5**	0/5	0/5
	Bedrock	0/2	0/2	0/2	**2/2**	0/2	**1/2**
Lower Toluene Tank Area	Overburden	0/2	**1/2**	0/2	**2/2**	0/1	0/1
Upper Toluene Tank Area	Overburden	**1/1**	**1/1**	0/1	**1/1**	0/1	0/1
	Bedrock	**1/1**	**1/1**	0/1	**1/1**	0/1	0/1
Reactor Facility	Overburden	0/1	0/1	0/1	0/1	0/1	0/1
	Bedrock	**1/1**	**1/1**	0/1	**1/1**	0/1	0/1
IT-MW01	Overburden	0/1	0/1	0/1	**1/1**	0/1	0/1
Southeast Bedrock Well	Bedrock	**1/1**	0/1	0/1	**1/1**	0/1	0/1

RBC exceedances indicated by bold/red

Map of Site-Wide Groundwater Analytical Results

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Conclusions

- Overburden Water Bearing Zone
  - → Organic Contaminants (VOCs, SVOCs)
    - Acid Area 1, Acid Area 3, and the Reactor Building do not exhibit impacts of organic compounds from past site activities
    - TNT B, TNT C, Burning Grounds Areas, and Lower Toluene Area exhibited sporadic exceedances of organics; however, these detections are not necessarily site related.
    - TNT A exhibited one SVOC that warrants further evaluation to determine if it is site related.
    - The Maintenance Area and Upper Toluene Area have been impacted by VOCs from past site activities.

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Conclusions

- Overburden Water-Bearing Zone (continued)
  - → Nitroaromatic Contaminants
    - TNT A and TNT B have been impacted by low levels of nitroaromatics
    - Pentolite Road and Red Water Ponds Areas exhibited the highest concentrations of nitroaromatics from previous site activities.

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Conclusions

- Overburden Water Bearing Zone (continued)
  - → Metals
    - Acid Area 2, the Maintenance Area, and the Reactor Facility did not exhibit dissolved metals at concentrations above RBCs.
    - TNT C, Acid Area 3, the Additional Burning Ground, the Snake Road Burning Ground and the Upper Toluene Area exhibited dissolved iron, manganese, and/or nickel at concentrations exceeding RBCs.
    - Acid Area 1 and the Lower Toluene Area exhibited dissolved iron and manganese at concentrations exceeding RBCs
    - TNT A, TNT B, the West Area Red Water Ponds and Pentolite Road Red Water Ponds exhibited larger suites of metals than other sites
    - Detected metals concentrations are believed to be naturally occurring but require additional study to confirm

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Conclusions

- Bedrock Water-Bearing Zone
  - ➔ Organic Contaminants (VOCs, SVOCs)
    - Natural petroleum and corresponding low levels of BTEX constituents are prevalent in bedrock across much of the site
    - The Additional Burning Ground and G-8 Burning Grounds do not exhibit organics at levels exceeding RBCs
    - The Pentolite Road Red Water Pond, TNTA, TNTC, Acid Area 2 and the Upper Toluene Tanks Area exhibited benzene and/or toluene at concentrations exceeding RBCs
    - West Area Red Water Pond and the Upper Toluene Tank Area exhibited two or more SVOCs at concentrations exceeding RBCs.
    - Sporadic detections of bis(2-ethylhexyl)phthalate require additional study to determine if it is site related or a sampling artifact

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Conclusions

- Bedrock Water-Bearing Zone
  - ➔ Nitroaromatic Contaminants
    - TNT A, Acid Areas 1 and 2, the Maintenance Area, and the West Area Red Water Ponds exceeded RBCs
  - ➔ Metals
    - Dissolved barium and manganese exceeded RBCs in most areas of PBOW.
    - Arsenic, iron, thallium, and vanadium were detected at concentrations exceeding RBCs
  - ➔ Cyanide
    - Cyanide exceeded RBCs at the West Area Red Water Ponds

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Conclusions & Recommendations

- Recommendations
  - → Investigate bedrock groundwater at the Middle Toluene Tank Area
  - → Conduct human health risk assessment for site-wide groundwater in the bedrock water-bearing zone
  - → Complete a residential/agricultural well survey to determine potential off-site receptors

Conclusions & Recommendations

- Recommendations (continued)
  - → Establish site-specific background for metals and BTEX constituents in groundwater
  - → Completion of a three-dimensional groundwater fate and transport model to aid in bedrock groundwater monitoring
  - → Evaluate need to sample downgradient off-site wells within proximity of the site

RESULTS OF THE RISK ASSESSMENT AND DIRECT-PUSH INVESTIGATION OF RED WATER POND AREAS AT THE FORMER PLUM BROOK ORDNANCE WORKS

