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December 4, 2008

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Submittal of the Final Feasibility Study for Groundwater,
TNT and Red Water Pond Areas
Former Plum Brook Ordnance Works, Sandusky, Ohio
Contract No. W912DR-05-D-0026: Shaw Project Number 119268

Dear Ms. McClanahan:

In accordance with the requirements of Delivery Order No. DX02 of Contract No. W912DR-05-D-0026 Shaw is pleased to submit this Final Feasibility Study for Groundwater that underlies the TNT and Red Water Pond Areas at the Former Plum Brook Ordnance Works located in Sandusky, Ohio.

Enclosed are six copies of the draft report and a single electronic copy on CD (inside Control Copy No. 1). Copies of this report have also been forwarded to those on the distribution list. As has been requested, only an electronic copy has been provided to the USACE HTRW Center of Expertise. An electronic copy has also been provided to the USACE Huntington District (inside Control Copy No. 7).

Should you have any questions or require additional information regarding this submittal, please do not hesitate to contact me at (865) 694-7496.

Sincerely,

Steven T. Downey, PE
Project Manager

Enclosures

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Final

Feasibility Study for Groundwater
TNT and Red Water Pond Areas
Former Plum Brook Ordnance Works
Sandusky, Ohio

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List of Acronyms

°F	degrees Fahrenheit
µg/L	micrograms per liter
ADNT	aminodinitrotoluene
2-ADNT	2-amino-4,6-dinitrotoluene
4-ADNT	4-amino-2,6-dinitrotoluene
AOC	area of concern
ARAR	applicable or relevant and appropriate requirements
BERA	baseline ecological risk assessment
bgs	below ground surface
BHHRA	baseline human health risk assessment
BSC	background screening concentration
BTEX	benzene, toluene, ethylbenzene, and xylene
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
COC	contaminant of concern
COPC	chemical of potential concern
DD	decision document
DNB	dinitrobenzene
D&M	Dames and Moore, Inc.
DNT	dinitrotoluene
DOD	U.S. Department of Defense
EPA	U.S. Environmental Protection Agency
FFS	focused feasibility study
FS	feasibility study
ft^2	square feet
GAC	granular activated carbon
gpm	gallons per minute
GSA	General Services Administration
H_2S	hydrogen sulfide
HI	hazard index
ICI	International Consultants Incorporated
ILCR	incremental lifetime cancer risk
ISCO	in situ chemical oxidation
ISEB	in situ enhanced bioremediation
IT	IT Corporation

LNAPL	light nonaqueous-phase liquid
LTM	long-term monitoring
LUCIP	land-use control implementation plan
MCL	maximum contaminant level
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MK	Morrison Knudsen Corporation
MNA	monitored natural attenuation
mV	millivolt
NASA	National Aeronautics and Space Administration
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NPDES	National Pollutant Discharge Elimination System
O&M	operation and maintenance
ODNR	Ohio Department of Natural Resources
OEPA	Ohio Environmental Protection Agency
ORP	oxidation-reduction potential
P&T	pump and treat
PAH	polycyclic aromatic hydrocarbon
PBOW	Plum Brook Ordnance Works
PCB	polychlorinated biphenyl
PETN	pentaerythritol tetranitrate
POTW	publicly owned treatment works
PRRWP	Pentolite Road Red Water Pond
RAO	remedial action objective
RBRC	risk-based remedial concentration
RBSC	risk-based screening concentration
RCRA	Resource Conservation and Recovery Act
RG	remedial goal
RI	remedial investigation
RO	reverse osmosis
ROD	record of decision
SAIC	Science Applications International Corporation
SCS	Soil Conservation Services
Shaw	Shaw Environmental, Inc.
SLERA	screening-level ecological risk assessment

SMCL	secondary maximum contaminant level
SOD	soil oxidant demand
SVOC	semivolatile organic compound
TAL	target analyte list
TAT	triaminotoluene
TBC	to be considered
TCL	target compound list
TDS	total dissolved solids
TNB	trinitrobenzene
TNT	2,4,6-trinitrotoluene
TNTA	TNT Area A
TNTB	TNT Area B
TNTC	TNT Area C
TOC	total organic carbon
TSS	total suspended solids
UIC	underground injection control
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
VOC	volatile organic compound
WARWP	West Area Red Water Ponds
WTI	WasteTron, Inc.
WWTP	wastewater treatment plant
yd^3	cubic yard
ZVI	zero-valent iron

Executive Summary

This report presents the results of the feasibility study (FS) for groundwater associated with the TNT and Red Water Pond Areas of the former Plum Brook Ordnance Works (PBOW) site in Sandusky, Ohio. The U.S. Army Corps of Engineers contracted Shaw Environmental, Inc. to conduct this FS under Delivery Order DX02 of IDT Contract W912DR-05-D-0026.

Site History/Description. The 9,009-acre PBOW facility was built in early 1941 as a manufacturing plant for 2,4,6-trinitrotoluene (TNT), dinitrotoluene, and pentolite. Production of explosives at PBOW began in December 1941 and continued until 1945. During PBOW operation, 12 process lines were used in the manufacture of explosives: 4 lines at TNT Area A (TNTA), 3 lines at TNT Area B (TNTB), and 5 lines at TNT Area C (TNTC). Manufacturing waste water ("red water" and "yellow water") from these production lines was stored at the two ponds in the West Area Red Water Ponds (WARWP) Area and the single pond at the Pentolite Road Red Water Pond Area (PRRWP) Area. The three former production areas, together with the WARWP and PRRWP Areas, are the potential source areas of concern (AOC) addressed by this FS. TNTA, TNTB, and TNTC comprise approximately 114, 55, and 119 acres, respectively. The single pond at the PRRWP Area had an area of about 2 acres, and the combined acreage of the two ponds in WARWP was approximately 8 acres at the time of operation. Currently, only the western pond at the WARWP still exists. The areas of groundwater study for groundwater and soil contamination include areas surrounding the (former) ponds.

Some of the areas used by the U.S. Department of Defense were decontaminated in the 1940s by the War Department. After decontamination, the property was initially transferred to the Ordnance Department, then to the War Assets Administration after it was certified by the U.S. Army to be decontaminated. In 1949, PBOW was transferred to the General Services Administration. In the 1950s and 1960s, the General Services Administration completed further decontamination of PBOW sites; other areas had been decommissioned, but not decontaminated. The National Aeronautics and Space Administration (NASA) acquired the property on March 15, 1963. NASA currently owns most of the former PBOW property, including the TNT and Red Water Pond Areas.

Groundwater Description. Two main water-bearing zones underlie PBOW: one in the overburden/shale and one in the limestone bedrock. The overburden/shale water-bearing zone is the shallower zone and demonstrates the highest observed levels of site-related groundwater contamination. This shallow water-bearing zone is limited in areal extent and is seasonally

dependant. During a direct-push investigation designed to collect overburden/shale groundwater from over 130 samples in these areas, the decision was made to curtail the event due to the paucity of water. This shallow groundwater zone was also found to have naturally occurring elevated levels of chloride, sulfate, total dissolved solids, and sodium. Groundwater does not exhibit nitroaromatics above risk-based screening limits in the competent shale bedrock. The structure of the shale and high organic content limits the downward vertical movement of contaminants. The limestone bedrock water-bearing zone is deeper and can produce sufficient water quantity for residential purposes, although the water quality is suspect due to the presence of naturally occurring hydrocarbons and hydrogen sulfide. Both the overburden/shale and limestone bedrock groundwater have concentrations of naturally occurring petroleum and metals that result in unacceptable risk for consumption, even in the absence of site-related nitroaromatics. The groundwater in these two units meets the definition of a Class III (nonpotable) aquifer.

Five residences downgradient of the PBOW facility were located during an off-site groundwater well survey that used groundwater from the limestone water-bearing zone. However, groundwater was from these locations was used for purposes other than a drinking water source.

Investigations/Previous Evaluations. Numerous environmental investigations have taken place at these five AOCs, beginning with preliminary assessment and contaminant evaluation sampling performed at the Red Water Pond Areas from the mid-1980s through 1991. Site investigations and remedial investigations at all five AOCs were performed from 1993 through 2000. This involved the collection of soil, sediment, surface water, and groundwater samples. Additional groundwater sampling was conducted at each of these areas through April 2002. These samples indicated that residual contamination remained in environmental media. In 2003, groundwater from five downgradient residences was sampled for nitroaromatic compounds only. No nitroaromatics were detected.

Human health and ecological risk assessments were conducted on the soil, sediment, and surface water at each of the five TNT and Red Water Pond Areas. Unacceptable human health risks and hazards were identified for TNTA, TNTB, TNTC, and the PRRWP Area. Potential ecological risks were also identified for soils in each of TNT Areas; potential ecological risks were also identified in WARWP soil, but the area associated with this contamination was very localized and judged as unlikely to adversely affect biological populations. Focused soil FSs were conducted for the five TNT and Red Water Pond Areas; for TNTC, the FS also included sediment.

A human health risk assessment was performed on groundwater associated with the TNT and Red Water Pond Areas. Because the overburden/shale has limited groundwater yield in these areas, exposure to the shallow groundwater was regarded as an incomplete exposure pathway and was only qualitatively evaluated. The limestone bedrock groundwater was quantitatively evaluated for risks. This quantitative evaluation was based both on risks associated with measured concentrations, and those based on potential future concentrations. These future concentrations were modeled for 2,4,6- TNT, 2,4-dinitrotoluene (2,4-DNT), and 2,6-dinitrotoluene (2,6-DNT), based on concentrations measured in the overburden/shale groundwater and in the soil and using site parameters for leaching and groundwater flow. Ecological risks were not evaluated for groundwater because no exposure pathway was identified via which ecological receptors come into contact with groundwater.

The Ohio Environmental Protection Agency (OEPA) criterion for noncancer hazards is a hazard index (HI) of 1, and the OEPA criterion for cancer risks is an incremental lifetime cancer risk (ILCR) of 1E-5. The Army likewise uses an HI of 1 for noncancer hazard, but uses an ILCR criterion of 1E-4 as a threshold to determine whether a remedial action may be required due to cancer risks. Based on analytical data collected from monitoring wells in the limestone unit, only TNTA and the WARWP Area exceed the HI criterion of 1. The estimated groundwater site-related cancer risks based on analytical data collected from limestone bedrock groundwater monitoring wells, assuming residential groundwater use, exceed the OEPA criterion at the following areas: TNTA, the PRRWP Area, the WARWP Area, and downgradient areas. Of these, only the WARWP exceeds the Army 1E-4 cancer criterion assuming residential use of groundwater. In summary, four areas (TNTA, the PRRWP Area, the WARWP Area, and downgradient areas) exceed the OEPA cancer or noncancer criteria, and two areas (TNTA and WARWP Area) exceed the Army cancer or noncancer criteria.

The estimated future concentrations of TNT, 2,4-DNT, and/or 2,6-DNT in limestone bedrock groundwater, based on the site modeling results, would exceed the OEPA 1E-5 ILCR criterion for cancer risks at each of the five AOCs and the boundary downgradient of TNTB, TNTC, and the PRRWP Area, assuming future residential use. The modeled concentrations would also exceed the Army ILCR criterion (1E-4) at each of these sites, except TNTB and the boundary area, although the exceedances for the PRRWP Area (1.5E-4) and WARWP (1.7E-4) would be marginal. The modeling results for these three compounds also indicated a noncancer hazard for TNTA and TNTC groundwater that would exceed the HI criterion. It is important to note, however, that groundwater modeling is conservative and the results are deemed to be biased high due to data limitations and uncertainties inherent to groundwater investigations. The two most

critical areas that bias the model results are the leachability of contaminants in the vadose zone, and the lack of a natural attenuation component in simulating the limestone bedrock groundwater. The uncertainties associated with both of these components are likely to introduce bias that tends to overestimate rather than underestimate resulting groundwater concentrations. The application of groundwater modeling results must be interpreted using best professional judgment, taking into account these uncertainties.

Because groundwater use may potentially pose a threat to human health and five downgradient sources are identified, this current FS was conducted. However, as previously noted, even in the absence of site-related contamination, the groundwater at PBOW is not suitable for human consumption due to elevated risks from naturally occurring petroleum and metals. Any remedial action taken at the site would not restore groundwater to drinking water quality. Specifically, the cancer risks associated with background contributions account for virtually all of the cancer risk for residential exposure to TNTB and TNTC groundwater, over 99 percent of the risks for PRRWP Area groundwater, approximately 98 percent for TNTA groundwater, and approximately 50 percent for residential exposure to WARWP Area groundwater. In each case, even if the U.S. Department of Defense (DOD)-related contaminants were not present, the cancer risk levels associated with residential groundwater use would exceed the 1E-5 OEPA risk management criterion by more than an order of magnitude. Thus, groundwater treatment, if performed, would only reduce or eliminate site-related contamination and would not address the broader issue of the natural petroleum, metals, dissolved solids, or hydrogen sulfide present in the aquifers, and groundwater after such treatment would not meet the OEPA or Army risk management criteria. Therefore, any use of groundwater at the site would require additional treatment to address the natural constituents in groundwater that are unrelated to past Army operations.

Soil Remediation Activities. The PBOW project team decided, after reviewing the FS documents, to perform soil remedial actions at the three TNT Areas and the PRRWP Area. These remedial actions were undertaken primarily to protect human and ecological receptors from direct contact with contaminated soil. However, the soil actions were generally designed to remove all soil from the surface to the top of the overburden water table, where present, so that these actions would effectively remove deeper sources of groundwater contamination as well.

The soil remedial actions at TNTB and the PRRWP Area are complete and the soil remedial actions at TNTA and TNTC are yet to commence. It is noted that TNTC also includes a small area of sediment to be removed. Only a small “hot spot” soil area removal was originally planned for the PRRWP Area. However, during removal of this small hot spot, extensive

additional contamination was discovered and delineated; remediation of this additional contamination was completed in September.

Remedial Action Objectives. The following remedial action objectives (RAO) have been developed in this FS for groundwater associated with the TNT and Red Water Pond Areas:

1. Prevent on-site human exposure to groundwater containing contaminants of concern (COC) at concentrations that exceed remedial goals (RG) for residential drinking water.

2. Prevent human exposure to downgradient off-site groundwater containing COCs at concentrations that exceed RGs for residential drinking water.

Groundwater is not currently used on site, off-site migration of contamination has not been detected, and groundwater is not known to be used as drinking water in households surrounding PBOW. Based on review of the analytical data, the groundwater meets the EPA definition of a Class III aquifer (nonpotable). Therefore, no current exposure to contaminants in PBOW groundwater exists and future exposure is unlikely given the groundwater quality and the fact water is supplied by public utilities. As long as NASA owns the property, it is expected that RAO No. 1 would be met. However, controls are not currently in place to protect potential future off-site users of groundwater.

Contaminants of Concern. Groundwater COCs were identified individually for each of the five separate AOCs (TNTA, TNTB, TNTC, WARWP Area, and PRRWP Area). Separate COCs were developed for the limestone bedrock groundwater and the overburden/shale groundwater. Each of the COCs for the limestone bedrock groundwater is also a COC for the overburden/shale groundwater in the corresponding area. RGs, which are human health risk-based levels developed as cleanup criteria for residential drinking water use, were developed for each COC. The COCs and their corresponding RGs are shown in Table ES-1.

Note that the RGs apply only to groundwater that is assumed to be used directly as drinking water. Based on previous investigations, groundwater within the overburden/shale is discontinuous, seasonally dependent, and of relatively low quality basted on concentrations of chloride, sulfate, sodium, and total dissolved solids that exceed secondary maximum contaminant levels. While secondary maximum contaminant levels are not regulatory enforceable, they are used as a guide to determine acceptable drinking water based on taste, smell, color, or appearance. If the overburden/shale groundwater cannot be used as drinking water due to poor yield volume and/or unsuitable quality, then these RGs should not be applied

to this shallow water-bearing unit. Even in the absence of site-related contamination, groundwater consumption would still result in an unacceptable risk due to naturally occurring petroleum and metals.

Table ES-1

Contaminants of Concern and Remedial Goal Option
TNT and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

Contaminants of Concern for Both Limestone Bedrock and Overburden/Shale Groundwater	Remedial Goal Option (µg/L)
2,4,6-Trinitrotoluene	*3*
2,4-Dinitrotoluene	*0.5*
2,6-Dinitrotoluene	*0.5*
2-Amino-4,6-dinitrotoluene	*1*
4-Amino-2,6-dinitrotoluene	*1*
2-Nitrotoluene	*0.6*
4-Nitrotoluene	*4*
Nitrobenzene	*0.5*
4,6-Dinitro-2-methylphenol	2
3-Nitroaniline	2
Nitrate	10,000
Additional Contaminants of Concern for Overburden/Shale Groundwater Only	**Remedial Goal Option (µg/L)**
1,3,5-Trinitrotoluene	109
1,3-Dinitrobenzene	0.4
3-Nitrotoluene	122
2,4-Dinitrophenol	7.3
4,6-Dinitro-2-methylphenol	0.4
4-Nitrophenol	4.9
3-Nitroaniline	1.1
Dibenzofuran	1.2
Fluorene	24
Toluene	1,000

µg/L – Micrograms per liter.

Areas and Volumes of Contaminated Groundwater. Estimated areas and volumes of contaminated groundwater that may be subject to remediation were determined. This determination was based on the output of the site groundwater model, groundwater analytical results, site-specific information on the AOCs, and experience with similar former TNT manufacturing facilities.

Two separate remedial strategies were developed for remedial alternatives that would use active remediation (i.e., not rely exclusively on administrative controls) to reduce potential risks. The

first is protection/mitigation of the limestone bedrock groundwater only. This is the strategy to which Alternative GW-3, introduced in the next section, correlates. Under this strategy, the overburden groundwater is not regarded as a potential source of drinking water. Therefore, the RGs are not applied to this shallow water unit. Under this first strategy, remedial action would target two areas: 1) the limestone bedrock groundwater where concentrations of COCs exceed the RGs, and 2) overburden/shale groundwater where contaminants could migrate downward and adversely impact the limestone bedrock groundwater.

The second strategy assumes that all groundwater underlying the AOCs is a potential future source of drinking water. The RGs are applied to both the overburden/shale groundwater and the limestone bedrock aquifer. Alternative GW-4, presented in the next section of this Executive Summary, correlates to this strategy. The estimated areas and volumes of contamination are presented in Table ES-2 under each of these strategies.

Table ES-2

Estimated Areas and Volumes of Contamination
TNT and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

	Protection/Mitigation of Bedrock Only		**Protection/Mitigation of All Groundwater**	
Overburden/shale	Area (feet$^{2)}$	Volume (gallons)	Area (feet^2)	Volume (gallons)
TNT Area A	86,100	2,533,000	116,300	2,833,000
TNT Area B	16.400	25,000	115,200	242,000
TNT Area C	52,900	770,000	60,200	1,372,000
PRRWP Area	320,000	6,224,000	440,000	8,558,000
WARWP Area	370,000	13,389,000	680,000	25,434,000
Totals	845,000	23,391,000	1,412,000	38,439,000
Limestone Bedrock				
PRRWP Plume	810,000	61,000,000	810,000	61,000,000
WARWP Plume	570,000	45,000,000	570,000	45,000,000
Totals	1,380,000	106,000,000	1,380,000	106,000,000

Remedial Alternatives. A broad range of remedial alternatives was developed in the FS that allow the project risk managers to assess the relative cost effectiveness of different remedial strategies that employ varying degrees of active remediation. A site-specific leaching and groundwater flow model was critical in the development of these alternatives, as the predictions of the model were used to identify target areas for remediation. Note the results of the groundwater model are considered to be conservative (i.e., biased high). The following remedial alternatives were developed and evaluated for contaminated groundwater at PBOW:

- Alternative GW-1: No further action
- Alternative GW-2: Groundwater monitoring, monitored natural attenuation, and institutional controls
- Alternative GW-3: In situ enhanced bioremediation (ISEB)/pump and treat (P&T) for mitigation/protection of the limestone bedrock groundwater, groundwater monitoring, and institutional controls
- Alternative GW-4: ISEB/P&T for mitigation/protection of the overburden/shale and limestone bedrock groundwater, groundwater monitoring, and institutional controls.

Evaluation of Remedial Alternatives. The remedial alternatives were evaluated against the seven threshold and primary balancing criteria required by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Some general conclusions are presented in the following paragraphs. Present value cost summaries are provided in Table ES-3.

Table ES-3

Estimated Present Value Cost Summaries and Contingencies
TNT and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

	Alternative			
	GW-1 No Further Action	GW-2 Monitoring/LUC	GW-3 Targeted ISEB/P&T	GW-4 ISEB/P&T
Present Value Estimate	$0	$2,002,000	$15,884,000	$19,614,000
Present Value Estimate (-30%)	$0	$1401,000	$11,119,000	$13,730,000
Present Value Estimate (+50%)	$0	$3,003,000	$23,826,000	$29,421,000

LUC = Land-use control; ISEB/P&T = In situ enhanced bioremediation/pump and treatment.

Alternative GW-1 does not protect human health and may not comply with all applicable or relevant and appropriate requirements (ARAR) under the assumption that site groundwater could be used as a potable source, as the maximum concentrations of nitrate and toluene in groundwater are above Ohio drinking water standards. This would represent a failure to meet at least one of the two threshold criteria required under CERCLA. However, even if DOD-related constituents are excluded, use of this water would exceed OEPA and EPA criteria for potable purposes and would not be protective of human health because of naturally occurring chemicals. Given the natural conditions of the groundwater, and its meeting of Class III (nondrinking) criteria, State drinking water standards would not be ARARs. If Alternative GW-1 were

employed, an assessment of whether DOD-related contamination is migrating off site could not be made, because there is no monitoring component of this alternative.

Alternative GW-2 protects human health and the environment by establishing groundwater use restrictions to prevent exposure to contaminated groundwater on site. Long-term groundwater monitoring would protect the surrounding community by providing advance notice of any potential off-site movement of contamination, allowing additional remedial action to be taken if necessary. The alternative may or may not comply with all ARARs, as the concentrations of nitrate and toluene in groundwater are above Ohio drinking water standards. Given the natural conditions of the groundwater, and its meeting of Class III (nondrinking) criteria, State drinking water standards would not be ARARs. It is possible that the concentrations of these chemicals may attenuate with time. The alternative includes evaluation of natural attenuation parameters to verify that degradation of nitroaromatics is occurring in the limestone bedrock groundwater. Alternative GW-2 does not include a treatment component. The total present value cost of the alternative is estimated to range from $1.4 to $3.0 million over 150 years.

Alternative GW-3 protects human health and the environment by establishing groundwater use restrictions and a long-term groundwater monitoring program as in Alternative GW-2. This alternative also includes treatment of groundwater in the overburden/weathered shale and limestone bedrock aquifers. The objective of this treatment is to reduce the concentrations of COCs in the limestone bedrock aquifer to drinking water quality, although groundwater modeling projects that this would take more than 150 years. Despite this objective, the aquifer is contaminated with naturally occurring constituents, such as petroleum hydrocarbons, that make the limestone bedrock groundwater unsuitable as potential drinking water. The treatment strategy would not ensure that all areas within the overburden/weathered shale aquifer would meet drinking water quality in the foreseeable future. The suitability of the overburden/shale unit as a potential drinking water source is doubtful due to its low yield and marginal quality (e.g., elevated concentrations of naturally occurring chloride, sulfate, total dissolved solids, and sodium). The treatment components of this alternative include a combination of ISEB in the overburden/weathered shale aquifer and P&T in the limestone bedrock aquifer. Groundwater treatment should ensure compliance with all ARARs, including Ohio drinking water standards. The total present value cost of the alternative is estimated to range from $11.1 to $23.8 million over 150 years.

Alternative GW-4 protects human health and the environment by establishing groundwater use restrictions and a long-term groundwater monitoring program, as in Alternatives GW-2 and GW-3. The objective of this treatment is to reduce the concentrations of COCs in both the

overburden/weathered shale and limestone bedrock aquifer to drinking water quality, although groundwater modeling projects that this would take more than 150 years in the limestone. The treatment components of this alternative include a combination of ISEB in the overburden/weathered shale aquifer and P&T in the limestone bedrock aquifer. The ISEB component in the overburden/weathered shale would be applied over a larger area than in Alternative GW-3. As mentioned in the preceding paragraph, the contamination of both aquifers by naturally occurring constituents and the low yield of the overburden/weathered shale groundwater may make both aquifers unsuitable sources of drinking water, even in the absence of any contamination by TNT operations. Groundwater treatment should ensure compliance with all ARARs, including Ohio drinking water standards. The total present value cost of the alternative is estimated to range from $13.9 to $29.4 million over 150 years.

Conclusions. Alternatives GW-2 through GW-4 meet the "protectiveness of human health" criterion through the implementation of land-use restrictions. A monitoring program would be included in Alternatives GW-2 through GW-4 to verify that groundwater contamination is not migrating off site. Under Alternatives GW-3 and GW-4, it is expected that limestone bedrock groundwater would be remediated over a period of time, and further contamination to the limestone bedrock from the overburden/shale would be prevented both through overburden/shale groundwater remediation and the soil remediation activities that are already planned or completed in the respective AOCs. Based on the site groundwater model, the remediation of the limestone bedrock groundwater would take more than 150 years at both the PRRWP Area and WARWP Area plumes. Alternative GW-4 is intended to result in eventual remediation of all overburden/shale groundwater to RGs, although the site groundwater model indicates that this goal would take more than 150 years to attain. However, even after RGs are met for the overburden/shale groundwater, naturally occurring conditions in this unit would likely render it unsuitable for potable use. Overburden/shale groundwater is not expected to meet drinking water quality in the foreseeable future, if ever, due to natural groundwater conditions, under Alternatives GW-2 and GW-3.

Given the potential low quality of both the overburden/shale and limestone bedrock groundwater due to naturally occurring chemicals, and the low yield of the overburden/shale, the benefits of remediating this groundwater may be negligible. However, the estimated costs for implementing either GW-3 ($11.1 million to $23.8 million) or GW-4 ($13.7 million to $29.4 million) are substantial. The costs of GW-2 are much lower ($1.4 million to $3.0 million) and would likely provide the same level of protection to human health.

1.0 Introduction

This report presents the results of the feasibility study (FS) for groundwater contamination associated with the TNT Areas and Red Water Pond Areas of the former Plum Brook Ordnance Works (PBOW) site in Sandusky, Ohio. The U.S. Army Corps of Engineers (USACE) is conducting studies under the Defense Environmental Restoration Program to determine the environmental impact of suspected hazardous waste sites at previously owned U.S. Department of Defense properties. PBOW is an Army Defense Environmental Restoration Program project currently managed and technically overseen by the Huntington, West Virginia, and Nashville, Tennessee, USACE district offices, respectively. USACE contracted Shaw Environmental, Inc. (Shaw) to conduct this FS under Delivery Order DX02 of Contract W912DR-05-D-0026.

The FS was completed in a manner consistent with U.S. Environmental Protection Agency (EPA) remedial investigation (RI)/FS guidance; the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (EPA, 1988); and subsequent guidance materials, including *Guidance on Implementation of the Superfund Accelerated Cleanup Model (SACM) under CERCLA and the NCP* (EPA, 1992).

1.1 Purpose and Scope

The purpose of this FS is to develop and evaluate remedial alternatives to address contaminated groundwater associated with the former TNT and Red Water Pond Areas of PBOW. The former TNT Areas are the three separate manufacturing areas where 2,4,6-trinitrotoluene (TNT) was manufactured; these are TNT Area A (TNTA), TNT Area B (TNTB), and TNT Area C (TNTC). Manufacturing wastewater ("red water" and "yellow water") from these production lines (TNT lines) was disposed of at the two former West Area Red Water Ponds (WARWP) and the former Pentolite Road Red Water Pond (PRRWP). The area of the former PRRWP has been filled in and regraded; the footprint and surrounding area of the former pond is referred to as the PRRWP Area. One of the former West Area ponds has since been breached and only a single pond remains. The footprint of the two former ponds (including one current pond) is referred to as the WARWP Area. This FS uses the term "TNT Areas" when referencing TNTA, TNTB, and TNTC and uses the term "Red Water Pond Areas" when referencing both the PRRWP Area and WARWP Area.

Limestone bedrock groundwater underlying the TNT and Red Water Pond Areas has elevated concentrations of naturally occurring constituents, including petroleum, hydrogen sulfide, and

inorganics, that render it undesirable for drinking water use (see Section 2.6). Evaluation of the of this groundwater indicates that even without the presence of site-related constituents (i.e., nitroaromatics), groundwater consumption would pose an unacceptable risk due to the presence of naturally occurring petroleum and inorganics. Additionally, the shallow overburden/shale aquifer is highly seasonal in these areas with limited saturated thickness during dry periods of the year and, therefore, may not provide adequate yield for household use (see Section 2.2.4.2). However, based on discussions between the USACE, National Aeronautics and Space Administration (NASA), and Ohio Environmental Protection Agency (OEPA), a full range of remedial approaches was developed for groundwater underlying the TNT and Red Water Pond Areas. This range includes a no-further-action approach (aside from completed or planned soil source removal) through aggressive groundwater treatment approaches. Development of the aggressive treatment approaches in this FS does not connote the recommendation on the part of the USACE, or any other member of PBOW project team, for active treatment of groundwater underlying the TNT and Red Water Pond Areas.

1.2 Site Background

PBOW is located in Erie County, Ohio, approximately 4 miles south of Sandusky and 59 miles west of Cleveland (Figure 1-1). Although most of the PBOW facility is within Perkins and Oxford Townships, the eastern edge of the facility extends into Huron and Milan Townships. PBOW is bounded on the north by Bogart Road, on the south by Mason Road, on the west by Patten Tract Road, and on the east by U.S. Highway 250. The area surrounding PBOW is mostly agricultural and residential (Shaw, 2005).

The 9,009-acre PBOW facility was built in early 1941 as a manufacturing plant for TNT, dinitrotoluenes (DNT), and pentolite (pentolite is composed of a mixture of 50 percent pentarerythritol tetranitrate [PETN] and 50 percent TNT) (International Consultants Incorporated [ICI], 1995). Production of explosives at PBOW began in December 1941 and continued until 1945. It is estimated that more than 1 billion pounds of nitroaromatic explosives were manufactured during the 4-year operating period.

Some of the areas used by the U.S. Department of Defense were decontaminated in the 1940s by the War Department. After decontamination, the property was initially transferred to the Ordnance Department, then to the War Assets Administration after it was certified by the U.S. Army to be decontaminated. In 1949, PBOW was transferred to the General Services Administration (GSA). In the 1950s and 1960s, GSA completed further decontamination of PBOW sites; other areas had been decommissioned but not decontaminated. NASA acquired the property on March 15, 1963. NASA currently owns most of the former PBOW property, which

is operated as the Plum Brook Station of the John Glenn Research Center, headquartered in Cleveland, Ohio. Most of the aerospace testing facilities built in the 1960s at the site are on standby or inactive status. On April 18, 1978, NASA declared approximately 2,152 acres of PBOW as excess. The Perkins Township Board of Education acquired 46 acres of the excess land and uses this area as a bus transportation area. GSA obtained ownership of the remaining excess acreage and currently has a use agreement with the Ohio National Guard for 604 acres of this land. NASA presently controls approximately 6,400 acres and is using the site to conduct space research as a satellite operation facility of the John Glenn Research Center (Shaw, 2005).

During PBOW operation, 12 TNT lines were used in the manufacture of explosives: 4 lines at TNTA, 3 lines at TNTB, and 5 lines at TNTC. Manufacturing wastewater ("red water" and "yellow water") from these production lines was stored at two ponds at the WARWP Area and a single pond at the PRRWP Area. The red and yellow waste water was generated during the manufacturing process of TNT. Yellow water was produced when the initial TNT product was washed with warm water and soda ash and later in the manufacturing process, red water was generated when TNT was rinsed with cold water and sellite. The three former production areas, together with the WARWP and PRRWP Areas, are the potential source areas of concern (AOC) addressed by this groundwater FS. Note that in this report, the term "facility" refers to the entire former PBOW property, and the term "site" refers to an AOC or other specified area within PBOW. Each of the AOCs is identified on Figure 1-2 and is briefly described in the following text.

TNTA. Located in the northeastern portion of PBOW, TNTA occupies approximately 114 acres. TNT Lines 1 through 4 were located at this area (Figure 1-3). It is mostly covered with prairie grasses and scrub trees, though it is partly wooded in the extreme southern section. It is slightly hilly, generally decreasing in elevation from southeast to northwest. The Engineering Building, occupied by NASA employees, is currently in the central portion of TNTA. The former process building foundations are still present, although they are covered with up to approximately 2 feet of fill material. The only remaining visible structures are water hydrants, water valves, abandoned railroad tracks, ditches, and sewer line manholes (IT Corporation [IT], 2001a).

TNTB. TNTB is located in the south-central portion of PBOW and comprises an area of approximately 55 acres (Figure 1-4). TNT Lines 5, 6, and 7 were located at TNTB. The area is relatively flat, with some low hummocks and marshy areas present. Two active NASA facilities are present: the Hypersonic Tunnel Facility and the Nitrogen Dewar Tanks. Most of the former process building foundations are still present, although they are covered with up to

approximately 2 feet of fill material. The only remaining visible structures are water hydrants, water valves, abandoned railroad tracks, ditches, and sewer line manholes (IT, 2001b).

TNTC. Located in the southwestern portion of PBOW, TNTC is densely wooded, with small areas of open grassland (Figure 1-5). It occupies approximately 119 acres. TNT Lines 8 through 12 were located at this area. TNTC is not used by NASA and one inactive building is present, which was formerly used by EPA. One foundation, as well as some of the building debris from an Acid and Fume Recovery Building and remnants of the wastewater settling tank, are still visible at the site. The other former process building foundations are still present, although they are covered with up to approximately 2 feet of fill material. Other remaining visible structures are water hydrants, water valves, abandoned railroad tracks, ditches, and sewer line manholes (IT, 2001c).

PRRWP Area. A single, unlined "red water" pond was located in the north-central portion of PBOW and had an area of approximately 2 acres (Figure 1-6). The AOC includes the areas that had been suspected of receiving potential impact from site activities in addition to the original pond footprint. During PBOW operations, "red water" and "yellow water" was pumped from manufacturing activities at TNTA and TNTB to the PRRWP. In 1977, "red water" was removed from the former pond and the area was regraded (Science Applications International Corporation [SAIC], 1991). Currently, the PRRWP Area is covered in grasses and is largely marshy. Ponded areas, which resulted from the regrading activities, are present in the PRRWP Area, but outside of the original PRRWP footprint. Note that the corresponding area on Figure 1-2 is larger than 2 acres, as it depicts the AOC. The AOC includes the areas that had been suspected of receiving potential impact from site activities, in addition to the original pond footprint. The PRRWP Area is not used by NASA, and no buildings are present.

WARWP Area. Two unlined "red water" ponds, an "east pond" and a "west pond," were present in the WARWP Area of the site and covered approximately 8 acres (Figure 1-7) (SAIC, 1991). During PBOW operations, the WARWP received "red water" from TNTC. Currently, only the "west pond" is present and occupies approximately 4 acres. The area of the former east pond is low lying and marshy. According to information from Dames and Moore, Inc. (D&M) (1997a), the east pond existed from the 1940s until the 1970s, when it was breached in an attempt to drain it. This area is not currently used by NASA, and no buildings are present.

1.3 Summary of Previous Investigations and Activities

The discussion in this Section includes environmental investigations and activities conducted at PBOW from 1945 through 2005. Relevant investigation reports include *Engineering Report of*

the Contamination Evaluation (IT, 1991); *Site Inspection Report* (Morrison Knudsen Corporation [MK] 1994); *Site Management Plan* (ICI, 1995); *Sitewide Groundwater Investigation Draft Report* (D&M, 1997b); *Final Report Site-Wide Groundwater Investigation* (IT, 1997); *2001 Groundwater Remedial Investigation* (IT, 2002a); *2002 Groundwater Summary and Evaluation Report* (Shaw, 2003a); and *2004 Groundwater Data Summary and Evaluation Report* (Shaw, 2005). A summary of previous environmental investigations and activities is provided in Table 1-1.

1.3.1 Early Decontamination Activities at the TNT Areas (1945–1963)

The U.S. Army began decontamination and decommissioning of all TNT, DNT, and PETN lines in September 1945. Typical decontamination and decommissioning methods of all the manufacturing lines involved removing and relocating any explosive waste from the building or structures to a burning ground for open burning. Aboveground portions of buildings and structures were demolished and burned where possible. Based on soil investigations completed at the TNT Areas, portions of concrete foundations were found still in place but covered by up to 2 feet of fill material. Steam lines used for facility heating and associated building drain lines were flushed and dismantled, but no records were found indicating the wash-out location. By December 1945, it was estimated that 65 percent of the necessary decontamination was complete (MK, 1994).

From January 1 to June 30, 1946, the USACE assumed responsibility for maintenance and custodial activities. Further decontamination activities were conducted, and the extent of contamination was certified (MK, 1994).

During 1954 through 1958, remedial procedures were conducted by the USACE through Ravenna Arsenal to decontaminate the surface and subsurface soil at the TNT Areas. In the summer of 1955, decontamination was performed first at TNTA. The decontamination process at TNTA included the removal of contaminated surface and subsurface soil around the wash houses, bi-tri houses, fortifier buildings, DNT sweating and graining building, DNT nitrating building, and nail houses. They also removed wooden and ceramic waste disposal lines containing from 1.0 to 2.5 inches of TNT. In addition, concrete catch basins containing thousands of pounds of TNT were discovered overlain by wood and scrap lumber. This lumber and TNT was removed and transported to the Burning Grounds, where it was burned. Decontamination of TNTB and TNTC was supposed to be modified to address only surface contamination detected by visual inspection and to leave underground flume lines in place. It is unknown whether this modification in the procedure took place as part of the 1955 decontamination of TNTB and TNTC (D&M, 1997c).

NASA acquired PBOW on March 15, 1963 and still utilizes the site. The GSA further decontaminated the TNT Areas to facilitate transfer. The decontamination is believed to have occurred prior to the transfer of property (D&M, 1997c), and work was accomplished in five steps:

- Inspecting then removing contaminated surface soil above the drain tiles, flumes, etc.
- Spot checking of subsurface soil in the vicinity of drain tiles, flumes, etc., to determine where the contaminated tiles and flumes were located. Where contamination was found, the flumes, tiles, etc., were removed in sections.
- Removal of some items previously decontaminated to three X (XXX) condition to a storage facility and additional decontamination of the remainder of the items to a five X (XXXXX) condition in order to be sold ("X" indicates the Army's specific decontamination level).
- Destruction of all buildings by fire, then removal of all debris and concrete foundations. All the materials were flashed in those areas, including the earth, and the area was then rough graded. During recent soil investigations at the TNT Areas, it has been observed that portions of the concrete building foundations remain in place.
- Decontamination of all sump basins and removal of the concrete.

The decontamination process also included the burning of nitroaromatic-filled flumes that were excavated. As shown in the records review (D&M,1997c), this was performed on July 10, 1963 near the intersection of Fox Road and Snake Road. This location is generally referred to as the Additional Burning Grounds or Snake Road Burning Ground.

1.3.2 Early Red Water Pond Area Investigations (1977–1991)

In April 1977, Plum Brook Station personnel reported pockets of reddish-brown water in the small surface ditch east of and adjacent to the PRRWP. The source of the reddish-brown water was discovered to be a broken drain tile that was formerly used to drain the ponds. As a corrective action, retention dikes and sump pits were excavated to prevent further leakage of the material to the stream. Approximately 60,000 gallons of the red water were removed from the PRRWP by a private contractor, and grading and drainage improvements were made to the area. The action also included backfilling of the former ponds and relocation of an existing drainage ditch to a new location approximately 300 feet east of the ponds to reduce standing surface water (D&M, 1997c).

OEPA first conducted a preliminary assessment of the redwater ponds in 1983 (ICI, 1995).

In 1984, Battelle Laboratories collected a surface soil sample from the spoils area at the WARWP Area. Concentrations of nitroaromatics were detected in the low parts per million range (IT, 2000a).

During the mid- to late 1980s, numerous studies were conducted of the surface water and sediment from the red water pond areas. In May 1985, the Ohio Department of the Interior placed tap nets in the western pond of the WARWP Area to determine if any aquatic life had been affected by possible TNT wastewater contaminants. It was determined that aquatic life had not been affected. Also in 1985, the Ohio National Guard collected soil, sediment, and surface water samples for TNT, PETN, and DNT analysis to facilitate a transfer of land from NASA to the Ohio Army National Guard. The highest values found in the screened sediments were less than 1 part per million (IT, 2000a).

Shaw investigated the Red Water Pond Areas during a 1989 contamination evaluation. Surface water, soil, and groundwater sampling was conducted to determine the presence or absence of residual chemical contamination from PBOW operations. Six surface soil samples and one surface water sample were collected and one overburden/shale monitoring well was installed at the PRRWP Area. Six surface and five subsurface soil samples were collected and one overburden/shale monitoring well was installed at the WARWP Area. Samples were analyzed for volatile organic compounds (VOC), semivolatile organic compounds (SVOC), nitroaromatics, metals, pH, sulfate, and nitrate (IT, 1991). In 1991, SAIC conducted a preliminary assessment for NASA and further confirmed that hazardous substances had been released into the environment at the WARWP Area (ICI, 1995).

1.3.3 Site-Wide Site Inspection (1993)

In 1993, MK conducted a site inspection at PBOW, including the TNT and Red Water Pond Areas. The site inspection included collection and analysis of collocated surface water and sediment sample pairs, soil samples, and overburden/shale groundwater samples. Samples were analyzed for nitroaromatics, VOCs, SVOCs, total and dissolved metals, pesticides, and polychlorinated biphenyls (PCB) (MK, 1994).

1.3.4 TNT Areas Site Investigation and Focused Remedial Investigation at the Red Water Ponds (1994)

In 1994, D&M conducted a TNT Areas site investigation (D&M, 1997c) and a focused RI at the Red Water Pond Areas (D&M, 1997a). The TNT Areas site investigation included subsurface soil and groundwater sampling. The overburden/shale groundwater was sampled at each TNT Area, and the bedrock groundwater was sampled at TNTA and TNTC. The focused RI at the Red Water Ponds Areas included surface and subsurface soil sampling and the installation and sampling of overburden/shale and bedrock groundwater wells. Soil samples from both events were analyzed for nitroaromatics and metals. Groundwater samples were analyzed for nitroaromatics, metals, and nitrates. In addition, groundwater samples from the six bedrock monitoring wells (wells at the PRRWP Area, the WARWP Area, TNTA, and TNTC) were also analyzed for VOCs and SVOCs.