AS REPORTED IN THE DRAFT RISK ASSESSMENT AND DIRECT-PUSH INVESTIGATION OF RED WATER POND AREAS

Presented to the Restoration Advisory Board

May 12, 1999

Location of Red Water Ponds

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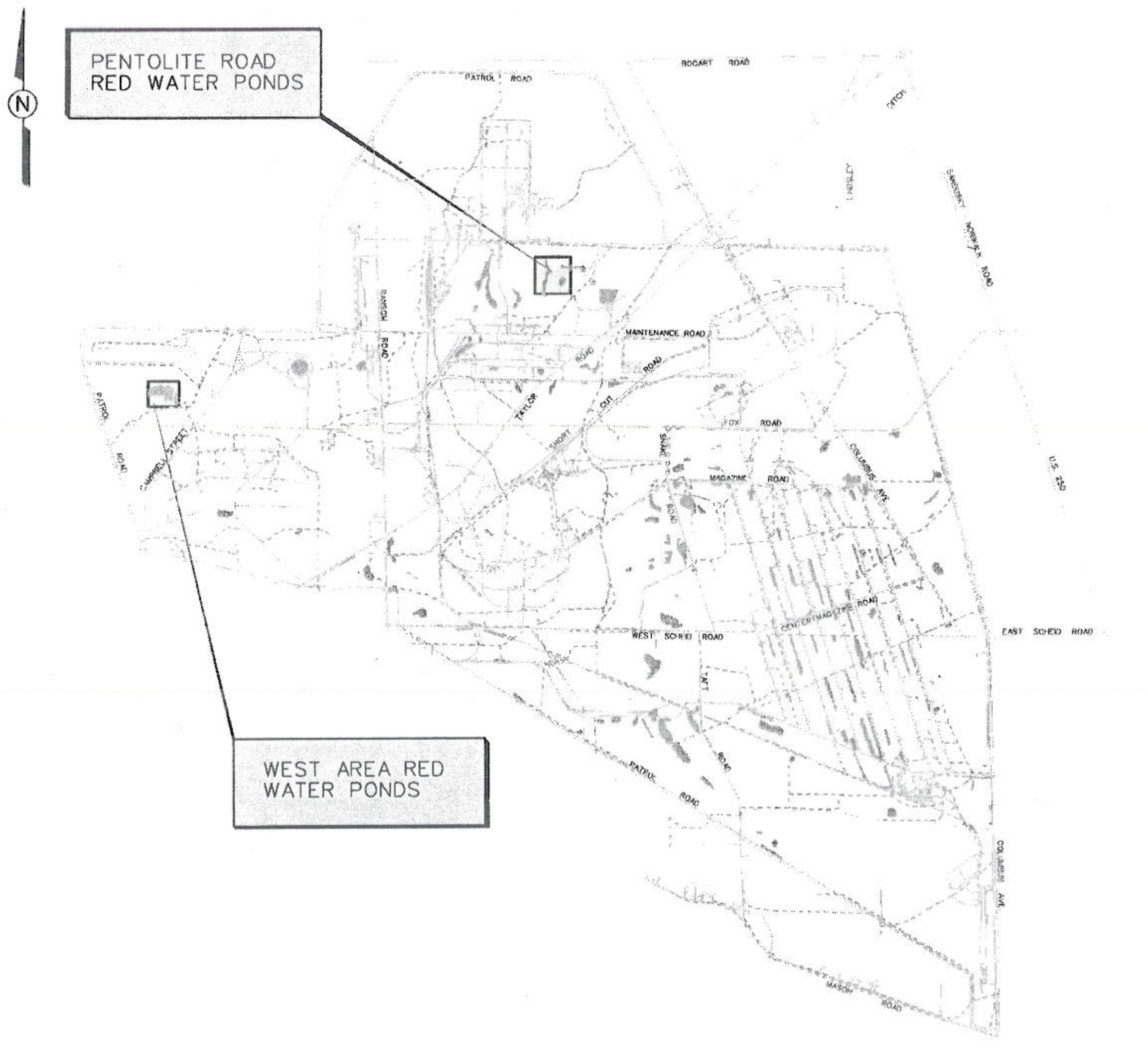

LEGEND:

- SITE
- BUILDINGS
- RAILROAD
- SURFACE WATER
- DITCH
- FENCE (PBOW BOUNDARY)

LOCATION OF RED WATER PONDS

FORMER PLUM BROOK ORDNANCE WORKS
NASA PLUM BROOK STATION
SANDUSKY, OHIO

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Purpose and Objectives

- Delineate the vertical and lateral extent of contamination in the overburden water-bearing zone to support potential future remedial action
- Collect data for use in fate and transport modeling
- Perform human health and ecological risk assessments

NOTE: Draft Risk Assessment and Direct Push Investigation of the Red Water Ponds Areas Report issued in March 1999. Therefore, findings, recommendations, and conclusions presented herein are draft and are subject to revision.

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Scope of the Direct Push Investigation

- Direct Push Surface and Subsurface Soil Sampling
  - → Thirty-nine borings completed for chemical analysis
  - → Nine borings completed for geotechnical analysis
- Direct Push Groundwater Sampling
  - → Fourteen groundwater samples (Overburden Water-Bearing Zone) collected from the West Area Red Water Ponds (WARWP)
  - → Twenty groundwater samples (Overburden Water-Bearing Zone) collected from the Pentolite Road Red Water Ponds (PRRWP)

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Scope of the Direct Push Investigation

- Surface Water and Sediment Sampling
  - → Six collocated surface water and sediment samples collected from the WARWP
  - → Four collocated surface water and sediment samples collected from the PRRWP