1.3.5 Site-Wide Groundwater Investigations (1996, 1997, and 1998)

Beginning in 1996, Shaw conducted several site-wide groundwater investigations, which included the TNT and Red Water Ponds Areas. A series of three sampling events were conducted in September/ October 1996 (IT, 1997), November 1997 (IT, 1999), and May 1998 (IT, 1999). During the 1997 field event, two bedrock monitoring wells were installed at TNTB. Groundwater samples were analyzed for nitroaromatics, VOCs, SVOCs, metals, pesticides, PCBs, and cyanide during each of the three events.

1.3.6 Remedial Investigation/Focused Feasibility Study/Risk Assessments (1998–2002)

1998 Remedial Investigation Activities. In July and November 1998, Shaw conducted RI activities at the Red Water Pond Areas. Direct-push groundwater and soil sampling (surface and subsurface) was performed at both the WARWP Area and PRRWP Area. Sediment and surface water sampling were also conducted at the WARWP Area. Samples were analyzed for nitroaromatics only (IT, 2000a).

In October and November 1998, RI activities were conducted at TNTB, including the collection and analysis of surface and subsurface soil, surface water, and sediment samples. Field screening and confirmation sampling of soil samples for nitroaromatics was performed. The surface water samples were analyzed for nitroaromatics, VOCs, SVOCs, and metals (IT, 2000b).

In 2000, Shaw completed reporting for the risk assessment and direct-push investigation of the Red Water Pond Areas (IT, 2000a) and in 2002, the corresponding focused feasibility study

(FFS) for soils report was completed (IT, 2002b). This group of investigations will collectively be referred to as the RI/FFS throughout this section.

2000 Remedial Investigation Activities. From June through October 2000, RI activities were conducted at TNTA and TNTC, including the collection and analysis of surface and subsurface soil, surface water, sediment, and overburden/shale groundwater samples. Field screening and confirmation sampling of soil samples for nitroaromatics was performed. Confirmation soil samples were also analyzed for VOCs, SVOCs, PCBs, and target analyte list (TAL) metals. Groundwater samples collected from temporary piezometers and most of the surface water samples were analyzed for nitroaromatics, VOCs, SVOCs, PCBs, and TAL metals (IT, 2001d).

2000–2001 Risk Assessments. In 2000, a screening-level ecological risk assessment (SLERA) and baseline human health risk assessment (BHHRA), combined with the report of findings, were prepared by Shaw for the Red Water Ponds Areas (IT, 2000a). Also in 2000, Shaw prepared a BHHRA and a baseline ecological risk assessment (BERA) for the TNTB Area (IT, 2000c). In 2001, BERAs were performed by Shaw for TNTA and TNTC (IT, 2001f) and Red Water Ponds Areas (IT, 2001e). Also in 2001, BHRRAs were performed by Shaw for TNTA and TNTC (IT, 2001g). The BHRRAs for the TNT Areas and the WARWP Area were for soil, surface water, and sediment. The BHRRA for the PRRWP Area was for soil only.

2001-2002 Remedial Investigation Activities. In July and August 2001, Shaw continued RI activities for the TNT Areas. Direct-push overburden/shale groundwater from temporary piezometers was screened for nitroaromatics and VOCs, but the operation was discontinued due to lack of groundwater. Bedrock groundwater wells were installed at each of the three TNT Areas (Shaw, 2003a).

In September and October 2001, the expanded groundwater RI continued with the first “dry season” groundwater sampling event at each of the TNT and Red Water Ponds Areas. In April 2002, the first “wet season” sampling event was conducted. Groundwater samples collected from the monitoring wells were analyzed for nitroaromatics, VOCs, SVOCs, filtered and unfiltered metals, cyanide, nitrate, sulfate, and water quality parameters (Shaw, 2003a).

Focused Feasibility Studies. Shaw prepared an FFS for TNTB soil in 2000 (IT, 2001b) and an FFS for the Red Water Ponds Areas soil in 2002 (IT, 2002b). In 2003, Shaw prepared an FFS for TNTA and TNTC soil and sediment (Shaw, 2003b).

1.3.7 TNTB Soil Remediation Activities

To minimize threat and provide adequate protection to human health and the environment from exposure to surface and subsurface soil contaminated from past TNTB manufacturing processes, a final action memorandum for removal of soil was prepared by the USACE (USACE, 2003a). Previous investigations, assessments, and studies have identified 13 contaminants of concern (COC) in impacted soil. The COCs identified in the soil include nitroaromatics, PCBs, and polycyclic aromatic hydrocarbons (PAH). Removal of contaminated soil would also further reduce contaminant migration from the soil to the groundwater. The selected remedy for soil removal was excavation, ex situ stabilization (composting), and off-site disposal.

In September 2002, removal of contaminated soil from TNTB began. A total of 30 areas were excavated from around and within 13 former building locations. A total of 5,439 cubic yards (yd^3) of soil from eight building areas of TNTB was excavated, treated, and disposed of from September 2002 through January 2003. Walls and floors of excavations were delineated with field screening and excavation extent limits confirmed below applicable PRGs with laboratory testing (WasteTron, Inc. [WTI], 2005a). Five additional building locations were excavated and backfilled with clean soil in 2006. These five areas totaled 6,716 yd^3. Thus, the total amount of soil remediated at TNTB was 12,155 yd^2 (WTI, 2005a). The TNTB soil remediation is further discussed in Section 1.5.

1.3.8 Initial PRRWP Area Soil Remediation Activities

Based upon the contamination evaluation in 1989 (IT, 1991), the focused RI (D&M, 1997a), the risk assessment and direct-push investigation (IT, 2000a), and the soil FS (IT, 2002b), TNT contaminated soils detected in the surface and subsurface soil samples were determined to present an unacceptable risk to human health and the environment (USACE, 2003b).

The proposed selected remedy for the PRRWP Area soil was excavation, ex situ stabilization, off-site disposal of the stabilized soil as nonhazardous waste, and backfilling with clean fill material. The anticipated volume of TNT contaminated soil was estimated to be 148 yd^3 (USACE, 2003b). This method was also chosen to remove areas of contaminated soil and further reduce contaminant migration from the soil to the groundwater.

Removal activities of PRRWP Area soil began in January 2003. A black seam, approximately 4 feet below ground surface (bgs), was encountered during excavation and found to exhibit TNT concentrations as great as 1,440 milligrams per kilogram (mg/kg). This seam was believed to represent the base of the former wastewater pond. The estimated area of soil caused by the previously encountered high TNT concentration was removed in the area of the previously

detected "hot spot" during 1994 soil sampling. The soil removal also involved abandoning monitoring well PR-MW08, which was installed at the same location. The volume of contaminated soil removed was 118 yd^3. Because TNTB soil excavations were being conducted concurrently, the USACE, with approval from OEPA, separately treated excavated PRRWP Area soil using ex situ bioremediation (composting), thereby reducing it to a nonhazardous soil prior to off-site disposal (WTI, 2005b). Currently, a pilot test is being conducted to assess possible remediation options for the remaining contaminated soil, especially the layer found at the apparent base of the former pond. The PRRWP Area soil remediation is further discussed in Section 1.5.

1.4 Soil, Surface Water, and Sediment Contamination and Risks

The following subsections present the nature and extent, as well as human health and ecological risks, of soil, surface water, and sediment. Note that the nature and extent of groundwater contamination, most pertinent to this FS, is discussed in Section 1.6.

1.4.1 Nature and Extent of Soil Contamination

The following sections briefly discuss the approaches and findings of previous investigations related to soil contamination. Because the FFSs have already been completed and recommended areas of soil remediation have already been agreed upon, the following paragraphs identify the soil COCs present in each area. Further description of the areas recommended for soil/sediment remediation is provided in Section 1.5.

TNTA. One surface soil sample was collected in the vicinity of TNTA in 1993 (MK, 1994), and 28 soil samples were collected as part of the 1994 site investigation (D&M, 1997c). Based on the results of these earlier samples and on site history, a total of 430 field screening samples were collected during the 2000 RI and analyzed for nitroaromatics using a modification of laboratory Method 8330. Also, 49 confirmation samples were collected during the RI to support the screening results and to conduct risk assessments. These confirmation samples were analyzed for target compound list (TCL) organics, TAL inorganics, and nitroaromatics (IT, 2001a).

The placement of samples within these areas during the RI was skewed toward specific locations that were most likely to be contaminated, such as those of former storage tanks, drowning tanks, catch basins, and underground pipelines associated with production. The resulting soil COCs for TNTA soil include the following nine constituents (IT, 2001g):

- Nitroaromatics: TNT, 2-4-dinitrotoluene (DNT), 2,6-DNT, 2-amino-4,6-dinitrotolutene (2-ADNT), 4-amino-2,6-dinitrotoluene (4-ADNT), 2-nitrotoluene, and 4-nitrotoluene

- PCBs: Aroclor 1260

- Lead.

TNTB. Two surface soil samples were collected in the vicinity of TNTB in 1993 (MK, 1994), and 26 soil samples were collected as part of the 1994 site investigation. Based on the results of these earlier samples and on site history, a total of 391 field screening samples were collected during the 1998 RI and analyzed for nitroaromatics using ion mobility spectroscopy. Also, 40 confirmation samples were collected during the RI to support the screening results and to conduct risk assessments. These confirmation samples were analyzed for TCL organics, TAL inorganics, and nitroaromatics (IT, 2000b).

The placement of samples within these areas during the RI was skewed toward specific locations that were most likely to be contaminated, such as those of former storage tanks, drowning tanks, catch basins, and underground pipelines associated with production. TNTB soil COCs include the following 13 nitroaromatics, PCBs, and PAHs (IT, 2000c):

- Nitroaromatics: TNT, 2,4-DNT, 2,6-DNT, 2-ADNT, 4-ADNT, and 2-nitrotoluene

- PCBs: Aroclor 1254 and Aroclor 1260

- PAHs: Dibenzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, dibenz(a,h)anthracene, and indeno(1,2,3-c,d)pyrene.

TNTC. Three surface soil samples were collected in the vicinity of TNTC in 1993 (MK, 1994) and 30 soil samples were collected as part of the 1994 site investigation (D&M, 1997c). Based on the results of these earlier samples and on site history, a total of 385 field screening samples were collected during the 2000 RI and analyzed for nitroaromatics using a modification of laboratory Method 8330 (IT, 2001c). Also, 30 confirmation samples were collected during the RI to support the screening results and to conduct risk assessments. These confirmation samples were analyzed for TCL organics, TAL inorganics, and nitroaromatics.

The placement of RI samples within these areas was skewed toward specific locations that were most likely to be contaminated, such as those of former storage tanks, drowning tanks, catch basins, and underground pipelines associated with production. TNTC soil COCs include the following 13 constituents (IT, 2001g):

- Nitroaromatics: TNT, 2,4-DNT, 2,6-DNT, 2-ADNT, and 4-ADNT
- PAHs: benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, dibenze(a,h)anthracene, and indeno(1,2,3-c,d)pyrene
- PCBs: Aroclor 1254 and Aroclor 1260
- Lead.

PRRWP Area. In 1989, six borings were drilled and eight soil samples were collected during the contamination evaluation. Soil samples were analyzed for VOCs, base neutral acid extractables, metals, nitrates, sulfates, and nitroaromatics. A total of seven nitroaromatic compounds were detected in the surface and subsurface soil samples. Maximum concentrations of 1,3,5-trinitrobenzene (TNB) (15 mg/kg), 1,3-dinitrobenzene (DNB) (6.4 mg/kg), TNT (0.74 mg/kg), and 2,4- DNT (20 mg/kg) were detected (IT, 1991).

Because nitroaromatics were encountered in 1989, 24 borings were drilled and 63 soil samples were collected during the 1994 focused RI sampling. Samples were analyzed for nitroaromatics and metals. Elevated concentrations of nitroaromatics were detected in surface and subsurface soil from a total of 32 soil samples. At sampling location PB-RWPPR-S14, TNT was detected at a concentration of 12,000 mg/kg at 3 to 5 feet bgs, and at a concentration of 340 mg/kg at 5 to 10 feet bgs. TNT was detected in only 2 of the other 61 PRRWP Area subsurface soil samples. In those two samples, concentrations of TNT were less than 1 mg/kg. Thus, with the exception of subsurface soil at boring PB-RWPPR-S14, detected concentrations of nitroaromatics were generally low, and nitroaromatics were not detected in most of the PRRWP Area soil samples (D&M, 1997a).

The RI investigation continued in 1998 with the drilling of 20 borings and collection of 20 surface and 39 subsurface soil samples. Samples were analyzed for VOCs, SVOCs, total TAL metals, PCBs, and nitroaromatics. Six nitroaromatic compounds were detected from 12 of the 59 soil samples. TNT was detected in only one of the surface soil samples (0.27 mg/kg) and one of the subsurface samples (0.38 mg/kg). 1,3,5-TNB was detected in 9 subsurface soil samples at concentrations ranging from 0.43 to 43 mg/kg; 1,3-DNB was detected in 5 samples between 0.25 and 9.3 mg/kg; 2,4-DNT was detected in 11 samples at 0.28 to 25 mg/kg; and 4-ADNT was detected in 1 surface soil sample at a concentration of 2.7 mg/kg (IT, 2000a).

WARWP Area. Six soil samples were collected during the 1989 contamination evaluation. Six borings were drilled and six soil samples were collected. Soil samples were analyzed for VOCs,

base method acid extractables, metals, nitrates, sulfates, and nitroaromatics. Maximum concentrations of 1,3,5-TNB (3.4 mg/kg), 1,3-DNB (0.59 mg/kg), TNT (0.68 mg/kg), and 2,4-DNT (0.91 mg/kg) were less than or approximately equal to the soil risk-based screening concentrations (RBSC) and thus regarded as low (IT, 1991).

Because nitroaromatics were encountered, 15 borings were drilled and 40 soil samples were collected during the 1994 focused RI sampling. Samples were analyzed for nitroaromatics and metals. TNT was detected in five soil samples, with a maximum detection of 2.1 mg/kg. A total of eight nitroaromatic compounds were detected. The most frequently detected compounds were 1,3,5-TNB (maximum of 5.5 mg/kg) and 2,4-DNT (maximum of 5.1 mg/kg) (D&M, 1997a).

The RI investigation continued in 1998 with the drilling of 19 borings and collection of 19 surface and 37 subsurface soil samples from these borings. Samples were analyzed for VOCs, SVOCs, total TAL metals, PCBs, and nitroaromatics. Four nitroaromatic compounds were detected from 4 of the 56 soil samples. All detections of nitroaromatics in WARWP Area surface soil were less than 1 mg/kg. Nitroaromatics were not detected in the majority of WARWP Area surface and subsurface soil samples (IT, 2000a).

1.4.2 Nature and Extent of Surface Water and Sediment Contamination

TNTA. In 1993, two collocated surface water and sediment samples were collected from Lindsey Ditch in the vicinity of TNTA as part of the MK site investigation (MK, 1994). During the 2000 RI, a total of 8 surface water and 10 sediment samples were collected within TNTA and the immediate vicinity from Lindsey Ditch and its tributaries (IT, 2001a). The surface water and sediment samples were analyzed for VOCs, SVOCs, TAL metals, PCBs, and nitroaromatics (IT, 2001a). The results of the surface water and sediment investigations indicate that former TNTA activities and contaminants do not appear to have adverse impacts on the surface water and sediment; thus, no surface water or sediment COCs were identified (IT, 2001g).

TNTB. Collocated surface water and sediment samples were collected in the vicinity of TNTB in 1993 as part of the site investigation (MK, 1994). During the RI, two additional collocated surface water/sediment samples were collected from tributaries to Ransom Brook and three additional sediment samples were collected in areas where surface water was not present at the time of sampling. The surface water and sediments samples were analyzed for VOCs, SVOCs, TAL metals, PCBs, and nitroaromatics (IT, 2000b). No nitroaromatics were detected; only VOCs and metals were detected in the surface water. Based on the low concentrations of these constituents in surface water and correspondingly low concentrations in TNTB soils, it was

determined that TNTB was not a major source of the constituents (IT, 2000b). The results of the surface water and sediment investigations indicated that former TNTB activities and contaminants do not appear to have adverse impacts on the Ransom Brook surface water and sediment; thus, no surface water or sediment COCs were identified.

TNTC. As part of the site investigation in 1993, one collocated surface water and sediment sample pair was collected just downstream of the confluence of Pipe Creek and a small tributary running east to west in the northern portion of TNTC (MK, 1994). As part of the 2000 RI, a total of 10 TNTC surface water and 15 TNTC sediment samples were collected (IT, 2001a); all were from on-site wet weather conveyances that flow to Pipe Creek. Fifteen surface water samples had been planned, but five of the locations were dry. The surface water and sediment samples were analyzed for VOCs, SVOCs, TAL metals, PCBs, and nitroaromatics (IT, 2001a).

The results of the surface water samples indicated low levels of nitroaromatics present, but not at concentrations that would adversely affect TNTC surface water; thus, no surface water COCs were identified. Contamination in sediment was found at concentrations that may potentially adversely affect human or ecological receptors at one location (TNTC-SD009), approximately 260 feet northwest of Building 618, but no surface water was present at this location. The following three constituents were identified as COCs in the sediment: TNT, 2-ADNT, and 4-ADNT (IT, 2001g).

PRRWP Area. In 1993, a site inspection investigated the PRRWP Area drainage ditch surface water and sediment. The PRRWP Area drainage ditch is located adjacent to Pentolite Road. The surface water and sediment samples were analyzed for VOCs, SVOCs, TAL metals, PCBs, and nitroaromatics. Surface water and sediment samples were collected in the PRRWP Area in 1998 (IT, 2000a). No nitroaromatics or other chemicals interpreted as potentially site related were detected in any surface water or sediment samples associated with the PRRWP Area.

WARWP Area. Surface water and sediment samples were collected from the WARWP Area during the 1994 focused RI sampling event (D&M, 1997a) and in 1998 (IT, 2000a). The surface water and sediment samples were analyzed for VOCs, SVOCs, TAL metals, PCBs, and nitroaromatics. Concentrations less than 1 mg/kg of several nitroaromatics were detected among the 12 WARWP Area sediment samples collected as part of the 1994 focused RI. No nitroaromatics were detected in the five WARWP Area sediment samples collected during the 1998 RI. Infrequent detections of nitroaromatics at low concentrations among the RI surface water and sediment samples indicate that contaminants associated with the former pond have not appreciably impacted surface water and sediment.

1.4.3 Human Health Risks for Soil, Surface Water, and Sediment

Human health risks were evaluated for potential current and future human receptors that may have direct contact with surface soil, total soil, surface water, and sediment, as applicable, at each of the three TNT Areas and two Red Water Pond Areas. Summaries of these evaluations are presented in this section. The evaluations in this section do not include the potential impact that soil may have on underlying groundwater. This soil-to-groundwater pathway is modeled and evaluated for potential future risks in the groundwater BHHRA, which is summarized in Section 1.8. The results of the risk assessments summarized in the following paragraphs do not reflect the removal of soil that is planned for TNTA and TNTC (which also includes limited sediment removal) or the soil removal that has been completed for TNTB and the PRRWP Area (refer to Section 1.5).

TNTA. A BHHRA was performed for exposure to TNTA soil, surface water, and sediment (IT, 2001c). Results of the BHHRA indicate that cumulative human health risks associated with TNTA total soil (combined surface and subsurface soil) for the potential future resident and construction worker exceed the respective OEPA risk management criteria for cancer risk (incremental lifetime cancer risk [ILCR] less than 1E-5) and noncancer hazard (hazard index [HI] less than 1). Exposure to surface water and sediment were found to contribute insignificantly to human health risks. Exposure to surface soil (as evaluated for the groundskeeper, indoor worker, and hunter/venison eater) resulted in noncancer and cancer risk estimates less than the risk management criteria. The chemicals identified as responsible for driving potential risks associated with TNTA total soil are lead, Aroclor 1260, and several nitroaromatics.

TNTB. A BHHRA was performed for TNTB (IT, 2000c). Total soil was found to exceed the cancer (ILCR less than 1E-5) and noncancer (HI less than 1) cumulative risk management criteria for both receptors evaluated (potential future resident and construction worker). Likewise, surface soil was found to exceed the respective risk management criteria for both receptors evaluated (groundskeeper and indoor worker). The chemicals identified as driving potential human health risks in TNTB soils include PAHs, two PCBs, and several nitroaromatics. The risks associated with exposure to surface water were insignificant, and the site-related risks associated with sediment were less than the risk management criteria.

TNTC. A BHHRA was performed for exposure to TNTC soil, surface water, and sediment (IT, 2001g). Results of the BHHRA indicate that cumulative human health risks associated with total soil for the potential future resident and construction worker exceed the respective risk

management criteria for cancer risk (ILCR less than 1E-5) and noncancer hazard (HI less than 1). Similarly, exposure associated with surface soil for the groundskeeper, indoor worker, and adult hunter exceeded the respective risk management criteria. The chemicals identified as driving potential human health risks in TNTC soils include lead, PAHs, two PCBs, and several nitroaromatics. Noncancer risks associated with exposure to sediment for the potential future resident and construction worker also exceeded the risk management range (ILCR less than 1E-5), and cancer risks associated with exposure to sediment contributed significantly to the overall ILCR of the construction worker and potential future resident. The chemicals identified as driving potential human health risks in TNTC sediments were TNT and the aminodinitrotoluene (ADNT) isomers.

PRRWP Area. A BHHRA was performed by Shaw for exposure of PRRWP Area surface soil and total soil (IT, 2000a). Results of the BHHRA indicate that site-related cumulative human health risks associated with total soil exceed the respective risk management criteria for cancer risk (ILCR less than 1E-5) and noncancer hazard (HI less than 1) in the potential future resident. Also, the noncancer hazards for the construction worker also exceed the risk management range for exposure to total soil. Several nitroaromatics were identified as driving potential site-related human health risks associated with exposure to PRRWP Area total soil.

WARWP Area. A BHHRA was performed for exposure to WARWP Area soil, surface water, and sediment (IT, 2000a). Results of the BHHRA indicate that site-related cumulative human health risks do not exceed the respective risk management levels for cancer risk (ILCR less than 1E-5) and noncancer hazard (HI less than 1) when summed across all media for any of the receptors evaluated.

1.4.4 Ecological Risks

Risks were evaluated for ecological receptors that may have direct contact with surface soil, surface water, and sediment, as applicable, at each of the three TNT Areas and two Red Water Pond Areas. The results of the risk assessments did not reflect the removal of soil that is planned for TNTA and TNTC (which also includes limited sediment removal) or that which has been completed for TNTB and the PRRWP Area (refer to Section 1.5). However, in the FSs for the TNT Areas, the effect of meeting human health-based remedial goals (RG) was evaluated for ecological risk reduction, as is discussed for the separate areas in the following paragraphs.

TNTA. A BERA was performed by Shaw for TNTA (IT, 2001f). The BERA estimated that ecological hazards associated with TNTA surface and total soils were elevated. These estimates are regarded as conservative and are associated with a considerable degree of uncertainty.

Additional investigation and evaluation would be necessary to provide more accurate estimates of ecological hazards. However, it was agreed that TNTA soils would be remediated to human health-based RGs. The resulting residual soil concentrations evaluated for ecological risk in the FFS were found to be protective of the environment (Shaw, 2003b). Because of uncertainties of estimating chemical concentrations in aquatic insects, the limited amount and low quantity of aquatic habitat, and the low hazard estimates, neither remedial action nor further study was recommended for surface water and sediment.

TNTB. The TNTB BERA estimated that ecological hazards associated with TNTB surface and total soils were elevated. These estimates are regarded as conservative and are associated with a considerable degree of uncertainty. Additional investigation and evaluation would be necessary to provide more accurate estimates of ecological hazards (IT, 2000c). However, it was agreed that TNTB soils would be remediated to human health-based cleanup levels. The resulting residual ecological risks to terrestrial receptors were reevaluated in the FFS based on cleanup of areas previously exceeding the cleanup levels. The resulting ecological risks were estimated to be reduced an average of approximately 750-fold. The BERA concluded that remediating the site to human health cleanup levels would result in residual concentrations that are protective of terrestrial receptors. Additionally, the BERA concluded that, due to the limited aquatic habitat and the lack of rare, threatened, or endangered species, the development of remedial action objectives (RAO) based on aquatic receptors was unwarranted (IT, 2001b).

TNTC. A BERA was performed for TNTC (IT, 2001c), which estimated that ecological hazards associated with exposure to TNTC surface and total soils were elevated for terrestrial receptors. Similarly, ecological hazards for aquatic organisms exposed to sediments, specifically at a location north of Building 616 within an ephemeral east-west drainage ditch, were estimated as elevated for aquatic organisms (e.g., raccoons) that that may encounter these sediments. The ecological hazard estimates are regarded as conservative and are associated with a considerable degree of uncertainty. Additional investigation and evaluation would be necessary to provide more accurate estimates of ecological hazards. However, it was agreed that TNTC soils and sediments would be remediated to human health-based RGs. The resulting residual soil and sediment concentrations evaluated for ecological risk in the FFS were found to be protective of the environment (Shaw, 2003b). Neither remedial action nor further study were recommended for aquatic receptors exposed to TNTC surface water based on the following: uncertainties associated with estimating chemical concentrations in aquatic insects; limited area and low quality of aquatic habitat; and relatively low hazard estimates, especially when using the lowest-observable-adverse-effect-level approach.

PRRWP Area. A SLERA was initially performed for the PRRWP Area (IT, 2000a). Based on the SLERA results, which suggested the potential for ecological impact, a full BERA (IT, 2001e) was performed to more accurately determine whether ecological receptors may be adversely impacted by PBOW food web models based on site-specific bioconcentration factors. It was concluded from the BERA, using the most conservative exposure assumptions, that only a low potential for adverse ecological effects exists upon exposure to PRRWP Area soil by terrestrial receptors. No site-related chemicals were identified as potentially impacting PRRWP Area surface water or sediment.

WARWP Area. A SLERA was initially performed for the WARWP Area (IT, 2000a). Based on the SLERA results, which suggested the potential for ecological impact, a full BERA (IT, 2001e) was performed to more accurately determine whether ecological receptors may be adversely impacted by PBOW-related chemicals in WARWP Area soil, surface water, or sediment. The BERA included revised food web models based on site-specific bioconcentration factors derived from tissue sample and site-specific aquatic and terrestrial toxicity testing. It was concluded from the BERA that PAH concentrations in one surface soil sample indicated some earthworm toxicity; however, survival was decreased moderately, as the earthworms from this one location exhibited a nearly 30 percent reduction in survival. However, the location at which this sample was collected is in a grassy area used for vehicle access by site visitors and drillers. It is possible that the PAHs at this one location are associated with vehicle emissions or minor leaking of petroleum from the vehicles. Also, these PAHs may be generated by controlled burning that is practiced at PBOW. Food chain modeling indicated some potential for ecological risk to the shrew associated with PAHs, but only under the most conservative assumptions. Given the weight of evidence, it is unlikely that WARWP Area soils represent an unacceptable ecological concern to either shrew or earthworm populations at the WAWRP Area. Iron concentrations in one sediment sample indicated the potential for ecological risk to the raccoon and heron through food chain modeling under the most conservative assumptions; risk estimates based on more typical central tendency assumptions did not support the potential for ecological risk. Toxicity study results suggested some toxicity to benthic invertebrates. However, the maximum iron concentration detected in the sediment samples (24,200 mg/kg) likely results from the native background soil which comprises the substrate of the pond. Iron concentrations in PBOW background soil range up to 234,000 mg/kg (mean of 40,100 mg/kg). Thus, there appear to be no site-related impacts to sediment with regard to ecological receptors in the WARWP Area.

1.4.5 Focused Feasibility Studies

FFSs on soil and sediment were conducted for TNTA, TNTB, TNTC and the Red Water Pond Areas. The TNTC FFS also includes sediment. The recommendations of these FFSs were incorporated into Action Memoranda for each of these areas (USACE, 2003a,b; 2004a,b). Remediation has been completed at TNTB and the PRRWP Area and is planned for TNTA and TNTC. Section 1.5 provides further detail regarding COCs and specific areas that have been or are being remediated.

TNTA. In 2003, Shaw prepared an FFS for soil at TNTA (Shaw, 2003b). Site-specific RGs for the TNTA soil COCs were derived in the FFS. The FFS recommended excavation (16,328 yd^3); windrow composting; on-site disposal of treated material; and off-site disposal of soil with lead contamination greater than 200 mg/kg (approximately 708 yd^3) and PCB contamination greater than 50 mg/kg (approximately 119 yd^3) at a Subtitle C hazardous waste treatment, storage, and disposal facility. Note that 200 mg/kg was used as the criterion for lead in soil that was contaminated with other COCs so that the material would meet Resource Conservation and Recovery Act (RCRA) Subtitle C land disposal restrictions; otherwise, 400 mg/kg served as the lead RG at or below which soil could be left in place. The total cost of the alternative for TNTA was estimated to be $7,688,000. The estimated cost for simultaneous remediation of TNTA and TNTC would be $10,987,000, which includes the cost savings realized for a single mobilization. Note that two additional building areas (Buildings 143 and 187) were identified in the TNTA Action Memorandum (USACE, 2004a), which added an additional 868 yd^3. The addition of these two building areas would slightly increase the remediation costs. The remediation of contaminated soil at TNTA will also preclude these areas from being potential sources of further groundwater contamination. Based on the analytical data presented in the TNTA FFS, the soil excavation planned for each of the remediation areas, which is designed to mitigate direct exposure to contaminated soil, should result in removal of soil to either the water table or competent shale in all except three of the excavations. The remaining areas had concentrations of nitroaromatics that were limited to the shallow subsurface.

TNTB. In July 2001, Shaw prepared an FS for TNTB (IT, 2001b). Site-specific RGs for TNTB surface and subsurface soil were derived for each of the COCs and serve as cleanup levels. The FS recommended excavation (estimated at 3,300 yd^3), ex situ stabilization, and off-site disposal at a nonhazardous waste landfill. The total cost of the alternative for TNTB was estimated to be $358,000. In September 2002, removal of contaminated soil began at TNTB. Soil above the site-specific cleanup levels was excavated, stabilized, and transported for off-site disposal. Remedial activities of soil were completed in 2006 (Section 1.5). The total volume of soil

removed from TNTB was 12,156 yd^3. Soil was remediated to the water table or bedrock at all locations at TNTB, effectively removing the potential sources of groundwater contamination.

TNTC. In 2003, Shaw prepared an FFS for TNTC (Shaw, 2003b). The FFS recommended excavation (9,205 yd^3); windrow composting; on-site disposal of treated material; and off-site disposal of soil with lead contamination greater than 200 mg/kg (approximately 400 yd^3) at a Subtitle C hazardous waste treatment, storage, and disposal facility. Note that 200 mg/kg was used as a criterion for lead in soil that was contaminated with other COCs, so that the material would meet land disposal restrictions; otherwise, 400 mg/kg served as the lead RG at or below which soil could be left in place. The total cost of the alternative is estimated to be $5,504,000. The estimated cost for simultaneous remediation of TNTC and TNTA would be $10,987,000, which includes the cost savings realized for a single mobilization. The remediation of contaminated soil at TNTC will also preclude these areas from being potential sources of further groundwater contamination. Based on the analytical data presented in the TNTC FFS, the soil excavation planned for each of the remediation areas, which is designed to mitigate direct exposure to contaminated soil, should result in removal of soil to either the water table or competent shale in all but one of the excavations. The remaining area had concentrations of nitroaromatics exceeding the RG levels in shallow subsurface soil.

Red Water Pond Areas. In December 2002, Shaw submitted an FFS for the two Red Water Pond Areas (IT, 2002b). It concluded that the cancer risk and the noncancer hazard associated with exposure to contaminants in surface soil, total soil, sediment, and surface water are within the risk management range or are de minimus for all receptors at the WARWP Area. Because no WARWP Area COCs were identified in the BHHRA, the FFS did not identify or evaluate any remedial alternatives for the WARWP Area.

The FFS evaluation of the PRRWP Area was initially based on the BHHRA and the COCs identified therein. During the FFS, a single location with elevated nitroaromatics concentrations, particularly TNT, was identified. It was determined that if this small (148 yd^3) "hot spot" was remediated, then the remaining soil would not pose a cancer risk or noncancer hazard for any PRRWP Area receptor at levels exceeding the respective risk management criteria (IT, 2002b). The footprint of this hot spot was removed in a remedial effort during 2002 and 2003. As discussed in Section 1.5, remediation of additional soil was completed for the PRRWP Area in September 2008. This soil remediation effectively mitigates further contamination of groundwater at the PRRWP.

1.5 Completed and Planned Soil Remediation

USACE previously agreed to perform soil remediation at TNTA (USACE, 2004a), TNTB (USACE, 2003a), TNTC (USACE, 2004b), and the PRRWP Area (USACE, 2003b), based primarily on human health and ecological risks associated with direct contact to soil. Soil remediation at TNTB and the PRRWP is complete, and soil remediation at TNTA and TNTC has not yet commenced. Although FSs for soil remediation at TNTA and TNTC have been completed, a proposed plan for soil remediation has not yet been presented to the public for either of these sites. For TNTC, sediment remediation of a small area of an ephemeral drainage ditch is also included. Based on the human health and ecological risk assessment results, it was concluded that exposure to WARWP soil or sediment are unlikely to represent a threat to human health and the environment. Therefore, it was determined that no remedial actions were warranted for WARWP Area soil or sediment based on direct contact (IT, 2002b).

TNTB. The TNTB soil remedial action was begun in September 2002 and completed in 2006. This removal included excavation, composting of nitroaromatics-contaminated and PAH-contaminated soil, stabilizing of lead-contaminated soil, disposal of treated soil at a nonhazardous waste landfill, and backfilling excavations with clean soil (USACE, 2003a; WTI, 2005a)

The following 13 building areas had one or more areas requiring remediation:

- Building 412 – Sweating and Graining House
- Building 417 – Wastewater Settling Tanks
- Building 452 – Bi-Tri House
- Building 453 – Fortifier House
- Building 456 – Wash House
- Building 462 – Bi-Tri House
- Building 463 – Fortifier House
- Building 466 – Wash House
- Building 472 – Bi-Tri House
- Building 473 – Fortifier House
- Building 476 – Wash House
- Northeast Nail House
- Northwest Nail House.

A total of 12,156 yd^3 were removed from these 13 building areas. The soil COCs for TNTB soil remediation are the following 13 chemicals:

- 2-ADNT
- 4-ADNT
- 2,4-DNT

- 2,6-DNT
- TNT
- 2-Nitrotoluene
- Aroclor 1254
- Aroclor 1260
- Benzo(a)anthracene
- Benzo(a)pyrene
- Benzo(b)fluoranthene
- Benzo(a,h)anthracene
- Indeno(1,2,3-c,d)pyrene.

During post-excavation sampling, lead contamination was found within five of the building areas: Buildings 412, 452, 456, and 463 and the Northeast Nail House. Therefore, stabilization and disposal of the lead-contaminated soil was added to the remedial activities after remediation began (WTI, 2005a). The footprints of the excavated areas at TNTB are shown on Figure 1-8.

PRRWP Area. Based on the original analytical data, a small hot spot removal comprising about 148 yd^3 (20 feet by 20 feet by 10 feet deep) was planned for the PRRWP Area (USACE, 2003b). During excavation of this area, a dark organic layer was entered at approximately 4 feet bgs. The original hot spot footprint was removed to a depth of only 8 feet (approximately 118 yd^3), because groundwater was encountered. The contaminated soil was composted and taken to a nonhazardous waste landfill. The organic layer was found to contain TNT, the only identified PRRWP Area soil COC, at concentrations up to 1,440 mg/kg at the hot spot. Trenches were dug to delineate the lateral extent of this layer, which is thought to represent the base of the former pond. It was estimated that an additional 7,630 yd^3 of soil would require excavation (WTI, 2005b). Nearly 8,000 yd^3 of soil were excavated, treated using composting, and removed to a nonhazardous waste landfill in 2008. The footprint of the excavated hot spot and the area delineated and removed based on the dark organic layer are shown on Figure 1-9.

TNTA. Remedial work at TNTA has not yet commenced. The planned remedial action will include the same approach as that taken at TNTB: excavation, composting of nitroaromatics-contaminated soil, stabilizing of lead-contaminated soil, disposal of treated soil at a nonhazardous waste landfill, and backfilling of excavations with clean soil (USACE, 2004b). The following building areas have been identified as having one or more areas requiring remediation:

- Building 111 – Mono House
- Building 112 – Bi-Tri House
- Building 116 – Wash House
- Building 119 – Acid and Fume Recovery House

- Building 126 – Wash House
- Building 129 – Acid and Fume Recovery House
- Building 131 – Mono House
- Building 133 – Fortifier House
- Building 139 – Acid and Fume Recovery House
- Building 141 – Fortifier House
- Building 142 – Bi-Tri House
- Building 143 – Fortifier House
- Building 143 – Fortifier House
- Building 146 – Wash House
- Building 148 – Nail House
- Building 182 – Bi-Tri House
- Building 187 – Waste Water Settling Tanks
- Building 192 – Bi-Tri House
- Building 195 – DNT Nitrating House.

A total of 17,196 yd^3 are estimated for removal from these 19 building areas (Shaw, 2003b; USACE, 2004b). The COCs for TNTA soil remediation are the following 12 chemicals:

- 2-ADNT
- 4-ADNT
- 2,4-DNT
- 2,6-DNT
- TNT
- Aroclor 1260
- Benzo(a)anthracene
- Benzo(a)pyrene
- Benzo(b)fluoranthene
- Benzo(a,h)anthracene
- Indeno(1,2,3-c,d)pyrene
- Lead.

The areas recommended for TNTA soil remediation are shown on Figure 1-10. An addendum to the TNTA FFS was prepared to update the original FFS that was issued in 2003 (Shaw, 2008a). Specifically, the FFS addendum included new remedial technologies that have been developed since 2003, revised the technology screening and detailed analysis of alternatives, revised and updated the cost tables, and revised the comparative analysis of the remedial alternatives.

TNTC. Remedial work at TNTC has not yet commenced. The planned remedial action will include the same approach as that taken at TNTB: excavation, composting of nitroaromatics-contaminated soil, stabilizing of lead-contaminated soil, disposal of treated soil at a nonhazardous waste landfill, and backfilling of excavations with clean soil (USACE, 2004a).

The following building areas have been identified as having one or more areas requiring remediation:

- Building 602 – Bi-Tri House
- Building 603 – Fortifier House
- Building 606 – Wash House
- Building 616 – Wash House
- Building 626 – Wash House
- Building 629 – Acid and Fume Recovery House
- Building 657 – Waste Water Settling Tanks
- Building 682 – Bi-Tri House
- Building 683 – Fortifier House
- Building 686 – Wash House
- Building 689 – Acid and Fume Recovery House
- Building 692 – Bi-Tri House
- Building 693 – Fortifier House
- Building 696 – Wash House.

A total of 9,205 yd^3 are estimated for removal from these 14 building areas. The COCs for TNTC soil remediation include the following 9 chemicals:

- 2-ADNT
- 4-ADNT
- 2,4-DNT
- 2,6-DNT
- TNT
- 2-Nitrotoluene
- 4-Nitrotoluene
- Aroclor 1260
- Lead.

The three COCs for TNTC sediment remediation are 2-ADNT, 4-ADNT, and TNT. The soil and sediment areas recommended for remediation are shown on Figure 1-11. An addendum to the TNTC FFS was prepared to update the original FFS that was issued in 2003 (Shaw, 2008b). Specifically, the FFS addendum included new remedial technologies that have been developed since 2003, revised the technology screening and detailed analysis of alternatives, revised and updated the cost tables, and revised the comparative analysis of the remedial alternatives.

1.6 Nature and Extent of Groundwater Contamination

The following sections discuss the findings of previous investigations related to groundwater contamination. The discussion in some of the following subsections includes references to results during “wet season” and “dry season” sampling. Based on site-specific data, the wet

season is defined as January through June, and the dry season is defined as July through December. Groundwater sampling locations are shown for each of the five AOCs on Figures 1-12 through 1-16. These figures also show "shadowbox" analytical results for explosives, SVOCs, VOCs, and water quality parameters nitrate and cyanide that may be COCs in either overburden/shale and/or bedrock groundwater. These figures also show elevated benzene, toluene, ethylbenzene, and xylene (BTEX) results; BTEX compounds are indicative of the presence of petroleum. The text below discusses inorganics results, but the inorganics are not shown on the figures because the presence of these compounds in site groundwater does not appear to be site-related (Shaw, 2006). Many of the metals, explosives, and petroleum compounds may present analytical results biased high due to a groundwater turbidity. In many cases, an associated filtered groundwater sample was collected for comparison to the unfiltered groundwater sample to assist in determining biased readings. A filtered sample was not always able to be collected due to a low producing source (i.e. piezometer, well). A biased high groundwater sample result with a high turbidity reading may be indicative of the contaminant sorbing to the soil; therefore, the analytical result is a measurement of the soil and not of the groundwater. The determination of groundwater COCs is presented in Section 3.3.

1.6.1 TNTA

TNTA groundwater samples were collected on several occasions, including sampling events in 1993 (MK, 1994), 1994 (D&M, 1997c), and as part of the site-wide groundwater investigations in 1996, 1997, and 1998 (IT, 1999). RI groundwater samples were collected beginning in 2001 (Shaw, 2005).

Overburden/Shale Water-Bearing Zone. A total of five overburden/shale wells are present on or immediately downgradient of TNTA. Three overburden/shale monitoring wells (MK-MW22, MK-MW23, and MK-MW24) were installed at TNTA in July 1993 by MK. Well MK-MW22 is in the northern middle portion of TNTA, MK-MW23 is located immediately northeast of TNTA, and MK-MW24 is located just outside the southwest corner of TNTA, upgradient of TNTA groundwater flow. These three wells were sampled in 1994 (D&M, 1997c), 1996, 1997, and 1998 (IT, 1999). Two newer wells, TNTA-MW-10 and TNTA-MW11, located on the northwest and central west sides of TNTA, respectively, were installed and sampled in 1994 (D&M, 1997c), 1996, 1997, 1998 (IT, 1999), 2001, and 2002 (Shaw, 2005). Ten temporary piezometers were installed in 2000 throughout TNTA at former manufacturing buildings likely to exhibit contamination sources. Of the 10 piezometers, only 9 could be sampled, since one (GW-09) was dry. Only six of the nine sampled piezometers had sufficient quantity of groundwater for collection of a filtered inorganics fraction (IT, 2001a). As part of the 2000 RI effort, 13 temporary piezometers were advanced into the overburden/shale, but only 2 had

sufficient water for sample collection. Additional piezometers had been planned, but installation of these was cancelled because of a paucity of water in the overburden/shale (Shaw, 2003a). TNTA overburden/shale well and direct-push sampling locations are shown on Figure 1-12.