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WARWP Sampling Locations

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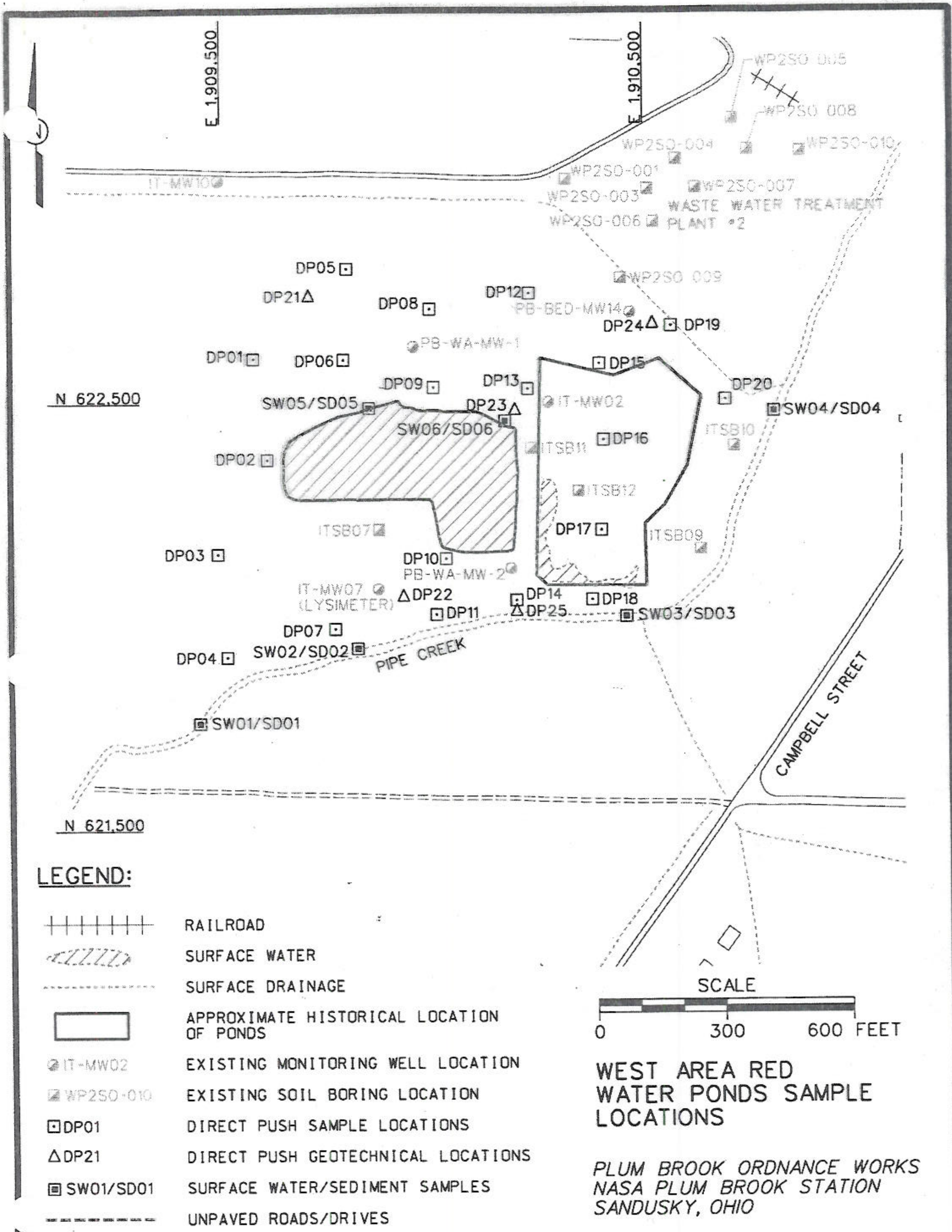

WEST AREA RED WATER PONDS SAMPLE LOCATIONS

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West Area Red Water Ponds Area Results

- Soils
  - ➔ Volatile Organic Contaminants
    - Low levels of acetone, methylene chloride, and/or toluene detected in eleven borings
  - ➔ Semivolatile Organic Contaminants
    - SVOCs detected in two surface soil samples and two subsurface soil samples
    - Fluoranthene and pyrene were the most frequently detected (3 samples each)
    - Two samples had ten SVOCs detected

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West Area Red Water Ponds Area Results

- Soils (continued)
  - ➔ Nitroaromatics
    - Nitroaromatics were not detected in any surface soil samples
    - Four nitroaromatics (1,3,5-TNB, 2,4,6-TNT, 2,4-DNT, and 2,6-DNT) were detected in six subsurface soil samples
    - Maximum detected concentrations of nitroaromatics in soils was 6.3 mg/kg
  - ➔ PCBs
    - PCBs were not detected in any of the soil samples
  - ➔ Inorganics
    - Twenty-one metals detected in at least one soil sample
  - ➔ Cyanide
    - Cyanide was not detected in any of the soil samples

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Soil Montage of Red Water Ponds Analytical Results

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West Area Red Water Ponds Area Results

- Groundwater
  - Volatile Organic Contaminants
    - 2-Butanone, benzene, carbon disulfide, ethyl benzene, and/or tetrachloroethene detected in seven samples
    - Concentrations of VOCs detected range from 0.13 ug/L to 1.8 ug/L.
  - Semivolatile Organic Contaminants
    - Five nitroaromatics were detected under the SVOC analyses
    - Concentrations of SVOCs detected ranged from 1.8 ug/L to 660 ug/L

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West Area Red Water Ponds Area Results

- Groundwater
  - Nitroaromatics
    - Five nitroaromatics (1,3,5-TNB, 1,3-DNB, 2,4,6-TNT, 2,4-DNT, and 2,6-DNT) were detected in ten samples
    - Maximum detected concentrations of nitroaromatics in groundwater was 950 ug/L (2,4-DNT)
  - PCBs
    - PCBs were not detected in any of the groundwater samples
  - Inorganics
    - Nine dissolved metals were detected in groundwater samples, excluding nutritionally essential elements
  - Cyanide
    - Cyanide was not detected in any of the groundwater samples

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Groundwater Montage of Red Water Ponds Analytical Results

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West Area Red Water Ponds Area Results

- Sediments
  - ➔ VOCs
    - Acetone and 2-butanone were detected in 3 samples at concentrations below 0.11 mg/kg.
  - ➔ SVOCs
    - Seven SVOCs were detected in sediment sample SD-01
    - One SVOC (fluoranthene) was detected in SD-04
  - ➔ PCBs
    - PCBs were not detected in any of the sediment samples
  - ➔ Inorganics
    - Fifteen metals were detected in at least one of the six sediment samples

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West Area Red Water Ponds Area Results

- Surface Water
  - ➔ VOCs
    - Bromomethane was detected in five of six samples at concentrations ranging from 0.16 to 0.22 ug/L.
  - ➔ SVOCs
    - Di-n-octyl phthalate (7.8 ug/L) was detected in one sample from the west pond
  - ➔ PCBs
    - PCBs were not detected in any of the surface water samples
  - ➔ Inorganics
    - Eleven dissolved metals were detected in at least one of the six surface water samples

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PRRWP Sampling Locations

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Pentolite Road Red Water Ponds Area Results

- Soils
  - ➔ Volatile Organic Contaminants
    - Low levels of acetone, methylene chloride, and/or toluene detected in four samples at concentrations below 0.09 mg/kg
  - ➔ Semivolatile Organic Contaminants
    - Three nitroaromatic compounds were detected under the SVOC analysis in one surface soil sample and five subsurface soil samples
    - Nitroaromatics detected were 2,4-DNT, 2,6-DNT and nitroaniline