Five nitroaromatics were detected above groundwater RBSCs in the overburden/shale groundwater at TNTA during the wet and dry seasons. Groundwater RBSCs are EPA Region 9 preliminary remediation goals (EPA, 2004) adjusted so that noncancer effects are based on a hazard quotient of no greater than 0.1 and cancer risks are based on an ILCR cancer risk of no greater than 1E-6 (Shaw, 2006). Benzene, toluene, and chloroform were the only VOCs detected in the groundwater above RBSC and/or background screening concentration (BSC) values. Three SVOCs (bis[2-ethylhexyl]phthalate, 2,4-DNT, and 2,6-DNT) were detected above RBSCs. Ten nitroaromatics were detected at concentrations exceeding the RBSCs in the TNTA overburden/shale samples collected using direct-push technology. In general, the concentrations of nitroaromatics are as much as two orders of magnitude higher in direct-push groundwater samples versus conventional monitoring wells. There are two plausible explanations for the discrepancy. Nitroaromatics tend to bind tightly to soil particles and in very turbid samples such as those collected with direct-push methods, there may be a greater contribution from the portion sorbed to the suspended sediment. In addition, the direct-push sampling locations were based on actual soil sampling results. That is, the groundwater samples were collected immediately adjacent to the known sources of contamination (e.g., sumps, drown tanks, etc). The monitoring wells, specifically those installed in the overburden, are not as close to the sources. Given that groundwater movement in the overburden tends to be dominated by vertical transport and the fact that nitroaromatics in general tend to sorb to soil particles, there is little lateral transport away from sources of contamination.

Unfiltered metals aluminum, arsenic, iron, manganese, and vanadium have been most commonly detected in the overburden/shale groundwater above both RBSC and BSC values during the wet and dry seasons. Filtration removed most of the metals above RBSC and BSC values, but manganese was still detected above the RBSC and/or BSC value in 14 of the 15 groundwater samples (Shaw, 2005).

Bedrock Water-Bearing Zone. There are two bedrock wells, TNTA-BEDGW-001 (located within the western side of the TNTA boundary) and BEDMW-18 (located just east of TNTA), in or immediately adjacent to TNTA (Figure 1-12). An additional bedrock well, BED-MW17, is located roughly 1,000 feet north (downgradient) of TNTA, near the PBOW facility boundary. BED-MW17 and BED-MW18 were installed and sampled in 1994 and were sampled again in 1996, 1997, 1998 (IT, 1999), 2001, and 2002 (Shaw, 2005). An additional bedrock well, TNTA-

BEDGW-001, was installed and sampled in 2001 and sampled again in 2002. Nitroaromatics 1,3-DNB, 4ADNT, 2,4-DNT, 2,6-DNT, 2-nitrotoluene, and nitrobenzene were detected above RBSCs in BEDMW-18. Detections of nitroaromatics at BED-MW18 have been sporadic and inconsistent, as none of the nitroaromatics detections have occurred in more than one sampling event. This observation suggests that natural attenuation is occurring.

Benzene, ethylbenzene, toluene, xylene, and methylene chloride were consistently detected at concentrations exceeding the RBSCs in both TNTA wells. The first four compounds are known as the "BTEX" compounds, which are typically related to petroleum. Naphthalene, 2-methylnaphthalene, and other PAHs, which also are known petroleum-related constituents, were also present at concentrations exceeding RBSCs. 2-Nitrotoluene is the only nitroaromatic detected in downgradient well BED-MW17, although the BTEX compounds, naphthalene, and 2-methylnaphthalene were likewise detected in this downgradient well at concentrations exceeding RBSCs.

1.6.2 TNTB

TNTB groundwater samples were collected on several occasions, including sampling events in 1993 (MK, 1994), 1994 (D&M, 1997c), and as part of the site-wide groundwater investigations in 1996, 1997, and 1998 (IT, 1999). RI groundwater samples were collected beginning in 2001 (Shaw, 2005).

Overburden/Shale Water-Bearing Zone. Four overburden/shale wells have been installed at TNTB or nearby at a downgradient location (Figure 1-13). Each of these four wells was completed in competent shale. The first, MK-MW17, was installed east of Building 417 (Wastewater Settling Tanks) by MK in 1993; the second, TNTB-BEDGW-001, was installed north-northwest of the TNTB boundary in 1997; and two additional wells, TNTB-BEDGW-003 and TNTB-BEDGW-004, were installed by Shaw in 2001 near Building 452 (Bi-Tri House) and Building 456 (Wash House), respectively. These four wells were sampled and analyzed for nitroaromatics, VOCs, SVOCs, filtered and unfiltered metals, and water quality parameters (Shaw, 2005). Even though Buildings 452 and 456 had some of the highest concentrations of nitroaromatics detected in the soil, nitroaromatics were not detected in either of the two corresponding wells, TNT-BEDGW-004 or TNT-BEDGW-003, nor were nitroaromatics detected in samples from TNT-BEDGW-001. Direct-push groundwater samples were also collected in 2001 at two locations, TNTB-GW2 and TNTB-GW3, which corresponded to elevated detections of nitroaromatics in soil at Buildings 453 (Fortifier House) and 452 (Bi-Tri House), respectively (Figure 1-13). The samples were analyzed for nitroaromatics, VOCs, SVOCs, filtered and unfiltered metals, and water quality parameters (Shaw, 2005); TNT was the

only nitroaromatic detected among the four wells (MK-MW17, TNTB-BEDGW-001, TNTB-BEDGW-003 and TNTB-BEDGW-004), but its concentration was less than the RBSC. Well MK-MW17 is the only location at which nitroaromatics were detected at concentrations exceeding RBSCs.

In summary, nitroaromatics were not detected at concentrations exceeding RBSCs in any of the wells or direct-push groundwater samples except those collected from well MK-MW17 (TNT at up to 68 micrograms per liter [µg/L]; ADNTs at up to 48 µg/L; DNTs at up to 10.6 µg/L). Benzene concentrations above the RBSC and BSC values were frequently detected in the groundwater samples from wells TNTB-BEDGW-003 and TNTB-BEDGW-004. Toluene concentrations have been frequently detected above the BSC in TNTB-BEDGW-003. The SVOC naphthalene was detected one time in a groundwater sample from TNTB-BEDGW-003 at a concentration above the RBSC. Barium, filtered and unfiltered, has been detected at concentrations above its RBSC in all four wells except TNTB-BEDGW-004. Monitoring well TNTB-BEDGW-004 exhibited the largest number of unfiltered metals detected above RBSC or BSC values. Metals detected during both sampling events include aluminum, arsenic, chromium, copper, iron, manganese, nickel, and vanadium. The unfiltered groundwater sample from TNTB-BEDGW-004 exhibited detections of iron and manganese above both the RBSC and BSC values. Filtration removed many of the metals from each of the groundwater samples. Remaining metals above both the RBSC and BSC included iron and manganese in TNTB-BEDGW-001 (November 1997) and TNTB-BEDGW-004 (October 2001 and April 2002). The four wells completed in shale showed variability in terms of anion concentrations. Wells TNTB-BEDGW-001 and TNTB-BEDGW-003 were chloride dominant for all except one sampling event. The remaining two wells were sulfate dominant. A difference of up to two orders of magnitude was observed in the chloride and sulfate concentrations.

Groundwater from monitoring wells that are screened within competent shale bedrock have not exhibited nitroaromatic detections above RBSC values. However, TNTB is the only area that has monitoring wells screened entirely within the competent shale bedrock. The limited detections of nitroaromatics in the shale is due to the tendency of nitroaromatics to sorb strongly to fine-grained soils of the overburden, limiting both lateral and vertical transport in groundwater. Further, the laminated structure of the shale coupled with its naturally high organic content likely further limits contaminant transport vertically into the shale.

Limestone Bedrock Water-Bearing Zone. No wells were completed in the limestone at TNTB. No limestone bedrock well was installed at TNTB because competent shale was encountered, dictating the need to complete wells in this zone. Deeper wells completed in the

limestone were not deemed necessary because of the lack of detectable concentrations of nitroaromatics in groundwater across the site.

1.6.3 TNTC

TNTC groundwater samples were collected on several occasions, including sampling events in 1994 (D&M, 1997c) and as part of the site-wide groundwater investigations in 1996, 1997, and 1998 (IT, 1999). RI groundwater samples were collected beginning in 2001 (Shaw, 2005).

Overburden/Shale Water-Bearing Zone. A total of five overburden/shale wells are present in TNTC. Four overburden/shale monitoring wells (TNTC-MW03 through TNTC-MW06) were installed at TNTC in 1994 (D&M, 1997c) and well IT-MW09 was installed in 1997. Well TNTC-MW03 is located downgradient adjacent to Building 657 (Wastewater Settling Basins); Building 657 Well TNTC-MW04 is located on the western side of TNTC, downgradient of Building 626 (Wash House); well TNTC-MW05 is located downgradient of Building 606 (Wash House); well TNTC-MW06 is located at Building 686 (Wash House); and IT-MW09 is located downgradient of the Northwest Nail House. Each of the initial four wells was sampled in 1996, 1997, and 1998. Well TNTC-MW03 was also sampled in 2002 and wells TNTC-MW04 and TNTC-MW05 were sampled in 2001 and 2002. Well IT-MW09 was sampled in 1997 and 1998. Ten temporary piezometers (GW-01 through GW-10) were installed in 2000 throughout the TNTC area. The piezometers were installed in close proximity to known sources of contamination such as drowning tanks and waste pits. Of the 10 piezometers, only 9 could be sampled since 1 (GW-01) was dry and only 3 of the 9 sampled piezometers had sufficient quantity for collection of a filtered inorganics fraction (IT, 2001a). As part of the 2001 RI effort, 13 temporary piezometers were advanced into the overburden/shale, but only 2 had sufficient water for sample collection (Shaw, 2003a). Installation of additional piezometers had been planned, but was cancelled because of a paucity of water in the overburden/shale. TNTC overburden/shale well and direct-push sampling locations are shown on Figure 1-14.

No nitroaromatics or other organics were detected in the TNTC overburden/shale wells at concentrations exceeding RBSCs. However, 10 nitroaromatics were detected at concentrations exceeding RBSCs in the direct-push samples, including TNT at 20,100 µg/L and total DNTs at 21,100 µg/L. No other organics were detected at concentrations exceeding RBSCs or BSCs. As previously noted in Section 1.6.1 (TNTA), the concentrations of nitroaromatics are as much as two orders of magnitude higher in direct-push groundwater samples versus conventional monitoring wells. The higher concentrations in direct-push samples are likely the result of proximity to sources and/or sorption of nitroaromatics onto suspended particles in very turbid samples.

The unfiltered metals aluminum, arsenic, iron, and manganese have been the analytes most commonly detected in the overburden/shale groundwater at concentrations above both the RBSC and BSC values during both the wet and dry seasons. In the 1997 dry season sample from TNTC-MW03, nickel was detected above both the RBSC and BSC. In the 2001 dry season, nickel was detected above the BSC in the filtered sample from TNTC-MW04. The filtered aluminum concentration also exceeded the BSC in the dry season. Chloride was detected at concentrations at least one order of magnitude greater than the corresponding sulfate concentrations in the groundwater from overburden/shale monitoring wells (Shaw, 2005).

Limestone Bedrock Water-Bearing Zone Results. There are two wells completed into the limestone (Figure 1-14). One bedrock well, BED-MW13, was installed near the northern (downgradient) boundary of TNTC in 1994. This well was sampled in 1994, 1996, 1997, 1998, 2001, and 2002 (Shaw, 2005). A second well, TNTC-BEDGW-001, was installed in 2001 in the southeastern portion of TNTC, downgradient Building 683 (Fortifier House). TNTC-BEDGW-001 was sampled in 2001 and 2002.

Nitroaromatics were not detected in the TNTC bedrock wells. VOCs have been detected consistently in both site wells since 1997. BTEX parameters were commonly above the RBSC and BSC values in the limestone screened monitoring wells. Reported concentrations of methylene chloride (a common laboratory contaminant) consistently exceeded the RBSC in both wells, though some were B qualified, meaning that the concentration detected in the sample was not reported at a concentration substantially greater than that detected in the blank. The SVOCs bis(2-ethylhexyl)phthalate, 2-methylnaphthalene, and naphthalene were detected at concentrations above RBSCs in every sampling event. The first two compounds were detected above this criterion exclusively in well BED-MW13. However, naphthalene exceeded the RBSC in all sampling events in all wells. Four unfiltered and filtered metals (arsenic, barium, manganese, and thallium) were detected at concentrations above the RBSCs in groundwater samples from the two TNTC bedrock wells. Barium was the metal most commonly detected at concentrations above its RBSC in both the unfiltered and filtered samples from most sampling events. In all sampling events, none of the detected metals exceeded BSCs. The detected anions varied in the bedrock wells at the site. In BED-MW13, chloride is the dominant anion, while sulfate is the dominant anion in well TNTC-BEDGW-001 (Shaw, 2005).

1.6.4 PRRWP Area

Field activities were conducted specifically to investigate environmental media at the Red Water Pond Areas in 1994 and 1998. Focused RI sampling was performed in 1994, including

overburden/shale and limestone bedrock groundwater sample collection from the PRRWP Area (D&M, 1997a). Direct-push groundwater sampling of the overburden/shale groundwater was conducted in 1998 (IT, 2000a).

Overburden/shale groundwater samples were collected from PRRWP Area wells in 1994, 1996, 1997, and 1998 (Shaw, 2005). Additional PRRWP Area overburden/shale groundwater samples were collected from direct-push borings in 1998 (IT, 2000a). Samples were collected from PRRWP Area bedrock wells in 1997, 1998, 2001, and 2002.

Overburden/Shale Water-Bearing Zone. Four overburden/shale wells were sampled in 1994, 1996, 1997, and 1998 (Shaw, 2005). These are wells IT-MW05, PR-MW07, PR-MW08, and PR-MW09. A total of 20 direct-push groundwater samples were collected in 1998 (IT, 2000a). Several nitroaromatics and SVOCs were detected at concentrations exceeding RBSCs in several of the overburden/shale wells and direct-push samples. PRRWP Area overburden/shale wells and direct-push sampling locations are shown on Figure 1-15.

Four nitroaromatics were detected at concentrations exceeding RBSCs in the overburden/shale well samples, including maximum concentrations of 1,3,5-TNB at 6,900 µg/L, 2,4-DNT at 4,100 µg/L, and 1,3-DNB at 5,200 µg/L. Seven additional compounds were detected as SVOCs in these wells; notable among these are 4,6-dinitro-2-methylphenol (up 20,000 µg/L) and 2,4-dinitrophenol (up to 6,900 µg/L). Nitroaromatics were detected in 15 of the 20 direct-push groundwater samples at concentrations exceeding the RBSCs, including maximum concentrations of 1,3-DNB and 2,4-DNT at 4,800 and 6,800 µg/L, respectively, in sample PRRWP-DP03. Similar to the PRRWP Area well samples, several SVOCs were also detected in the direct-push samples, including 4,6-dinitro-2-methylphenol (2,200 µg/L) and 2,4-dinitrophenol (5,900 µg/L). 4,6-Dinitro-2-methylphenol was formerly used as a pesticide and herbicide and is unlikely to be associated with the former PBOW manufacturing process or to be a breakdown product. Only low concentrations of VOCs (less than 2 µg/L) were detected in both the well and direct-push groundwater samples (Shaw, 2005).

The metals most frequently detected at concentrations above both RBSC and BSC values include aluminum, chromium, iron, and manganese. Manganese was the filtered metal most frequently detected at concentrations above both the RBSC and BSC. It was detected at concentrations ranging from 108 µg/L (DP13) to a maximum concentration of 62,500 µg/L (DP10). Total cyanide was also detected in the groundwater above the RBSC at two locations and nitrate was detected above its RBSC at three locations. In addition to nitrate, sulfate is the dominant anion in this area (Shaw, 2005).

Limestone Bedrock Water-Bearing Zone. Two bedrock monitoring wells, BED-MW15 and BED-MW23, are associated with the PRRWP Area (Figure 1-15). BED-MW15 was sampled in 1997, 1998, 2001, and 2002; BED-MW23 was sampled in 2001 and 2002. Only low concentrations of nitroaromatics were detected in BED-MW15. Most notably, 2,4-DNT and 2,6-DNT were each detected at a concentration of 0.89 µg/L in the sample collected during May 1998; nitroaromatics were not detected in any samples collected from BED-MW23. Each of the wells had concentrations of VOCs, especially BTEX compounds, that exceeded the respective RBSCs. BED-MW23 exhibited combined BTEX concentrations of 4,690 µg/L in the sample collected in April 2002, and BED-MW15 exhibited combined BTEX concentrations of 2,350 µg/L in the May 1998 sample. Similar BTEX concentrations were detected in samples from these wells during the dry season. Several SVOCs were also detected at concentrations greater than the RBSCs, notably naphthalene (up to 31 µg/L), 2-methylnaphthalene (up to 37 µg/L), and methylphenols (up to 80 µg/L) (Shaw, 2005). These SVOC compounds and the BTEX compounds are likely associated with naturally occurring petroleum in the limestone bedrock.

Filtered and unfiltered groundwater samples exhibited barium concentrations consistently above its RBSC in well BED-MW15 during all four sampling events. Iron and manganese concentrations were usually detected above the RBSC and BSC values in the filtered and unfiltered samples from well BED-MW23. Arsenic was found to be above the RBSC in BED-MW23 in the dry season in both the filtered and unfiltered samples. Chloride is the dominant anion in the bedrock, detected at concentrations one to two orders of magnitude greater than the concentrations of sulfate (Shaw, 2005).

1.6.5 WARWP Area

Field activities were conducted specifically to investigate environmental media at the Red Water Pond Areas in 1994 and 1998. Focused RI sampling was performed in 1994, including overburden/shale and limestone bedrock groundwater sample collection from the WARWP Area (D&M, 1997a). Direct-push groundwater sampling of the overburden/shale groundwater was conducted in 1998 (IT, 2000a).

Overburden/shale groundwater samples were collected from WARWP Area wells in 1994, 1996, 1997, and 1998 (IT, 1999). Additional WARWP Area overburden/shale groundwater samples were collected from direct-push borings in 1998 (IT, 2000a). Samples were collected WARWP Area bedrock wells in 1997, 1998, 2001, and 2002 (Shaw, 2005).

Overburden/Shale Water-Bearing Zone. Four WARWP Area overburden/shale wells were sampled during 1989, 1993, 1994, 1996, 1997, and 1998 (Shaw, 2005). These wells are WA-MW01, WA-MW02, IT-MW02, and IT-MW10. Nitroaromatics were detected at concentrations exceeding RBSCs in WA-MW02 and IT-MW02, including 2,4-DNT at up to 55 µg/L and 1,3-DNB up to 23 µg/L. Similar nitroaromatics concentrations were observed for these wells in both the wet and dry season of 1998. A total of 14 direct-push groundwater samples were also collected from the WARWP Area in 1998 (IT, 2000a). Nitroaromatics were detected at concentrations exceeding RBSCs in 10 of the 14 direct-push samples. These include maximum concentrations of 2,4-DNT at 950 µg/L, 1,3-DNB at 270 µg/L, and 1,3,5-TNB at 670 µg/L. WARWP Area overburden/shale well and direct-push sampling locations are shown on Figure 1-16.

Among the wells and direct-push samples, the following three additional SVOCs were detected at concentrations exceeding RBSCs (maximum concentrations in parentheses): 3-nitroaniline (330 µg/L), 4,6-dinitro-2-methylphenol (24 µg/L), and 2,4-dinitrophenol (7.6 µg/L). 4,6-Dinitro-2-methylphenol is an herbicide and pesticide that is not known to be associated with former PBOW operation. One VOC, tetracholorethene, was detected above its RBSC, but may not be related to former PBOW activities. The unfiltered metals most frequently detected at concentrations above both RBSC and BSC values include aluminum, iron, and manganese. Most of the inorganic constituents were removed or their concentrations were reduced by the filtration process, but manganese concentrations remained above its RBSC and BSC value in seven of the eight direct-push groundwater samples and five of the seven well samples since 1997. Sulfate was the dominant anion present. In addition, nitrate was detected in this area above the RBSC.

Limestone Bedrock Water-Bearing Zone. Well BED-MW14 is the only bedrock monitoring well at the WARWP Area and it was sampled in 1997, 1998, 2001 and 2002 (Shaw, 2005) (Figure 1-16). Three nitroaromatics were detected as SVOCs in this well at concentrations exceeding the RBSCs. The SVOCs were likewise detected at concentrations exceeding the RBSCs. Five nitroaromatics (2,4-DNT, 3-nitroaniline, nitrobenzene, 2,4-dinitrophenol, and 4,6-dinitro-2-methylphenol), all detected as SVOCs, were detected at concentrations above the RBSCs during the wet season of May 1998. 2,4-DNT was also detected above the RBSC during the April 2002 wet season. Among all TNT and Red Water Pond Area AOCs and downgradient bedrock wells, 2,4-DNT was detected in well BEDMW-14 at the highest concentrations (19 and 16 µg/L). Benzene was detected only once (November 1997 dry season) and at a concentration above the RBSC and BSC. No other VOC was detected at a concentration exceeding its RBSC.