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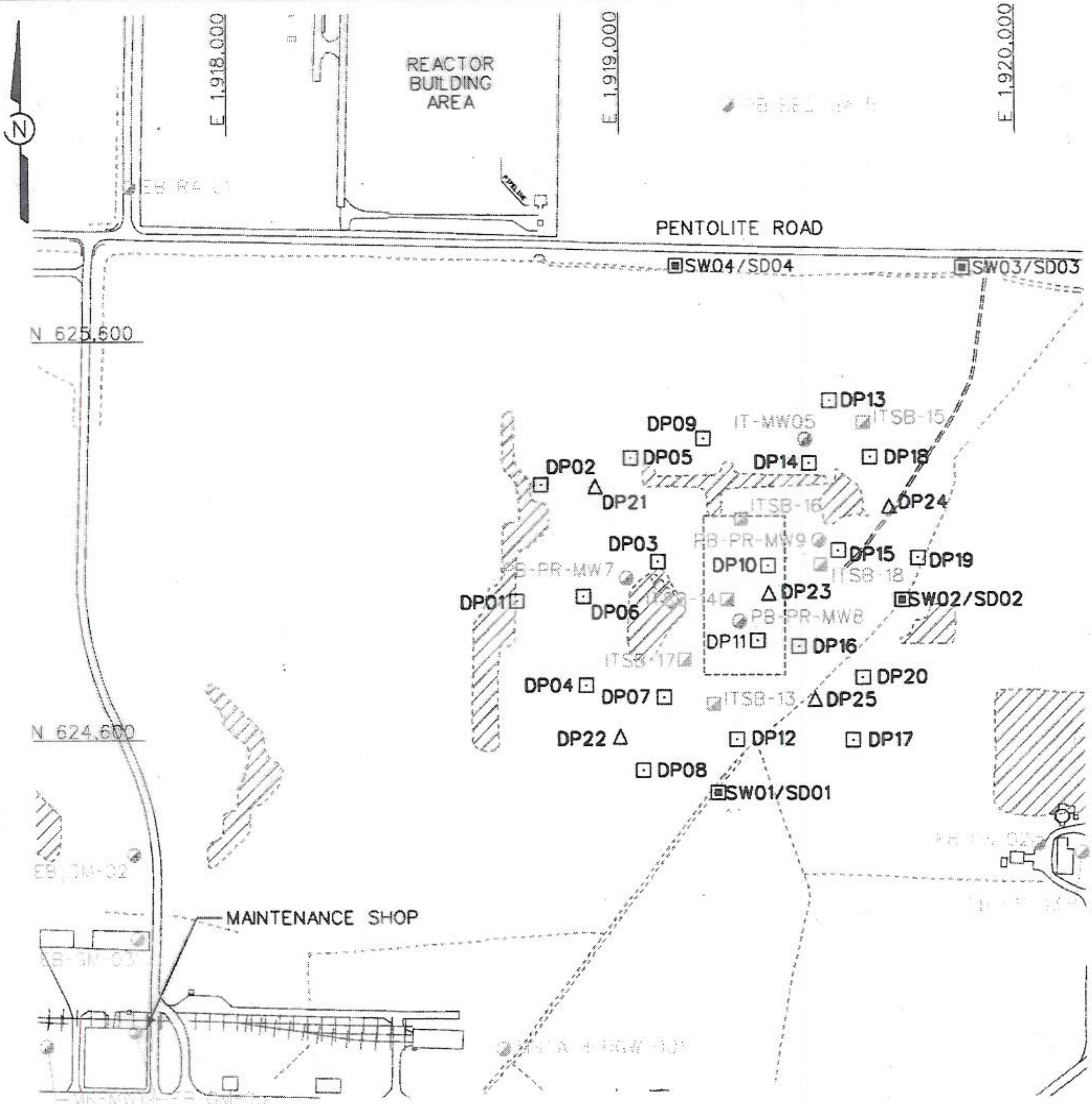

LEGEND:

- BUILDINGS
- RAILROAD
- SURFACE WATER
- SURFACE DRAINAGE
- APPROXIMATE HISTORICAL LOCATION OF PONDS
- FENCE (PBOW BOUNDARY)
- IT-MW02 — EXISTING MONITORING WELL LOCATION
- ITSB-13 — EXISTING SOIL BORING LOCAITON
- DP01 — DIRECT PUSH SAMPLE LOCATIONS
- DP21 — DIRECT PUSH GEOTECHNICAL LOCATIONS
- SW01/SD01 — SURFACE WATER/SEDIMENT SAMPLES

SCALE
0 400 800 FEET

PENTOLITE ROAD RED WATER PONDS SAMPLE LOCATIONS

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Pentolite Road Red Water Ponds Area Results

- Soils (continued)
  - Nitroaromatics
    - Nitroaromatics were not detected in any surface soil samples
    - Six nitroaromatics (1,3,5-TNB, 1,3-DNB, 2,4,6-TNT, 2,4-DNT, 2,6-DNT and 4-amino-2,6-DNT) were detected in eleven subsurface soil samples
    - Maximum detected concentrations of nitroaromatics in soils was 43 mg/kg
  - PCBs
    - PCBs were not detected in any of the soil samples
  - Inorganics
    - Twenty-one metals detected in at least one soil sample
  - Cyanide
    - Cyanide was not detected in any of the soil samples

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Soil Montage of Red Water Ponds Analytical Results

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Pentolite Road Red Water Ponds Area Results

- Groundwater
  - Volatile Organic Contaminants
    - 2-Butanone, 2-hexanone, acetone, benzene, carbon disulfide, ethyl benzene, tetrachloroethene, total xylenes, and trichloroethene were detected at low concentrations
    - Concentrations of VOCs detected range from 0.13 ug/L to 24 ug/L.
  - Semivolatile Organic Contaminants
    - Ten SVOCs, including eight nitroaromatics were detected under the SVOC analyses
    - Concentrations of SVOCs detected ranged from 1.5 ug/L to 9,200 ug/L

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Pentolite Road Red Water Ponds Area Results

- Groundwater (continued)
  - Nitroaromatics
    - Five nitroaromatics (1,3,5-TNB, 1,3-DNB, 2,4-DNT, 2,6-DNT, and tetryl) were detected in twelve samples
    - Maximum detected concentrations of nitroaromatics in groundwater was 6,800 ug/L (2,4-DNT)
  - PCBs
    - PCBs were not detected in any of the groundwater samples

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Pentolite Road Red Water Ponds Area Results

- Groundwater (continued)
  - ➔ Inorganics
    - Nine dissolved metals were detected in groundwater samples, excluding nutritionally essential elements
  - ➔ Cyanide
    - Cyanide was detected in three groundwater samples ranging in concentration from 23 to 780 ug/L

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Groundwater Montage of Red Water Ponds Analytical Results

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Pentolite Road Red Water Ponds Area Results

- **Sediments**
  - **VOCs**
    - Acetone and 2-butanone were detected in two samples at concentrations below 0.06 mg/kg.
  - **SVOCs**
    - Fifteen SVOCs, primarily PAHs were detected in sediment samples SD-02 and/or SD-04
  - **PCBs**
    - PCBs were not detected in any of the sediment samples
  - **Inorganics**
    - Fifteen metals were detected in at least one of the four sediment samples

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Pentolite Road Red Water Ponds Area Results

- **Surface Water**
  - **VOCs**
    - Acetone, chloroform, bromomethane, bromodichloromethane, and dibromochloromethane were detected in at least one surface water sample at low concentrations
  - **SVOCs**
    - Phenol was detected in three samples and bis(2-ethylhexyl)phthalate was detected in one sample at concentrations below 3 ug/L.
  - **Nitroaromatics**
    - Nitroaromatics were not detected in any of the surface water samples

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Pentolite Road Red Water Ponds Area Results

- **Surface Water (continued)**
  - **PCBs**
    - PCBs were not detected in any of the surface water samples
  - **Inorganics**
    - Twelve dissolved metals were detected in at least one of the six surface water samples

Red Water Ponds Area Summary

Site	Media Sampled	Number of Detections/Total Number of Samples			
		VOCs	SVOCs	Nitroaromatic	Metals
West Area Redwater Ponds	Surface Soil	5/5	2/5	1/5	5/5
	Subsurface Soil	6/11	2/11	4/11	11/11
	Groundwater	7/12	6/12	9/12	16/16
	Surface Water	5/6	0/6	0/6	6/6
	Sediment	3/6	2/6	0/6	6/6
Pentolite Road Red Water Ponds	Surface Soil	1/3	1/3	2/3	3/3
	Subsurface Soil	3/13	5/13	10/13	13/13
	Groundwater	7/17	12/17	12/17	17/17
	Surface Water	4/4	3/4	0/4	4/4
	Sediment	2/4	2/4	0/4	4/4

Human Health Risk Assessment Results

- Human Health Risk Assessment
  - ➔ PRRWP: Incremental Lifetime Cancer Risk (ILCR) and Hazard Index (HI) do not exceed OEPA limits
  - ➔ WARWP: Site related ILCR and HI's are near the OEPA limit for residential exposure to soil, surface water, and sediment, with the driver for this scenario being metals in surface water. Data are insufficient to determine whether the metals are site related

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Ecological Risk Assessment Results

- Ecological Risk Assessment
  - ➔ High Hazard Quotients are predicted for certain receptors due to potential 4-amino-2,6-DNT uptake by invertebrates from surface soil and sediment, aluminum ingestion by the racoon at the WARWP, and iron uptake by fish from surface water.

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Conclusions

- Ecological Risk Assessment
  - ➔ High Hazard Quotients are predicted for certain receptors
    - Because of conservative estimates used to account for uncertainties in estimating ecological risk, Hazard Quotients may be overestimated.

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Recommendations

- Determine site-specific background concentrations of metals in surface water and sediment
- Evaluate human health risk from bedrock groundwater following completion of the characterization of bedrock water quality at the two Red Water Pond Areas
- Conduct earthworm bioassay to estimate uptake and bioavailability of organics from surface soil
- Conduct fish uptake study to estimate bioaccumulation and bioavailability of metals from surface water
- Conduct literature search to obtain more accurate avian NOAEL for 4-amino-2,6-DNT

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8.0 Conclusions

IT has completed two semi-annual groundwater sampling events and four quarterly groundwater level measurement events of overburden and bedrock monitoring wells under the GWI at PBOW. Previous chapters of this report have presented results from these sampling and measurement events as well as hydrogeologic interpretations and conceptual site models developed as part of the site-wide GWI. The following sections present conclusions of the GWI based on the data and interpretations previously presented.

8.1 Overburden Water-Bearing Zone

A total of 38 overburden wells were sampled on a semi-annual basis while groundwater levels were measured in 58 overburden wells on a quarterly basis under the annual GWI.

8.1.1 Groundwater Sampling Results

8.1.1.1 Organic and Explosives Constituents

As presented on Table 8-1, analytical results from sampled overburden monitoring wells indicate that several areas of PBOW do not exhibit impacts of organic or explosive compounds from past site activities. Specifically, wells sampled at AA1, AA3, and the Reactor Building do not show organic or explosives contaminants at levels that would be considered to pose unacceptable risk to human health. While not presented on this table, the background well (IT-MW01) shows a similar absence of organic and explosives contaminants consistent with its stated purpose as an overburden background well.