Nickel was the inorganic most commonly detected at a concentration that exceeded screening levels. Nickel concentrations exceeded the BSC during all four sampling events in both the unfiltered and filtered groundwater samples, and nickel concentrations exceeded the RBSC (73 μg/L) during the September 2001 dry season and the April 2002 wet season in both the filtered and unfiltered samples. Concentrations of cobalt and copper were above BSC values during the September 2001 and April 2002 sampling events in both the filtered and unfiltered samples. Arsenic was detected at a concentration above the RBSC and BSC during the last two sampling events. Anions in the bedrock groundwater are dominated by sulfate, which was detected at concentrations up to two orders of magnitude higher than the concentration of chloride in all sampling events except September 2001. In this latter event, sulfate data were not available (Shaw, 2005).

1.7 Groundwater Modeling and Fate-and-Transport Modeling

Groundwater flow and fate-and-transport modeling was conducted in support of the groundwater FS (Appendix A). The purpose of the model is to estimate potential future concentrations in the overburden/shale and limestone bedrock groundwater and to provide a tool for evaluating the efficacy of remedial alternatives in achieving drinking water quality with respect to the COCs. The goal of drinking water quality was selected based on NASA's desire for unrestricted future land use. Estimated potential future groundwater concentrations of 2,4-DNT, 2,6-DNT, and TNT were modeled for each of the AOCs and downgradient areas. This model is based on soil-to-groundwater leaching and overburden/shale groundwater-to-bedrock groundwater migration.

The site groundwater model includes all groundwater data collected from these areas since 1997 (Shaw, 2003a, 2005; IT, 2000a) and all soil analytical data conducted under the site investigations (D&M, 1997a,c) and soil RIs (IT, 2001a,c; 2000a,b). The site groundwater model also includes completed and planned soil remediation. USACE previously agreed to perform these soil remedial actions at TNTA, TNTB, TNTC, and the PRRWP Area as described in Section 1.5. It was determined that no soil remediation was required for the WARWP Area. The primary basis for selection of the remedial actions at these four AOCs was direct contact with soil; however, the remedial actions were also considered a source removal with respect to groundwater. A soil removal action has been completed for TNTB, but planned remediation has not been completed for TNTA and TNTC. Remediation for the PRRWP Area was recently completed (September 2008), but this remediation had only been ongoing at the time of groundwater modelling.

The site groundwater model accounted for both the planned and completed soil actions. Several of the remediated TNTB areas were excavated to the water table. In some of these areas,

previously collected soil analytical data show detections of 2,4-DNT, 2,6-DNT, or TNT. The collection of deeper vadose soil from these areas that were saturated during excavation is possible because of the highly variable water table. These deeper vadose zone samples and the accompanying water table data were left in the groundwater model, rather than attempting to adjust the model to more closely reflect conditions encountered at the time of excavation at TNTB. Samples of water were collected from some of the TNTB excavations. The analytical results of these pit water samples (WTI, 2005a) were used as overburden/shale groundwater input to the site groundwater model for the areas at which they were collected. With respect to TNTA, TNTC, and the PRRWP Area, the modeling was performed under the assumption that the planned remediation is already complete. At the PRRWP Area, the delineated organic layer containing nitroaromatics and associated soil were assumed by the model to be remediated; remediation in this area was only recently completed (after groundwater modeling was performed). In addition, known areas of overburden/shale groundwater contamination identified during the RI were also used as input to evaluate potential long-term (i.e., up to 150 years) impact to the limestone bedrock groundwater.

In addition, the results of the groundwater monitoring indicate that some of the known areas of overburden/shale groundwater contamination potentially will impact the deep limestone aquifer in the future. However, the degree to which these areas impact the limestone aquifer, or if they will impact it at all, is a combination of residual contaminant concentrations and the thickness of weathered and unweathered shale. Groundwater samples collected for the overburden/shale during RI activities had maximum concentrations of nitroaromatics exceeding 30,000 µg/L. In addition to the known areas of overburden/shale groundwater contamination, there are also some areas where continued soil leaching from residual soil contamination is predicted to lead to additional overburden/shale groundwater contamination. However, this leaching is relatively minor, and these sources are not significant enough to cause unacceptable concentrations of nitroaromatics in the limestone bedrock.

While modeling is an important tool that aids in understanding very complex vadose and saturated conditions at contaminated sites, the limitations of the data and assumptions that are made can bias results. In general, where data are limited or sometimes lacking, conservative estimates are used for model inputs based on literature values. For example, organic carbon data is frequently estimated based on soil types. A high organic content tends to limit contaminant leaching of certain types of compounds, including nitroaromatics. In addition, the vadose zone is treated as if this media were homogeneous, meaning that surface water infiltration occurs uniformly across a site. In reality, soil fractures and textural changes in the soil generally result

in preferential pathways for infiltration. Also, nitroaromatics in soil tend to be relatively heterogeneously distributed rather than homogeneous as assumed by the model. In addition, in areas where the concentrations of nitroaromatics in soils varied, the higher values were assumed for the leaching model, further biasing the results.

Even in the best characterized sites, input parameters for groundwater flow and fate and transport modeling are based on widely spaced monitoring wells and assumptions are made regarding input parameters such as porosity, groundwater elevation and hydraulic conductivity where measurements are not available. Porosity is typically based on literature values based on specific soil types. Bedrock porosity is more difficult to determine since it is driven by fracture networks. At PBOW, groundwater elevations tend to fluctuate, particularly in the overburden/shale. During periods of low precipitation, the overburden/shale groundwater is found in discrete pockets and is not interpreted to represent a continuous saturated unit across the site. During wetter periods, the overburden/shale may be saturated across the entire site. The transient nature of groundwater at PBOW leads to difficulties in modeling since the model is calibrated against one set of groundwater conditions. The groundwater elevation data chosen was based on a period of average precipitation resulting in the overburden/shale being completely saturated across the site. This in effect will result in increased groundwater movement laterally through the overburden/shale, and also increased downward movement of groundwater into the limestone bedrock.. The end effect is that the plumes tend to get larger in the overburden/shale and more contamination is transported from the overburden/shale into the limestone bedrock. Hydraulic conductivity in the model is initially based on results of aquifer tests from single wells. These slug tests only determine hydraulic conductivity for a small area surrounding the well with the results extrapolated across the site. Some error is inherent in estimating the hydraulic conductivity in areas that are not adequately characterized, but model calibration is done to minimize the effect. The end result, however, is that actual groundwater flow may be faster or slower than what is predicted.

Groundwater models such as MODFLOW applied to fractured bedrock assume that it behaves as an equivalent porous media. That is, the modeling is done assuming there is a dense network of fractures that result in the system behaving in a similar fashion to unconsolidated material. However, if the fracture flow system were to be dominated by a small number of widely spaced fractures, this accuracy of the flow model would decrease. In addition, data needed for fully characterizing fracture flow systems is difficult and costly to obtain. A key component of the site conceptual model includes natural attenuation. Because there are no data available, the groundwater model assumed no attenuation was occurring. This assumption introduces

potentially a very strong bias that would result in an overestimate of the contaminant concentrations and aerial extent of plumes in groundwater.

An example of some of the uncertainties in the model is the relative location of contamination to the water table. It is noted that the site groundwater model is highly sensitive to low concentrations of COCs that are within 2 feet or less of the water column. In such instances, the model has predicted that a DNT concentration as low as 0.16 mg/kg (less than the detection limit) would result in overburden/shale groundwater concentrations that exceed the RG by an order of magnitude. However, such soil concentrations were typically not found to correlate with such high concentrations based on the empirical results of collocated soil and groundwater samples. Again, the model does not predict that such low soil concentrations would at all impact the limestone bedrock aquifer. Similarly, small changes in groundwater flow gradients from groundwater extraction at the WARWP and PRRWP caused increased leaching in the TNT areas during the model simulations. This seems unlikely given the distance to the TNT areas and likely causes another bias in the modeling results.

As previously stated, the groundwater model is a tool that must be interpreted using site-specific knowledge and best professional judgment. Most of the identified uncertainties are effectively managed through the model calibration process that reduces the errors associated with estimated input parameters and the extrapolation of sparse site-specific data. The two most critical areas that bias the model results are the leachability of contaminants in the vadose zone, and the lack of a natural attenuation component in simulating the limestone bedrock groundwater. The uncertainty associated with both of these components are likely to introduce bias that tends to overestimate rather than underestimate resulting groundwater concentrations.

1.8 Groundwater Risks

A BHHRA was conducted in 2006 to evaluate human health risks associated with exposure to groundwater underlying TNTA, TNTB, TNTC, PRRWP Area, the WARWP Area, and downgradient areas (Shaw, 2006). A qualitative screening was performed on bedrock and overburden/shale groundwater in each of these areas. Overburden/shale groundwater was not further evaluated for risks associated with direct contact because this groundwater zone greatly fluctuates seasonally and would not yield adequate quantities for tap water uses. However, contamination in overburden/shale groundwater was included in the site groundwater model and used to estimate future contaminant concentrations in the limestone bedrock groundwater (Appendix E of Shaw, 2006), which were quantitatively evaluated for risk. Chemicals in bedrock groundwater which failed the qualitative screen were identified as chemicals of potential

concern (COPC) and were evaluated quantitatively for risks. This quantitative risk assessment of the COPCs includes an exposure assessment, toxicity assessment, risk characterization, and uncertainties analysis. The risk characterization includes site-related risks associated with measured contaminant concentrations in bedrock groundwater and total risks which combine both site-related and non-site-related risks. The risk characterization also provides an evaluation of potential future risks associated with modeled concentrations of 2,4-DNT, 2,6-DNT, and TNT (based on measured concentrations in overlying soil and overburden/shale groundwater) that may be present in the limestone bedrock groundwater in the future. Non-site-related risks are quantified by simply subtracting the site-related risks from the total risks reported in the groundwater BHHRA.

The bedrock groundwater risks associated with each of the five AOCs and downgradient areas was evaluated under two separate scenarios. Current risk was estimated based on measured concentrations of contaminants into groundwater samples collected over the past 10 years. Future risk was based on exposure to the estimated concentration of contaminants derived from soil leachate modeling and groundwater fate and transport modeling. The results are summarized in the following text.

Site-related and non-site-related noncancer hazards are compared to the target threshold value of 1 in the following subsections. An HI of 1 is recognized by OEPA and the Army as the hazard value at or below which any adverse noncancer health effects are regarded as unlikely among the population. For simplicity, the noncancer HI values presented in this FS are the total HI values (regardless of target organ) for non-site-related and site-related hazards, except in the case where the total HI exceeds a value of 1 but the target HI value does not. In this case, which applies only to non-site-related hazards for the worker at TNTB, the highest target organ-specific value was used. In all other cases, both the total HI and the highest target organ HI is greater than 1 or the total HI does not exceed 1. Currently, there are no groundwater users either on site or at the facility boundary. Thus, the risks and hazards presented below are for potential or hypothetical human receptors, not for any currently exposed individuals.

Based on the OEPA cancer risk criterion of 1E-5, residential and on-site worker use of bedrock groundwater at each of the five AOCs was found to result in unacceptable cancer risks, and residential use was identified as having the potential to produce adverse noncancer health effects due to a combination of site-related contaminants and naturally occurring petroleum and metals. Long-term worker exposure to groundwater in each of these areas, except TNTC, was also found to result in levels of exposure that would exceed the noncancer target level. Note that at the

downgradient boundary areas, only residential use was evaluated; OEPA cancer and noncancer criteria were exceeded for residential use of groundwater at the property boundary.

The U.S. Army has generally used a cancer risk criterion of 1E-4 in the recent past, rather than 1E-5, as a threshold to determine whether a remedial action should be performed. This value of 1E-4 represents the upper end of the EPA (1990) National Oil and Hazardous Substances Pollution Contingency Plan (NCP) acceptable range of 1E-6 to 1E-4. This 1E-4 value is also consistent with EPA (1997; 1991) guidance. Under a hypothetical residential exposure scenario, each of the five AOCs would exceed the Army 1E-4 criterion based on cancer risks associated with a combination of naturally occurring chemicals and site-related contaminants. Under a future on-site worker scenario, only cancer risks associated with the use of TNTA and PRRWP Area groundwater would exceed the Army 1E-4 cancer risk criterion.

At the downgradient areas and at each AOC, except the WARWP Area, the nonsite-related COPCs dominate both the cancer risk and noncancer hazards; at the WARWP Area, residential and worker ILCR values associated with nonsite-related arsenic also exceed the target ILCR. The following classes of COPCs are dominant with respect to cancer risk and/or noncancer hazard for the five AOCs and the downgradient areas; site-related COPCs are specifically noted as such:

- TNTA – Naturally occurring petroleum-related organic compounds
- TNTB – Inorganics and naturally occurring petroleum-related organic compounds
- TNTC – Naturally occurring petroleum-related organic compounds
- PRRWP Area – Naturally occurring petroleum-related organic compounds
- WARWP Area – Site-related nitroaromatics and naturally occurring arsenic
- Downgradient – Naturally occurring petroleum-related organic compounds.

For each of these areas, even if no site-related COPCs were present, noncancer hazards associated with residential groundwater use, cancer risk associated with residential groundwater use, and cancer risks associated with worker use would result in respective HI and ILCR values that would exceed the target HI criterion of 1 and/or the U.S. Army target cancer risk of 1E-4 (as well as the OEPA target cancer risk of 1E-5). Site-related risks associated with groundwater are discussed for the respective site areas in Sections 1.8.1 through 1.8.6.

Potential pathways for exposure to ecological receptors, such as groundwater discharge to surface water and sediment, were also considered (IT, 2001a,b; 2000). Groundwater itself is not an exposure point. Discharge of contaminated shallow groundwater via seeps or springs to surface water would be considered an exposure pathway to aquatic life, wetlands, and some

wildlife where the groundwater discharges to surface water. No such points of discharge were identified for any of the five site areas. Also, the water table is strongly seasonally dependent at these site areas. The groundwater gradient accordingly demonstrates a pronounced downward vertical component, and the lateral flow in the shallow overburden/shale appears to be minimal. This paucity of lateral flow would be expected to result in little, if any, contribution to surface water flow. The WARWP Area generally has the shallowest water table and is in close proximity to Pipe Creek; thus, if groundwater to surface water discharge were to occur, the WARWP Area is the most likely area. Although the BERA showed that surface water in Pipe Creek adjacent to the WARWP Area had slight toxicity to water fleas, this toxicity could not be correlated to either site-related or naturally occurring chemicals. Thus, based on site reconnaissance, the results of the BERAs, and current understanding of the PBOW site hydrogeology, groundwater contamination does not appear to be adversely impacting ecological receptors at the TNT Area and Red Water Pond Areas.

1.8.1 TNTA

As previously discussed, risk to an on-site worker and resident from exposure to bedrock groundwater was evaluated for current receptors using existing groundwater analytical data and for future receptors based on soil leachate modeling and groundwater fate and transport modeling. BHHRA evaluated risks from both site-related chemicals (e.g., nitroaromatics) and those considered to be naturally occurring (e.g., petroleum-related compounds and metals). The results are summarized in the following text. Note that for the resident, noncancer HI values for the young child are referenced, as the child is a more sensitive receptor; for residential cancer risks, the ILCR for the site child and adult are summed.

Current Site Conditions. Site-related risks associated with residential use of TNTA groundwater (ICLR=4E-5; HI=2), assuming current site conditions, were found to exceed the 1E-5 OEPA target cancer risk criterion and the target HI criterion, but those associated with on-site worker use (ILCR=1E-5; HI=0.2) were not. Site-related cancer risks associated with the TNTA on-site resident are less than the 1E-4 Army target cancer risk criterion.

Non-site-related risks for on-site worker (ILCR= 2E-4; HI=10) and residential (ILCR=2E-3; HI=345) use of groundwater exceed the OEPA 1E-5 target cancer risk criterion and the target HI criterion due mainly to naturally occurring petroleum-related compounds (benzene and chrysene), as well as arsenic. The non-site-related cancer risks for the resident and worker also exceed the Army target risk criterion of 1E-4. These results indicate that even in the absence of site-related contaminants, the groundwater at TNTA would not be considered suitable for human consumption based on OEPA and Army criteria.

Future Site Conditions. The modeled nitroaromatics concentrations for TNTA indicate unacceptable cancer risks for the resident (ILCR=5E-4) with respect to both the Army (1E-4) and OEPA (1E-5) cancer risk criteria. Also, the noncancer HI (4) for the resident based on modeled TNTA nitroaromatics exceeds the target HI. The worker ILCR based on future modeled concentrations equals the Army ILCR criterion of 1E-4, but exceeds the OEPA criterion of 1E-5. The worker HI (0.5) is less than the noncancer target criterion of 1.

As previously noted, the current nonsite-related risk indicates that the groundwater at TNTA is not suitable for human consumption based on the presence of petroleum related compounds and arsenic. Because these compounds are naturally occurring, it is expected that similar concentrations will be present in the future. That is, in the absence of site-related contamination, the groundwater would still be considered unsuitable for future human consumption based on OEPA cancer and noncancer criteria. The planned soil remediation that is based primarily on direct-contact exposure has not yet commenced (see Section 1.5). Therefore, the modeled results used for the groundwater BHHRA assumed that no soil had been remediated. As noted in Section 1.5, the planned soil removal for direct contact is anticipated to mitigate future leaching to groundwater from TNTA.

1.8.2 TNTB

Evaluation of site risks for TNTB follow the same procedures as outlined in Section 1.8.1. The results are summarized below.

Current Site Conditions. No site-related COPCs were identified for TNTB groundwater. Site-related cancer risks from naturally occurring compounds for the resident (ICLR=3E-4) and on-site worker (ICLR=7E-5) exceed the OEPA cancer criterion and the noncancer criterion (1E-5 and 1, respectively). The non-site-related ILCR value for the resident also exceeds the Army ILCR criterion of 1E-4, but the worker ILCR does not. The cancer risk is associated with naturally occurring benzene and arsenic. The noncancer hazard associated with naturally occurring groundwater exceeds the target HI for the resident (HI=18), but not for the worker (HI=0.8). Noncancer hazards are primarily associated with arsenic and iron. The results suggest that the groundwater at TNTB is not suitable for human consumption due to risk and hazards associated with background concentrations of petroleum and metals.

Future Site Conditions. The modeled nitroaromatics concentrations for TNTB indicate that cancer risks (ILCR=2E-5) only marginally exceed the OEPA target cancer risk criterion for the resident, but not for the worker (ILCR=6E-6); both of these values are less than the Army's

criterion of 1E-4 used to trigger remedial action concern. It is noted that the groundwater model is likely to be conservative with respect to human health protection. The HI values associated with residential use (0.1) and worker use (0.02) of groundwater at modeled concentrations meet the target noncancer HI.

The risks associated with background conditions for bedrock groundwater are not expected to vary significantly in the future. Because of this, the risks associated with exposure to groundwater will be mainly from naturally occurring concentrations of petroleum-related compounds and metals, not site-related compounds. A soil remedial action, based on risks associated with direct contact, was completed at TNTB in 2006. This remedial action was accounted for in the soil-to-groundwater leaching model. Thus, the model results indicate that soil removal based on direct contact was effective for groundwater protection as well at TNTB.

1.8.3 TNTC

Evaluation of site risks for TNTC follow the same procedures as outlined in Section 1.8.1. The results are summarized in the following text.

Current Site Conditions. No site-related COPCs were identified for TNTC groundwater. Based on the evaluation of non-site-related risk, bis(2-ethylhexyl)phthalate, benzene, and methylene chloride were the main cancer risk drivers for both the on-site worker (ILCR=9E-5) and resident (ILCR=1E-3). The ILCR for the resident exceeds both the OEPA and Army criteria, but the worker ILCR exceeds only the OEPA criterion. An HI of 1 was calculated for the on-site worker due to exposure to benzene. For the resident, an HI of 65 was calculated, which exceeds the noncancer criterion. This HI is primarily due to 2-methylnapthalene, bis(2-ethylhexyl)phthalate, naphthalene, benzene, bromomethane, and xylenes. The bedrock groundwater would not be considered a suitable source of potable water based on the findings of the BHHRA, due to cancer risks associated with the presence of naturally occurring constituents.

Future Site Conditions. The modeled nitroaromatics concentrations for TNTC indicate unacceptable cancer risks for the worker (ILCR=4E-4) and resident (ILCR=2E-3) with respect to both the OEPA (1E-5) and Army (1E-4) cancer risk criteria. The HI (8) of the resident based on nitroaromatic modeling also exceeds the target criterion of 1. The risks associated with background conditions for bedrock groundwater are not expected to vary significantly in the future. Because of this, the risks associated with exposure to groundwater, even without the site-related nitroaromatic compounds, will still result in the groundwater being unsuitable for human consumption. The planned soil remediation for TNTC that is based primarily on direct-contact exposure has not yet commenced (see Section 1.5). Therefore, the modeled results used for the

groundwater BHHRA assumed that no soil had been remediated. As noted in Section 1.5, the planned soil removal is anticipated to mitigate future leaching to groundwater from TNTC.

1.8.4 PRRWP Area

Evaluation of site risks for the PRRWP Area follow the same procedures as outlined in Section 1.8.1. The results are summarized in the following text.

Current Site Conditions. The site-related noncancer hazard (HI=0.07) and cancer risk (ICLR=4E-6) for the on-site worker associated with PRRWP Area bedrock groundwater use meet the target HI of 1 and the OEPA target cancer risk of 1E-5, as well as the Army cancer risk criterion of 1E-4. The site-related HI (0.6) for the resident also meets the noncancer criterion. The site-related ILCR associated with residential use of PRRWP Area bedrock groundwater (2E-5) slightly exceeds the OEPA criterion, but is less than the Army criterion. Additionally, the elevated sulfate present appears to be site-related.