A small suite of organic contaminants exceeding RBCs are evident in wells sampled at TNTC, AA2, the Maintenance Area, the ABG, the Snake Road Burning Ground, and the Lower Toluene Area (Table 8-1). At TNTC, bis(2-ethylhexyl)phthalate was detected in two wells at concentrations of 7.3 µg/L and 28 µg/L, well below the maximum detected concentration of this compound (Table 8-2). One well (MK-MW10) at Acid Area 2 exhibited chloroform (0.45 µg/L) and bis(2-ethylhexyl)phthalate (11 µg/L). The Maintenance Area Well (MK-MW19) exhibited consistent detections of 1,1,1-TCA and 1,1-DCA at concentrations near or above the RBCs; note that these constituents were not detected in other overburden wells (Table 8-2). At the ABG, benzene was detected at concentrations slightly above the RBCs during both sampling events, while one well (GCL-MW01) at the Snake Road Burning Grounds exhibited bis(2-ethylhexyl)phthalate at 100 µg/L during the second sampling event which is well above the

RBC. With the exception of results from the Maintenance Area, these detections have not been consistent over the two sampling events and are not necessarily attributable to site contamination. However, it is concluded that the overburden water-bearing zone at the Maintenance Area has been impacted by VOCs from past site activities.

TNTA exhibited one SVOC (bis(2-ethylhexyl)phthalate) and one nitroaromatic compound (4-amino-2,6-DNT) at concentrations exceeding the RBC. Of these, bis(2-ethylhexyl)phthalate was detected in May 1998 in MK-MW23 at a concentration of 890 µg/L, well above the RBC and is the maximum detected concentration at PBOW over the two sampling events. However, this compound was not detected in November 1997. 4-Amino-2,6-DNT was detected in MK-MW22 at concentrations exceeding the RBC during both sampling events; this well also exhibited other explosives at concentrations below the RBC during both sampling events. These results suggest that while the overburden water-bearing zone has been impacted by low levels of explosives in the north-central portion of TNTA, bis(2-ethylhexyl)phthalate warrants further evaluation to determine whether it is due to site contamination.

TNTB exhibited 4-amino-2,6-DNT at concentrations exceeding the RBC during both sampling events in MK-MW17 (3.6 to 5.7 µg/L). It is concluded that the overburden water-bearing zone on the north side of TNT Area B has been impacted by explosives from past site activities.

The Upper Toluene Area has exhibited a larger suite of organic contaminants than other sites exceeding RBCs, including toluene, 2-methylphenol, 4-methylphenol, and bis(2-ethylhexyl)phthalate (Table 8-1). The detected concentrations of these compounds have been well above the RBCs and have been detected during both sampling events, clearly indicating that the overburden water-bearing zone in this area has been impacted by organic contaminants from past site activities.

Two areas of PBOW have exhibited the largest suites of organic and explosive contaminants in the overburden water-bearing zone; the WARWP, and the PRRWP (Table 8-1). Although a slightly larger set of contaminants have exceeded RBCs at the WARWP, the highest concentrations of contaminants have been documented at the PRRWP. However, both areas exhibit significant impacts from past site activities, primarily because of their role as wastewater disposal areas. In addition, groundwater from several overburden wells in these areas have been documented to contain red water, consistent with the high levels of nitroaromatic compounds.

In summary, the overburden water-bearing zone at PBOW has been impacted by organic and/or explosive contaminants to different extents by past site activities. Nitroaromatic compounds, explosives residues, and SVOCs have significantly impacted the PRRWP and the WARWP areas. Lesser impacts by nitroaromatic compounds are evident at TNTA and TNTB, with bis(2-ethylhexyl)phthalate also exceeding RBCs at TNTA. Two areas, the Upper Toluene Area and the Maintenance Area, have exhibited impacts by non-explosive organic contaminants at levels well above the RBCs. Lower levels of organic contaminants are evident at TNTC, AA2, the ABG, the Snake Road Burning Grounds, and the Lower Toluene Area. Three areas, AA1, AA3, and the Reactor Building Area, have not been impacted by past site activities.

8.1.1.2 Inorganic Constituents

As presented on Table 8-3, many total metals were determined to exceed the corresponding RBCs in overburden wells sampled across PBOW. However, as discussed in previous sections, many of these total metals were due to suspended soils in the unfiltered sample and were therefore not attributable to site contamination. Therefore, the following discussion focuses on dissolved metals except for total cyanide and nitrate.

The overburden water-bearing zone within three geographic areas did not exhibit dissolved inorganic compounds at concentrations above the RBCs; AA2, the Maintenance Area, and the Reactor Facility. Five areas (TNTC, AA3, the ABG, the Snake Road Burning Ground, and the Upper Toluene Area) exhibited only dissolved iron, manganese, and/or nickel at concentrations exceeding the RBCs (Table 8-3). Detected concentrations in these five areas were between 684 to 9,240 µg/L for dissolved iron, between 36.4 to 4,020 µg/L for dissolved manganese, and between 56.8 to 77.1 µg/L for dissolved nickel. Comparing these concentrations to site-wide detections (Table 8-4), it is evident that all were at least one order of magnitude below the maximum detected concentration. However, since background concentrations have not been established for metals in groundwater at PBOW, these metals will require further evaluation.

Two dissolved metals (iron and manganese) were detected at concentrations exceeding the RBCs at AA1 and the Lower Toluene Area. Detected concentrations ranged from 226 to 39,100 µg/L for iron and from 30.7 to 5,550 µg/L for manganese. Although dissolved manganese appears to be well within the range of detected concentrations across PBOW (Table 8-4), the dissolved iron concentrations at the two sites may be elevated and warrant additional evaluation.

Larger suites of inorganic compounds were detected in wells from the WARWP, PRRWP, TNTA, and TNTB (Table 8-3). Although not necessarily attributable to site contamination, many of these metals were detected infrequently in the overburden water-bearing zone across PBOW (Table 8-4) and may warrant further evaluation.

8.1.2 Overburden Geologic and Hydrogeological Conclusions

Groundwater flow in the overburden is predominantly to the north-northeast. The general flow direction in the overburden aquifer largely mirrors the surface topography and is strongly correspondent to the topography of the top of the bedrock; thus, groundwater on the western side of the site flows toward a groundwater low. Groundwater elevation fluctuations are very similar among overburden wells implying a high degree of connectivity between the site wells although slug tests reveal significant variability in the hydraulic conductivities in various overburden wells.