The non-site-related hazard (HI=15) and non-site-related cancer risk (ICLR=5E-4) for the worker exceed the HI criterion and the OEPA cancer criteria, respectively. The non-site-related cancer risks also exceed the Army 1E-4 cancer risk criterion. Similarly, the non-site-related hazard (HI=234) and cancer risk (ICLR=7E-3) exceed the OEPA and Army criteria for the resident. Benzene is the main cancer risk driver for both the on-site worker and resident. The HI for the resident is primarily due to thallium, 2-methylnapthalene, napthalene, acetone, benzene, and xylenes. For the on-site worker, the HI is driven by thallium and benzene. As with the previous sites, the bedrock groundwater would not be considered a suitable source of potable water based on the findings of the BHHRA.

Future Site Conditions. The modeled nitroaromatics concentrations associated with PRRWP Area bedrock groundwater indicate unacceptable cancer risks for the worker (ILCR=4E-5) and resident (ILCR=2E-4) based on the OEPA cancer risk criterion (1E-5). The cancer risks associated with the resident also exceed the Army criterion (1E-4), but those based on the worker do not. The HI values of the worker (0.1) and resident (0.7), based on the modeled nitroaromatics concentrations, meet the target criterion of 1. While the modeled results indicate unacceptable cancer risks for the worker (OEPA cancer criterion only) and resident, the exposure to background concentrations of petroleum-related compounds and metals would also result in exceedance of OEPA and Army criteria. The data suggest that, as with other areas of PBOW, the groundwater is not a suitable source of potable water even without the presence of site-related contaminants. The soil remediation for the PRRWP Area that is based primarily on direct-contact exposure has only recently been completed (see Section 1.5). The modeled results

used for the groundwater BHHRA are based on the assumption that only a small "hot spot" of the PRRWP Area soil had been remediated at the time the BBHRA was completed. As noted in Section 1.5, the soil removal is anticipated to mitigate future leaching to groundwater from the PRRWP.

1.8.5 WARWP Area

Evaluation of site risks for the WARWP Area follow the same procedures as outlined in Section 1.8.1. The results are summarized in the following text.

Current Site Conditions. The WARWP Area is the only area evaluated in this BHRRA where the nonsite-related groundwater COPCs do not dominate both the overall HI and ILCR values. The site-related cancer risks and noncancer hazards for residential groundwater use (ILCR=2E-4; HI=61) exceed the target criteria, including the cancer criteria for both the OEPA (1E-5) and Army (1E-4). The site-related noncancer hazards for groundwater use by the worker (HI=9) exceed the target HI of 1. Site-related cancer risks for the worker (ILCR=6E-5) exceed the OEPA criterion, but not the Army criterion. These HI and ILCR values are mostly associated with site-related nitroaromatics.

The ILCRs for naturally occurring arsenic (2E-4 for the resident; 5E-5 for the worker) are approximately as high as those associated with site-related nitroaromatics. These non-site-related cancer risks for the resident exceed both the OEPA and Army ILCR criteria. The non-site-related cancer risks associated with the worker exceed the OEPA criterion for acceptable risks in background groundwater, but not the Army criterion. In addition, the non-site-related noncancer hazards for the resident (HI=2) exceed the target criterion, although the worker HI of 0.4 is less than the target value. In summary, even if no site-related contamination were present, the background groundwater would not be suitable as a potable water source for residential consumption, and the groundwater does not meet the OEPA cancer criteria for worker use.

Future Site Conditions. The modeled nitroaromatics concentrations for the WARWP Area indicate that noncancer hazards would meet the target criterion for both the future worker (HI=0.09) and resident (HI=0.6). The cancer risks associated with the future worker (ILCR=4E-5) and resident (ILCR=2E-4) would both exceed the OEPA criterion of 1E-5, but only the risks of the future resident groundwater user would exceed the 1E-4 Army criterion.

1.8.6 Downgradient

Evaluation of site risks for the downgradient area follow the same procedures as outlined in Section 1.8.1. The results are summarized in the following text.

Current Site Conditions. Because land use outside of the PBOW facility boundary cannot be prescribed, only the resident was evaluated at the facility boundary. Based on current, measured concentrations of COPCs in groundwater, the site-related noncancer HI (0.4) meets the target criterion of 1. The site-related ILCR (3E-5) exceeds the OEPA criterion of 1E-5, but is less than the Army criterion of 1E-4. Site-related nitroaromatics were primarily responsible for this exceedance. Thus, under the conditions of the BHHRA, if a hypothetical resident were to drink water from the PBOW downgradient facility boundary at current concentrations, the associated ILCR is estimated to be greater than the OEPA criterion, within the range regarded as acceptable by the NCP, and less than the Army cancer risk trigger level. Review of the non-site-related risk (ICLR=4E-4; HI=99) suggest that even without the nitroaromatics present, the groundwater would still be unsuitable for human consumption due to cancer risks associated with the presence of benzene and noncancer hazards associated with the presence of benzene, 2-methylnapthalene, naphthalene, xylenes, iron, and manganese.

Future Site Conditions. Three downgradient areas along the PBOW facility boundary were identified and modeled for future concentrations of nitroaromatics. These modeled concentrations were evaluated for risk. The HI values for the resident (0.002 to 0.08) meet the target HI of 1 for noncancer effect at each of the three modeled downgradient locations. The ILCR values for boundary areas downgradient of TNTA (4E-7) and the WARWP Area (1E-6) meet the OEPA target cancer risk criterion of 1E-5. The ILCR for areas downgradient of TNTB, TNTC, and the PRRWP Area at the PBOW facility boundary (2E-5) slightly exceeds the OEPA criterion for cancer risk, but is less than the Army criterion. As discussed in Section 1.8, exposure associated with cancer risks in the range of 1E-6 to 1E-4 are identified in the NCP as acceptable. The value (2E-5) associated with areas downgradient of TNTB, TNTC, and the PRRWP Area is near the logarithmic midpoint of this NCP acceptable range.

These results indicate that potential future users of groundwater at the property boundary are unlikely to suffer adverse site-related human health effects or an unacceptable additional risk of cancer, with the possible exception of cancer risk along the northern PBOW boundary that is downgradient of TNTB, TNTC, and the PRRWP Area. As noted with all other areas previously discussed, the background concentrations of naturally occurring petroleum-related compounds and metals result in unacceptable risks even without considering the contributions of site-related contamination.

1.8.7 Summary

Evaluation of site-related compounds indicates that the past Army activities at PBOW have negatively impacted groundwater. At current groundwater concentrations, site-related worker and/or resident cancer and noncancer risks exceed OEPA criteria for current conditions for all sites except TNTB and TNTC. Cancer risks associated with site-related contaminants do not exceed the Army criterion except at the WARWP Area, and only for residential use in this area. Site-related noncancer hazards exceed the target criterion of 1 for TNTA (residential use) and the WARWP Area (residential and worker use). Thus, using Army criteria, only the groundwater underlying TNTA and the WARWP Area would be unacceptable with respect to site-related contaminants (based on noncancer hazards) for the resident, and only the groundwater underlying the WARWP Area would be unacceptable (based on noncancer hazards) with respect to site-related contaminants for the worker.

However, with the exception of the WARWP Area, non-site-related (i.e., naturally occurring) petroleum hydrocarbons and metals dominate the total risks for the site. Even without considering the impact from site-related nitroaromatics, bedrock groundwater would not be suitable for human consumption. Although cancer and noncancer risks from nitroaromatics are dominant at the WARWP Area, the cancer risks associated with background conditions still exceed OEPA and Army criteria.

Evaluation of future conditions at the site indicate that risks associated with the use of groundwater will exceed OEPA criteria due to continued leaching from residual contamination in the soil and saturated rock. As discussed in Appendix A (uncertainties in the groundwater modeling), the groundwater model produces very conservative estimates of future concentrations of nitroaromatics in groundwater. These are not generally substantiated by current conditions at the site. This bias needs to be tempered with observed conditions at the site and best professional judgment when interpreting results. Also, as previously noted, potable use of water at the natural background concentrations of petroleum and metals would also result in cancer risks and noncancer hazards that exceed OEPA and Army criteria.

1.9 Feasibility Study Report Organization

This FS report is organized as follows: Chapter 1.0 presents the introduction to this report; Chapter 2.0 presents site and groundwater use and characteristics; Chapter 3.0 presents RAOs; Chapter 4.0 presents screening of remedial action technologies; Chapter 5.0 presents the development and detailed analysis of remedial alternatives for groundwater; Chapter 6.0 presents a comparative analysis of remedial alternatives; Chapter 7.0 presents the conclusion; and Chapter 8.0 lists all references used in support of this FS.

Appendices for this report are as follows: Appendix A – Groundwater Fate and Transport Modeling; Appendix B – Evaluation for Monitored Natural Attenuation of Nitroaromatics in Groundwater; Appendix C – Identification of Chemicals of Concern and Derivation of Remedial Goal Options; Appendix D – Sample Federal Facility Land-Use Control Record of Decision Checklist with Suggest Language; and Appendix E – Engineering Calculations. Appendix F presents Comments and Responses.

2.0 Site and Groundwater Use and Characteristics

Characteristics specific to the PBOW and the potential use of underlying and downgradient groundwater are key components that should be considered in any strategy or decision concerning remediation. The following sections describe the geology and hydrogeology of the former PBOW, current and potential groundwater use, and discussion of groundwater quality. This information provides a framework to contextualize the discussion of any site remediation strategies considered in the remainder of the FS.

2.1 Geography, Topography, and Surface Drainage

PBOW is located within the Eastern Lake Region of the Central Lowland Province (Soil Conservation Service [SCS], 1971). Erie County is overlain by lacustrine sediment, glacial outwash, and glacial till. The surface is a plain with a slight slope to the north-northeast toward Lake Erie at approximately 25 feet per mile. Elevations at the site range from 680 feet above mean sea level at the intersection of Taylor Road and Patrol Road on the southwestern side of the site (approximately 1,400 feet west of well BEDMW-25) to 625 feet above mean sea level at the northern portion of the installation (Figure 2-1). In general, the topography of PBOW is characterized by a flat ground surface with occasional low hummocks caused primarily by glacial scouring and deposition. A low escarpment trends from the western to the northeastern portion of the site.

PBOW lies in the eastern region of the Pickeral Creek-Pipe Creek Basin, which is part of the St. Lawrence River drainage basin (D&M, 1997c). Eleven streams exist within PBOW and flow north-northeast toward Lake Erie, which is located approximately 3.5 miles north of the site. The site is part of four drainage areas: (1) Sawmill Creek (southern PBOW); (2) Plum Brook (central PBOW); (3) Pipe Creek (western PBOW); and (4) Storrs-Hemminger Ditch (north central PBOW). All four drainage areas flow into Sandusky Bay (D&M, 1997b). Surface water for TNTA specifically drains into ditches that are tributaries to Lindsley Ditch, which eventually drains (off site) into Plum Brook. Surface water on the northern side of TNTB drains to ditches that are tributaries to Ransom Brook, while surface water on the southern side of TNTB drains to tributaries flowing into Plum Brook. Surface water at TNTC flows into tributaries which flow into Pipe Creek. Surface water drainage at the WARWP Area flows into tributaries for Pipe Creek, while surface water at the PRRWP Area is drained by tributaries for Plum Brook. The drainage pattern is dendritic where streams are incised into bedrock and is poorly developed where they have not yet eroded to the bedrock. Two drainages at the site, Kuebler Ditch and Plum Brook, are being monitored by NASA Plum Brook Station for National Pollutant

Discharge Elimination System (NPDES) outfall permits. In addition to the streams, 17 isolated ponds and reservoirs are located at PBOW (U.S. Geological Survey [USGS], 1992; D&M, 1997b). Note that the 17 isolated ponds and reservoirs were not directly related to any of the TNT manufacturing processes nor are they interpreted to be potential sources of contamination.

2.2 Geology

2.2.1 Regional Geology

The bedrock in northern Ohio consists of Devonian and Silurian carbonates (limestone and dolomite) and clastics (shale, siltstone, and sandstone). These units unconformably overlie older sedimentary sequences of Ordovician and Cambrian Age rocks, which in turn unconformably overlie pre-Cambrian basement rocks (D&M, 1997c). The local bedrock is situated on the eastern flank of the Findlay Arch. In the Devonian and Silurian of northern and western Erie County, weathering of the carbonates has produced cavernous porosity and karst topography.

2.2.2 Local Geology

Four formations, all of Devonian Age, are encountered at the PBOW site (Figure 2-1). The Columbus limestone is the lowermost formation screened by several site bedrock wells. It is distinguished by a brown to gray, finely crystalline, fossiliferous limestone with tan to buff gray, partly sandy dolomite at the base. The Delaware limestone overlies the Columbus limestone. The Delaware limestone is characterized as a hard, dense, finely crystalline limestone and dolomite. The unit is typically buff colored, massive, and usually described as fossiliferous. The Columbus and Delaware limestone both have similar bedrock characteristics. Because no distinct contact is found between the Delaware and Columbus limestone bedrock units that easily permits identification of which sequence contains the groundwater in question, the bedrock will be referenced simply as “limestone.”

Using only rock core borelogs and photographs obtained during drilling events, the Delaware and Columbus limestone units are difficult to differentiate at PBOW. One characteristic found from the PBOW borelogs, air monitoring, and rock core photographs, was that hydrogen sulfide and natural petroleum were commonly encountered soon after limestone bedrock drilling began. In addition, in the vicinity of PBOW, quarries (Hanson Aggregates to the north, Hanson-Sandusky Crushed Stone to the southwest, and abandoned Castalia quarry to the west) mine limestone from the Delaware. Traces of natural petroleum-derived hydrocarbons and hydrogen sulfide (also known as H_2S) are common in all three quarries.

Overlying the Delaware Limestone is the Olentangy Shale. Geographic Information System data calculations indicate that the Olentangy shale of PBOW dips to the southeast at a slope of approximately 21.1 feet per mile. Two members of the Olentangy Shale have been characterized at the site, the Plum Brook Shale and the overlying Prout Limestone. The Plum Brook Shale is interpreted to consist of approximately 35 feet of bluish-gray, soft, fossiliferous shale containing thin layers of dark, hard, fossiliferous limestone. The Prout Limestone has been described as an approximate 15- to 50-foot thick unit which occasionally outcrops in a 1,000-to-2,000-foot-wide, northeast-striking band across the middle portion of PBOW. It is described as a dark gray to blue, very hard, siliceous, fossiliferous limestone or dolomitic mudstone. The uppermost formation at the site is the Ohio Shale. Geographic Information System data show that the Ohio Shale dips to the southeast at a slope of approximately 26.4 feet per mile. Only one member of the Ohio Shale, the Huron Shale, is present in the PBOW area,. This unit has been described as black, thinly bedded, with abundant carbonaceous matter. Some large pyrite/carbonate concretions are also present in the Huron Shale, some as large as 6 feet in diameter (D&M, 1997c).

2.2.3 Hydrogeology

2.2.3.1 Regional Hydrogeology

Regional groundwater flow is to the north-northeast towards Lake Erie, although local flow may vary due to local topography. Water in the limestone typically occurs in joints and along bedding planes or in solutionally enlarged openings. Although some limestones in the middle of the county provide well yields of up to 500 gallons per minute (gpm), the overburden/shale and the majority of the other formations can sustain groundwater pumping of only 10 gpm or less (D&M, 1997b). A hydrogeological study conducted by the USGS on the glacial deposits in Sandusky in 1990 reported a horizontal hydraulic conductivity of 0.046 feet per day and a vertical hydraulic conductivity of 1.2 feet per day (USGS, 1992).

2.2.3.2 General Site Hydrogeology

At PBOW, the bedrock groundwater has been divided into three zones based on location and yield. Zone 1 occurs in the north and northwestern portion of PBOW. It has been characterized as yielding from 100 to 500 gpm from karstic limestone approximately 100 feet below grade. Zone 2 is in the northern portion of PBOW and has yields of 15 gpm or less from limestone approximately 300 feet below grade. Zone 3 is located in the eastern and southern portion of the site in predominantly shale bedrock. In addition to being found in the shale, groundwater is located in thin sand and gravel horizons interbedded with silt and clay deposits. Most Zone 3 wells are poor yielding, many of them providing less than 3 gpm (D&M, 1997a).

Two main water-bearing zones at PBOW are present: one in the overburden/shale and one in the limestone bedrock. Data from investigations conducted over the past decade (Shaw, 2005; IT, 1997; 1999) have found that groundwater in the overburden/shale is in discontinuous pockets during dry time periods exemplified by monitoring wells that are typically dry or areas in which wells could not be installed due to a lack of water in the overburden/shale soil at the time of drilling. Because of the general lack of water in the overburden/shale, only limited lateral migration of contaminants would typically occur during the dry period. During a wet period, the general flow direction in the overburden/shale water-bearing zone (where present) is to the north-northeast, largely mirroring surface topography. The flow also corresponds somewhat to the topography of the top of the bedrock. In contrast, the limestone bedrock water-bearing zone is saturated year-round. The conceptual model of the site is that groundwater flow in the limestone water-bearing zone migrates and is influenced by the frequency, orientation, density, and connectivity of fractures in the bedrock. Similar to the overburden/shale flow direction, groundwater in the limestone flows to the north-northeast towards Lake Erie.

2.3 Climatological Setting

The climate of Erie County is continental but strongly influenced by Lake Erie, with cold and cloudy winters and warm, humid summers. Wind is from the southwest 55 percent of the time (MK, 1994; D&M, 1997a).

Based on 30-year metrological data from the Midwestern Regional Climate Center (http://mcc.sws.uiuc.edu/Precip/OH/337447_psum.html), the U.S. Weather Bureau station in Sandusky, Ohio, reported the average annual precipitation from 1971 to 2000 was 34.46 inches. Within that 30-year time, February had the lowest monthly precipitation average with 1.72 inches, whereas June had the highest of 4.19 inches. The maximum daily high temperature recorded in Sandusky from 1896 to 2001 was 105 degrees Fahrenheit (ºF) measured on August 6, 1918, and July 14, 1936. The lowest recorded daily temperature in this time period was minus 20º F on January 19, 1994. On the average, July is typically the warmest month (averaging 81.8º F), while January is the coldest (averaging 18.9º F). The county's first freezing temperature is usually in October, and its last freezing temperature is typically in April.

2.4 Site Conceptual Model

Figure 2-2 presents a generalized block diagram or conceptual model of PBOW, showing the possible contaminant migration transport routes, the overburden/shale and bedrock water-bearing units, the geologic units, and the interrelationship between the water-bearing zones. Groundwater sampling investigations and groundwater monitoring well measurement events

have found that groundwater in the overburden/shale may be limited to discrete areas during dry time periods of little rainfall. During these periods of low precipitation, only limited migration of contaminants would occur due to less infiltration of rainwater. The site conceptual model illustrates this seasonal, discontinuous nature of the overburden/shale groundwater.

Based on analytical data, lateral movement of contamination in the overburden/shale is limited. The groundwater tends to occur in discrete pockets in the overburden and does not represent a contiguous lateral unit. Wells screened in competent shale indicate that vertical contaminant transport downward from the overburden is limited. In areas where the competent shale is thin to absent (i.e., WARWP and PRRWP), nitroaromatics have been detected sporadically and at low concentrations. This behavior suggests that contamination from the overburden may be released in slugs during periods of high precipitation to the underlying limestone bedrock. The strongly reducing conditions within the limestone bedrock result in degradation of the nitroaromatics.

The site conceptual model also illustrates groundwater flow in the limestone bedrock water-bearing zone through fractures. Groundwater flow paths and velocity are dictated by the frequency, orientation, density, fracture size, and connectivity of these bedrock fractures. In addition to fractures, some solutional cavities may be present in the limestone bedrock. Generally, groundwater in the bedrock flows to the north-northeast. The limestone bedrock water-bearing zone also has natural petroleum, hydrogen sulfide, and metals present that make it unsuitable for a source of potable water (see Section 2.7 for further discussion).

Based on historical data, groundwater geochemistry varies between the overburden/shale, shale, and limestone. Geochemistry results show that monitoring wells screened in the overburden/shale typically have higher concentrations of dissolved oxygen with sulfate as the dominant anion. The higher concentrations of sulfate are likely due to the oxidation of residual sulfide minerals in the unconsolidated materials and weathered shale. Monitoring wells that are screened in more competent shale and limestone tend to be depleted of dissolved oxygen due to the limited infiltration of precipitation, oxidation of sulfide minerals, and the presence of organic material.. Chloride is the dominant ion partially because these sediments were originally deposited in a marine environment and also because the lower dissolved oxygen limits the oxidation of sulfide minerals. The significance of the varying groundwater geochemistry is that waste products from the manufacture of TNT include nitrate from nitric acid and sulfate from sulfuric acid, as well as sellite. The presence of these compounds in groundwater may be indicative of potential impact by waste disposal activities (ponds, tanks, etc.), even if nitroaromatics are not detected.