8.2 Bedrock Water-Bearing Zone

A total of 17 bedrock wells were sampled on a semi-annual basis while groundwater levels were measured in 19 bedrock wells on a quarterly basis under the annual GWI.

8.2.1 Groundwater Sampling Results

8.2.1.1 Organic and Explosives Constituents

As presented on Table 8-5, two of the areas sampled under the site-wide groundwater investigation failed to exhibit any organic or explosive contaminants at levels exceeding RBCs. The bedrock water-bearing zone in these areas (ABG and BG8) along with the background well (PB-BED-MW20) are therefore interpreted to not have been impacted by past site activities. VOCs have impacted the bedrock water-bearing zone in ten areas of the site. The most common VOC exceeding RBCs was benzene, with detected concentrations ranging from 0.14 µg/L to 780 µg/L (Table 8-6). This constituent was detected in 23 of the 34 samples analyzed for VOCs, and it is known to occur naturally within the Delaware Limestone. However, maximum detected benzene concentrations at the PRRWP (780 µg/L), TNTC (130 µg/L), AA2 (130 µg/L), and Upper Toluene Tanks Area (490 µg/L) are well above levels seen in other areas (including background well PB-BED-MW20) and are considered site-related contaminants (Figure 8-1). Toluene was also detected at concentrations above RBCs in several areas (Table 8-5), with detected concentrations of this VOC ranging from 1.3 to 550 µg/L (Table 8-6). As with benzene, toluene is a naturally occurring BTEX constituent in the Delaware Limestone. However, the maximum detected concentrations at the PRRWP (550 µg/L), TNTA (140 µg/L), TNTC (170 µg/L), and the Upper Toluene Tanks Area (390 µg/L) are well above levels seen in other areas and are considered site-related contaminants (Figure 8-1). Another location which is likely to have site-related BTEX compounds at high concentrations is the area upgradient of AA1. The tanks at the Middle Toluene Tank Area are possible sources for the toluene (50 µg/L) and xylene (500 µg/L) found 2,400 feet downgradient at the AA1 well IT-AA1-BED-GW001. Presently, no wells have been installed in the vicinity of the Middle Toluene Tank Area. Other detected VOCs exceeding RBCs at the PRRWP (1,1,2-TCA, chlorobenzene, and ethylbenzene), AA2 (chlorobenzene), and the Upper Toluene Tank Area (ethyl benzene) are considered to be site-related contaminants.

Several SVOCs have also been detected at levels exceeding the RBCs in the bedrock wells. Of these, bis(2-ethylhexyl)phthalate was detected at concentrations exceeding the RBC most frequently (Table 8-5). Detected concentrations ranged from 1.7 to 920 µg/L (Table 8-6). This compound was detected sporadically and further evaluation will be needed to determine whether it is a site-related contaminant or a sampling artifact in the affected areas. Two areas (WARWP and Upper Toluene Tank Area) exhibited two or more SVOCs at concentrations exceeding the RBCs. At the WARWP, 2,4-dinitrophenol, 2,4-DNT, 4,6-dinitro-2-methylphenol, and nitrobenzene have impacted the bedrock water-bearing zone because of past site activities. The Upper Toluene Tank Area exhibits impacts from 1,3-dichlorobenzene and bis(2-ethylhexyl)phthalate.

Three nitroaromatic compounds (1,3-DNB, nitrobenzene, and RDX) were detected at concentrations exceeding the RBCs at TNTA, AA1, AA2, and/or the Maintenance Area; note that explosives also exceeded RBCs at the WARWP under the SVOC analysis. At TNTA, the bedrock wells have been impacted by low levels of explosives from past site activities. AA1 and AA2 as well as the Maintenance Area have also have also been impacted by low levels of nitroaromatic compounds from past site activities.

In summary, the bedrock water-bearing zone at PBOW has been impacted by organic and/or explosive contaminants to different extents by past site activities, although to a lesser degree than the overburden. Nitroaromatic compounds and SVOCs have impacted the WARWP, while VOCs have impacted the bedrock wells at the PRRWP. Lesser impacts by nitroaromatic compounds are evident at TNTA and AA1 and AA2 and the Maintenance Area. VOCs have also impacted the bedrock water-bearing zone at TNTC, AA2, and the Upper Toluene Tanks Area; SVOCs also exhibit impacts on water quality at the Upper Toluene Tanks Area.

8.2.1.2 Inorganic Constituents

As presented on Table 8-7, many total metals were determined to exceed the respective RBCs in bedrock wells sampled across PBOW. However, as discussed in previous sections, many of these total metals were due to suspended soils in the unfiltered sample and were therefore not attributable to site contamination. Therefore, the following discussion focuses on dissolved metals except for total cyanide.

Only two areas (WARWP and AA3) lacked any detected dissolved inorganic compound at a concentration exceeding the RBC. However, cyanide did exceed the RBC at the WARWP. Two dissolved metals (barium and manganese) were commonly detected in the bedrock wells at concentrations exceeding the RBCs in most areas of PBOW (Table 8-7). Detected concentrations exhibited a wide range (Table 8-8), suggesting that some detections may be due to site contamination. However, these metals will require further evaluation once background has been established.

Other less frequently detected dissolved metals at concentrations exceeding RBCs in the bedrock water-bearing zone include arsenic, iron, thallium, and vanadium (Table 8-7). The frequency of detection, as well as range of concentrations, for these metals is presented on Table 8-8. However, further evaluation of these metals is required once background is established to determine whether they are due to site contamination.

8.2.2 Bedrock Geologic and Hydrogelogical Conclusions

Groundwater flow in the bedrock is predominantly to the north-northeast. Little groundwater elevation fluctuation occurred over time in the wells monitoring the Ohio Shale and the Olentangy Shale; however, wells monitoring the Delaware Limestone showed significant variability. There is a similar groundwater elevation fluctuation between wells REACTOR 1, 2, 3, and PB-BED-MW13 located on the west side of PBOW along a bedrock low coming from the Reactor Building Area.

Slug tests revealed that the Ohio Shale had the highest hydraulic conductivity of the three bedrock units tested at approximately 20 ft/day. The Delaware Limestone and Olentangy Shale had hydraulic conductivities of three orders of magnitude lower.

Quarries mining the Delaware Limestone in the vicinity of PBOW have some minor natural hydrocarbon. This is evident in PBOW wells monitoring the bedrock based on drilling notes, H_2S readings, and BTEX compounds detected in the groundwater.

In general, there is a downward vertical gradient from the overburden to the bedrock in the western and northern portions of the site. The greatest groundwater elevation difference was 25 feet in overburden/Delaware Limestone pair IT-AA1-GW002/IT-AA1-BED-GW001 located in the north central portion of the site. In contrast, the central and southern portions of the site showed very similar groundwater elevations in overburden/Ohio Shale pairs. This may indicate a high degree of connectivity between groundwater in the overburden and Ohio Shale.

Peaks in calculated recharge rates appear to correlate with groundwater highs taking into account a lag time. Similarly, lows in recharge rates correspond somewhat (taking into account the lag time) with lows in the groundwater.

9.0 Recommendations

As presented in Chapter 8.0, Conclusions, the two water-bearing zones at PBOW have exhibited inorganic, organic, and nitroaromatic constituents at concentrations that have exceeded their respective RBCs. It is recommended that additional investigations be performed as follows:

- Determination of site-specific reference levels for VOC constituents and background concentrations for metals in the bedrock water-bearing zone
- Investigation of bedrock groundwater at the Middle Toluene Tank Area
- Completion of a three-dimensional groundwater fate and transport model utilizing data generated during the site-wide groundwater investigation as well as pertinent historical data to aid in bedrock groundwater monitoring
- Completion of a human-health risk assessment for site-wide groundwater to define contaminants of concern and to aid in determining whether additional sampling or remedial actions are warranted
- Complete a residential/agricultural well survey to determine potential off-site receptors; sampling of downgradient off-site wells within proximity of the site should be considered.

Further investigation and monitoring of the overburden water-bearing zone is not recommended under current and anticipated future land use scenarios for the following reasons:

- There are no identified receptors for groundwater from the overburden water-bearing zone
- The State of Ohio (DERR) has indicated that the overburden water-bearing zone is not considered a potable water source
- The overburden water-bearing zone is not likely to be used as a drinking water source now or in the future due to low permeability.

Contaminant migration issues between the overburden and bedrock water-bearing zones can be addressed through monitoring of bedrock wells. Bedrock monitoring should consist of selected wells within the bedrock contaminant plumes (and/or beneath overburden plumes), bedrock wells downgradient of plumes and near the facility boundary, and any residential/agricultural wells deemed appropriate for this purpose.

Should facility usage change in the future to allow for public reuse, additional monitoring and/or evaluation of the overburden water-bearing zone may be necessary.

The following paragraphs provide additional detail regarding the scope of recommended actions.

9.1 Background Determination

Site-specific reference levels for VOC constituents and background concentrations for metals should be determined for the bedrock water-bearing zone. It is recommended that two existing bedrock wells (PB-BED-MW20 and IT-BG8-BED-GW001) be used for this determination along with three new bedrock wells. Background wells should be sampled on a quarterly basis for 1 year; wells should be analyzed for metals (total and dissolved) and VOCs.

It is recommended that the specific locations of new background wells, sampling frequency, analytical parameters, and statistical approach be developed by CELRN and IT. The specifics of background determination should then be proposed to OEPA and NASA, potentially during a site visit and team meeting at the Plum Brook Station.

9.2 Groundwater Investigation

Additional DOD areas of concern are scheduled for investigation in the near future. These investigations will primarily evaluate soils in each area of concern, but results may suggest that additional wells be installed in order to evaluate potential impacts on the groundwater.

Monitoring wells have not been successfully installed at the Middle Toluene Storage Tanks Area, located approximately 1,500 feet southwest of the intersection of Fox Road and Taylor Road. Based on the results from the Upper and Lower Toluene Tanks Areas, consideration should also be given to the installation of bedrock water-bearing zone wells in this area.

9.3 Groundwater Modeling

A three-dimensional groundwater model should be completed to provide a basis for determining the effectiveness of any chosen remedial actions or groundwater-monitoring program at PBOW. This model should be based largely on the refined conceptual site model developed herein. The groundwater modeling effort should be supported with pump tests or dye trace studies to augment the current understanding of local water-bearing zones. Additional well clusters may also be necessary to understand vertical hydraulic gradients between the overburden and the bedrock. In addition, approximate pumping rates of the sump pumps at the Reactor Area should be obtained and utilized to understand the effect that these wells have on drawdown of local groundwater.

9.4 Risk Assessment

In addition to metals determined to exceed background concentrations, COPC identified herein should be carried forward to appropriate human health risk assessments for the bedrock water-bearing zone:

- WARWP - nitroaromatics, SVOCs, and cyanide
- Pentolite Road Area - BTEX compounds
- TNTA - BTEX and nitroaromatics
- TNTC - BTEX compounds
- AA1 - nitroaromatics
- AA2 - VOCs and nitroaromatics
- Maintenance Area - nitroaromatics
- Upper Toluene Tanks Area - BTEX compounds and SVOCs

The site-wide bedrock water-bearing zone risk assessments should be conducted following completion of the pending site investigations to ensure that any groundwater concerns identified during these investigations are adequately addressed. If additional wells and groundwater samples are deemed necessary to assess the potential impact of these sites on groundwater quality, then that data should be collected and evaluated prior to the risk assessment.

Results of the risk assessment should then be used to determine (1) the need for additional groundwater monitoring and; (2) the need for remedial action.