2.5 Site Use and Groundwater Use

2.5.1 Site Use

The facility is currently surrounded by a chain-link fence, and the perimeter is patrolled regularly. Access by authorized personnel is limited to established checkpoints. Public access is restricted except during the controlled annual deer hunting season. Current use of the PBOW facility is classified as industrial. It is the desire of NASA to release PBOW for unrestricted use. D&M (1997b) describes the following potential future users of all or portions of the facility:

- Continued industrial use (NASA activities and programs).
- Recreational use of portions of the site by hunters and fishermen.
- Portions of the site may be sold to state or local government or private individuals (unrestricted land use).
- Parts of the facility may be used for residential or agricultural purposes.
- Parts of the facility may be used for training by the National Guard.
- Construction activities may be performed during development of any of the sites.

2.5.2 Groundwater Use

The majority of residents in Erie County receive household drinking water from public utilities whose primary sources are surface water. Residences to the north and east of PBOW are connected to city, county, or rural services. The Erie County Health Department does not allow the use of surface water as private drinking water.

Erie County's main groundwater source is from the Delaware Limestone aquifer found in the western end of the county. Some wells surrounding PBOW are used for agricultural purposes, including irrigation, which could have an effect on drawdown near the site (ICI, 1995). A few wells in the vicinity of PBOW were determined to be used for private and public consumption (SAIC, 1991); however, no wells within the facility boundary are used. The nearest private well to PBOW is approximately 840 feet to the northeast and the use of the well is unknown (Figure 2-1).

Two deep or bedrock aquifer systems are used for drinking water in the area: a carbonate aquifer (limestone) to the west and a shale aquifer to the east (IT, 1997). Groundwater wells in the central and eastern portions of the county tap lower yielding shale and sandy zones in the

overburden/shale (D&M, 1997a). PBOW is located within the transition of the two bedrock systems.

There are six known private wells within 1 mile downgradient of PBOW, the nearest being 840 feet northwest of the facility boundary, in the east-middle portion of PBOW (northeast of abandoned well BED-MW27). Owners of five of these wells agreed to participate in a well survey conducted by the USACE in 2003 (refer to Appendix A of Shaw, 2006). Three of these wells were being used for watering lawns and gardens, one was being used for irrigating an herb farm, and the other well was not being used for any purpose. Note that nitroaromatics were not detected in any of these five wells.

Overburden/shale groundwater exists within the unconsolidated material atop the bedrock under portions of PBOW. The overburden/shale water within the five AOCs included in this FS is isolated, discontinuous, and seasonally dependent, generally resulting in low and undependable production where it exists. Therefore, overburden/shale groundwater is not a suitable drinking water source in these AOCs. Overburden shale-to-bedrock modeling was performed to determine the potential impact that nitroaromatic contaminants in the perched zone may have on the bedrock water-bearing zone (Appendix A of Shaw, 2006).

2.5.3 Groundwater Withdrawal

In addition to potable and irrigation uses of groundwater, groundwater withdrawal (i.e., dewatering) is known to occur in and around PBOW. Within the site itself, NASA operates a groundwater extraction and treatment system in the north central portion of PBOW to address groundwater contamination associated with underground storage tanks. The system reportedly removes approximately one million gallons of water per year from the overburden water-bearing zone. In addition, in the northern portion of PBOW at the reactor area, sump wells installed in the limestone bedrock dewater the overburden/shale and shallow limestone bedrock in the area to prevent water from infiltrating the basement of the reactor building. The amount of groundwater removed by this system is unknown. The reactor is currently being decommissioned; once decommissioning is completed, the sump wells will no longer be functional.

A limestone quarry is located approximately 1 mile north of the PBOW site. The quarry discharges on average between 750,000 and 1,000,000 gallons of water per day to a surface drainage near the site, based on discussions with quarry employees. By contrast, the amount of precipitation received in this area of Ohio (34.5 inches/year) and the estimated size of the quarry (400 acres) would account for approximately 1,000,000 gallons per day. This does not include evaporation losses which would reduce the daily average; however, it is clear that the bulk of the

water being discharged by the quarry is due to precipitation, not from groundwater withdrawal. Discussions with the quarry employees indicate that the quarry only discharges water following precipitation events.

There does appear to be groundwater drawdown in the vicinity of the quarry extending south to PBOW. The groundwater trough extending through the site seems to be a reflection of groundwater withdrawal to some degree, although most of the source areas addressed in this FS report are not interpreted to be significantly impacted by the withdrawal.

2.6 Groundwater Quality

Overburden/Shale. As mentioned in Section 2.5.2, groundwater within the overburden/shale at the TNT Areas and Red Water Pond Areas does not provide dependable water production for household use. Analytical data from background wells completed in the shale indicate maximum concentrations of chloride (34,600 milligrams per liter [mg/L]), sulfate (416 mg/L), and total dissolved solids (TDS) (43,800 mg/L) (Shaw, 2004) that far exceed the respective secondary maximum contaminant level (SMCL) of 250, 250, and 500 mg/L, respectively (EPA, 2006). Of the 47 samples collected from the 6 upgradient wells, 77 percent exceed the SMCL for TDS, 45 percent exceed for iron, and 64 percent for manganese. While SMCLs are not regulatory enforceable, they are used as a guide to determine acceptable drinking water based on taste, smell, color, or appearance. No SMCL exists for sodium, but EPA lists a health advisory of 20 mg/L for individuals on a low sodium diet and a range of 30 to 60 mg/L as a taste threshold. The maximum sodium concentration in PBOW background groundwater is 9,130 mg/L, which is more than two orders of magnitude greater than these values (Shaw, 2004). In total, 84 percent of the background samples exceeded the SMCL for sodium. Other regional-based information indicates that occasional salt or petroleum may be present in the shale (SAIC, 1991).

Limestone Bedrock. The limestone bedrock units typically yield greater quantities of water than do the shale bedrock units, but the limestone groundwater is regionally regarded as being of lower quality because of high mineral content (Ohio Department of Natural Resources [ODNR], 1962). The limestone bedrock groundwater exhibits high concentrations of sulfate. The sulfate concentrations at TNTC well BEDGW-001 (1,080 and 1,340 mg/L) and the three samples collected from downgradient well BED-MW27 (868 to 1,280 mg/L) (Shaw, 2006) all exceeded the SMCL of 250 mg/L (EPA, 2006). Even though the SMCL is not a health-based or regulatory enforceable level, exceedances of this value indicate that this groundwater is undesirable for household uses. These samples had relatively low sodium concentrations, with maximum concentrations of 55.2 mg/L in BEDGW-001 and 109 mg/L in BEDMW-27. This indicates that

the elevated sulfate concentrations are unlikely to be associated with the past use of sellite (sodium sulfite and cold water were the final rinsing agents in the manufacturing process of TNT). It is noted that sulfate levels at the WARWP Area limestone bedrock well BEDMW-14 (maximum detection of 1,335 mg/L) also exceed the SMCL, but the sulfate may be largely associated with the past disposal of sellite (sodium sulfite) in this area. The elevated sodium concentrations (average of 629 mg/L) in limestone bedrock groundwater samples collected from BEDMW-14 without a correspondingly elevated concentration of chloride (average of 57 mg/L) indicate that this may be site-related rather than resulting from natural saline conditions (Shaw, 2006; 2005). Evaluation of analytical data from eight limestone bedrock wells indicate that 61 percent of the samples exceed the chloride and TDS SMCLs and 68 percent exceed the upper threshold limit for sodium.

At PBOW, evidence of naturally occurring petroleum was encountered at all wells completed in the limestone, except BED-MW18. This well was completed across the contact of the Olentangy Shale and Delaware Limestone. Evidence of naturally occurring petroleum included petroleum stains on rock cores, visible petroleum on drilling bits, free product detected during groundwater sampling, and detectable levels of H_2S in boreholes and monitoring wells. The petroleum encountered during drilling was always only in the limestone bedrock unit and typically at depth, although petroleum hydrocarbon was detected throughout the limestone drilling process. Groundwater from all of the wells completed in the limestone (including BED-MW18) had reportable concentrations of petroleum-related compounds. In total, 68 percent of samples collected from eight limestone bedrock wells exceed the maximum contaminant level (MCL) for benzene. Note that nitroaromatics were not present in most of the limestone groundwater samples; this observation provides additional evidence that the petroleum is not site-related.

Based on the uncertainty of the origin of the petroleum hydrocarbon encountered in several bedrock monitoring well boreholes during drilling, well gauging, and groundwater sampling activities, on August 15, 2007 NASA collected laboratory samples of the suspect liquid from three different monitoring wells (BED-MW23, AA1-BED-GW-001, and TNTA-BEDGW-001). The purpose of the laboratory analysis was to determine if the hydrocarbon was from a natural or anthropogenic source. The laboratory fingerprint analyses was conducted by the following methods:

- High resolution hydrocarbon fingerprinting (via gas chromatography and flame ionization detector) – EPA SW-846 Method 8015M
- Polycyclic aromatic hydrocarbon concentration – EPA SW-846 8270M

- Biomarker concentration (via gas chromatography and mass spectrometer) – EPA SW-846 8270M.

Laboratory analytical results from the monitoring well samples were compared against a reference crude oil analytical sample. The reference crude oil sample was identified as Alaskan North Slope Crude Oil. The comparison of the Alaskan Crude Oil to the nonaqueous-phase liquid, found that the nonaqueous-phase liquid contained a crude oil of a common origin; therefore, it is not refined, but from a natural source (SAIC, 2007). Even though the petroleum was deemed to be from a natural source, there are issues associated with its presence in the groundwater that pose issues for any active remediation that may be needed. This impact is addressed in the evaluation of remedial alternatives presented in Chapter 5.0. In addition to its relevance to this FS report, the occurrence of petroleum in any future investigative work should be addressed as a site-specific issue. That is, the evaluation of any potential anthropogenic sources should be conducted to ensure the protection of human health and the environment. This would be particularly important should free product be found in the overburden groundwater since naturally occurring free-phase petroleum has only been found in the deeper limestone bedrock.

Regulatory Considerations. As noted in regulatory guidance, determination of potential future uses should consider State groundwater classifications or other designations and Federal groundwater guidelines (e.g., Class I, II, and III groundwaters) (EPA, 1997). The Federal Guidelines define "nonpotable," or Class III, groundwater aquifers as those that contain more than 10,000 mg/L TDS; yield less than 150 gallons per day; or are so contaminated by naturally occurring conditions (e.g., salinity) or broad-scale human activity not related to a specific contaminant source that cleanup is not practicable. While the overburden/shale and limestone bedrock may not be limited by yields, analytical data indicate that based on TDS and naturally occurring petroleum and metals, the groundwater underlying these areas meets the definition of a Class III aquifer.

2.7 Potential for Natural Attenuation of Nitroaromatics

Evaluation of the nature and extent of nitroaromatic contamination in the overburden/shale and bedrock aquifers suggests that natural attenuation may be occurring. As a component of this FS, existing hydrogeologic and analytical data were evaluated to determine if the low, sporadic detections of nitroaromatics in the limestone bedrock groundwater are due to reducing and diluting groundwater conditions. This evaluation is summarized in the following paragraphs; refer to Appendix B for further detail.

Where present, the shale unit may effectively limit the downward migration of contamination from the overburden to the limestone. The overburden and shale are treated as a single unit from a hydrogeologic perspective; that is, the hydraulic properties of the two units are similar and there appears to be one continuous water-bearing zone with complete hydraulic communication. However, the movement of contamination appears to be impeded in the shale unit, likely due to higher organic content. This interpretation is primarily based on the distribution of nitroaromatics in the limestone. Where the shale unit is thin to nonexistent (e.g., the Red Water Ponds), limited and sporadic detections of nitroaromatics are observed. In addition, these limited and sporadic concentrations of TNT and DNT isomers along with breakdown products (i.e., the ADNT isomers) may be detected.

To determine if groundwater conditions are suitable for the degradation of nitroaromatics, geochemical parameters (dissolved oxygen, oxidation-reduction potential [ORP], etc.) were evaluated. From available data, anaerobic dissolved oxygen levels (less than 1 mg/L) from low-flow groundwater sampling events indicate that conditions are favorable for the reduction of nitroaromatics. ORP values in limestone bedrock wells were at or below 0.0 millivolts (mV), which is favorable for the biodegradation of TNT. In four of the eight wells sampled, ORP levels ranged from minus 297.6 to minus 358.4 mV. ORP required for abiotic reduction of TNT is below minus 200 mV. The ORP data suggest that conditions are reducing and favorable for the biotic and abiotic reduction of nitroaromatics in the limestone bedrock water-bearing zone at PBOW. Evaluation of nitrate and sulfate concentrations does not suggest that these will significantly affect the degradation of nitroaromatics.

Based on the available data, the presence of degradation products, along with favorable groundwater geochemical conditions, indicate that natural attenuation of nitroaromatics is likely occurring in the limestone bedrock groundwater-bearing zone at PBOW. A more detailed analysis may be warranted to definitively state that natural attenuation of nitroaromatics will address the current contaminant concentrations present in the limestone and any future leaching to bedrock that may occur should no active remediation be taken at PBOW. Monitored natural attenuation (MNA) is also discussed in Section 4.3.2.

2.8 Risk Management

Any potential actions taken to address site-related nitroaromatic contamination must consider all the characteristics of PBOW groundwater. The following factors should be considered in evaluating the value of site-wide groundwater as a potential future drinking water resource:

- The overburden/shale groundwater at the site is discontinuous.
- The overburden/shale groundwater meets the definition of a Class III aquifer due to high dissolved solids concentration.
- The presence of naturally occurring petroleum and metals in the limestone bedrock groundwater renders it unfit for human consumption.
- Hydrogen sulfide in the limestone bedrock groundwater could present an inhalation hazard if the groundwater was used as drinking water source.
- Drinking water in the area is supplied by public utilities.

The above factors support a conclusion that drinking water is not a reasonably expected future use of site groundwater.

Any remedial action taken at the site would not restore groundwater to drinking water quality. Specifically, the cancer risks associated with background contributions account for virtually all of the cancer risk associated with residential exposure to TNTB and TNTC groundwater, over 99 percent of the risks associated with PRRWP Area groundwater, approximately 98 percent of TNTA groundwater, and approximately 50 percent of WARWP Area groundwater. In each case, even if the U.S. Department of Defense-related contaminants were not present, the cancer risk levels associated with residential groundwater use would exceed the 1E-5 OEPA risk management criterion by more than an order of magnitude. Thus, groundwater treatment, if performed, would only reduce or eliminate site-related contamination and would not address the broader issue of the natural petroleum, metals, dissolved solids, or hydrogen sulfide present in the aquifers, and groundwater after such treatment would not meet the OEPA risk management criterion. Therefore, any use of groundwater at the site would require additional treatment to address the natural constituents in groundwater that are unrelated to past Army operations.

Ultimately, the cost associated with restoration of site groundwater to natural conditions must be weighed against the likelihood that this groundwater will be developed as a potable source. Treatment of residual nitroaromatic contaminants in groundwater will not result in either the overburden/shale or limestone bedrock groundwater meeting even minimal standards for consumption. This FS follows the standard CERCLA process and includes an evaluation of remedial alternatives that treat the overburden/shale and limestone bedrock groundwater to remove contamination caused by past Army operations at the facility. The remedial action objectives discussed in Chapter 3.0 were developed based in discussion with OEPA to include the full range of potential actions at the site. These RAOs, which focus on site-related COCs,

address only a portion of the overall risk associated with groundwater. While the technologies evaluated are appropriate for the site-related COCs, it is important to balance the costs associated with implementing these technologies against their overall benefit. That is, regardless of the degree to which a specific remedial alternative is implemented, restoration of groundwater at this site to drinking water quality will not be achieved due to the unacceptable background risk posed by the natural contaminants present in groundwater.

3.0 Remedial Action Objectives

This chapter provides RAOs and other key information for the evaluation of groundwater underlying TNTA, TNTB, TNTC, the PRRWP Area, and the WARWP Area. RAOs are developed during the FS and finalized in the record of decision (ROD) to protect human health and the environment. RAOs provide the basis for the identification, detailed analysis, and selection of remedial alternatives. RAOs specify COCs to be addressed; relevant exposure route(s) and receptor(s); and chemical concentration limits specific to COCs, environmental media, and specific locations at the site. RAOs for this FS pertain specifically to groundwater.

3.1 Identification of Remedial Action Objectives

The following RAOs have been developed for the TNT and Red Water Ponds Areas:

- Prevent on-site human exposure to groundwater containing COCs at concentrations that exceed RGs for residential drinking water.
- Prevent human exposure to downgradient off-site groundwater containing COCs at concentrations that exceed RGs for residential drinking water.

The groundwater RGs are provided in Table 3-1. A range of remedial alternatives has been developed to meet the RAOs listed.

3.2 Site-Specific Considerations

The overburden/shale groundwater within the five AOCs included in this FS (TNTA, TNTB, TNTC, PRRWP Area, and WARWP Area) is isolated, discontinuous, and seasonally dependent, generally resulting in low and undependable production where it exists. Therefore, this groundwater is not a suitable drinking water source in these AOCs. In addition, as discussed in Section 2.6, evaluation of water quality data indicates the overburden/shale groundwater unit meets the definition of a Class III aquifer. For this reason, the USACE and OEPA agreed to quantitatively characterize risks associated with limestone bedrock groundwater in the groundwater BHHRA, but only qualitatively characterize risks associated with overburden/shale groundwater (Shaw, 2006). Overburden/shale zone-to-bedrock modeling has been performed in support of this FS to determine the potential impact that nitroaromatic contaminants in the overburden/shale may have on the limestone bedrock water-bearing unit.

As discussed in Section 2.6, neither the overburden/shale nor the limestone bedrock is a desirable source of groundwater for human consumption. Both units meet the EPA definition of a Class III aquifer. The overburden/shale groundwater has naturally occurring elevated concentrations

of TDS, chloride, sulfate, and sodium, as mentioned, and is unlikely to be found in sufficient quantity. The limestone bedrock groundwater contains naturally occurring petroleum and elevated sulfate concentrations. The petroleum likely contributes to the reducing conditions found in the bedrock groundwater. As discussed in Section 2.7, the reducing conditions in the limestone bedrock groundwater may facilitate the breakdown of nitroaromatics. Appendix B evaluates the potential for natural attenuation in groundwater at PBOW.

3.3 Identification of Chemicals of Concern

COCs were identified separately for the limestone bedrock and the overburden/shale groundwater for each of the five AOCs. The methods used for COC identification are summarized in the following paragraphs. Appendix C presents the identification process for limestone bedrock COCs and overburden/shale COCs in further detail. As noted in Section 2.6, the aquifer meets the definition of a Class III aquifer. The aquifer is not being used in the vicinity of PBOW for potable water; therefore, the exposure pathway is incomplete.

Limestone Bedrock COCs. Groundwater COCs were identified separately for the limestone groundwater underlying each of the three TNT areas and the two Red Water Pond Areas based on future use of the water as a residential drinking water source. COC identification was based on three general criteria (or a combination of these): 1) significant contribution to risks and/or hazards in the groundwater BHHRA based on current bedrock groundwater concentrations; 2) chemicals identified as soil COCs that were determined as reasonably likely, based on groundwater modeling, to leach to bedrock groundwater and potentially result in future risks; and 3) status as an isomer of another limestone bedrock groundwater COC (e.g., 2,6-DNT in the WARWP Area) that was found to co-occur with its related COC in soil and/or overburden/shale groundwater. Table 3-2 lists the limestone bedrock groundwater COCs for each area.

Overburden/Shale COCs. The overburden/shale COCs were selected based on the assumption that wells would be installed into this discontinuous groundwater and that this groundwater would be used as a residential drinking water source. The suitability of the overburden/shale groundwater as a potential drinking water source is highly unlikely due to its low yield and marginal quality (e.g., elevated concentrations of naturally occurring chloride, sulfate, TDS, and sodium). COC identification for the overburden/shale groundwater was based on the following criteria (or a combination of these): 1) significant contribution to risks and/or hazards as indicated by the exceedance of the RG (refer to Section 3.4); 2) chemicals identified as soil COCs that were determined as reasonably likely to leach to overburden/shale groundwater; and 3) status as an isomer of another overburden/shale groundwater COC that was

found to co-occur with its related groundwater COC in soil. Table 3-3 lists the overburden/shale groundwater COCs for each area. Appendix C details the identification of the COCs.

3.4 Remedial Goal Options

Limestone RGs. RGs were developed for each limestone groundwater COC. Derivation of the groundwater RGs is summarized in the following paragraphs and detailed in Appendix C. The first step in the development of limestone RGs is the identification of chemical-specific applicable or relevant and appropriate requirements (ARAR) (Section 3.8.2). MCLs for drinking water are recognized as legally enforceable ARARs for groundwater that is a potential source of drinking water. The MCL for nitrate is 10,000 µg/L. MCLs are not available for any other of the COCs. The State of Ohio has established groundwater protection standards under Ohio Administrative Code 3745-81-11, but no groundwater standards, which are equivalent to the MCLs, are available for the COCs other than nitrate. Therefore, nonstatutory criteria, known as "to be considered" (TBC) criteria, were used to determine RGs for the other COCs. This TBC information includes reference doses and cancer slope factors that were used in the back-calculation of risk-based remedial concentrations (RBRC) from the BHHRA.

Limestone groundwater RGs were developed assuming residential use. Each of the 10 limestone bedrock COCs contributed substantially to a noncancer HI exceeding a value of 1 and/or an ILCR greater than 1E-5 in one or more of the five AOCs. RBRCs were back-calculated in the groundwater BHHRA using site-specific methods and assumptions, based on hazard quotients of 0.1 and 1 and on ILCR values of 1E-6 and 1E-5. These were adjusted in the derivation of the RGs to minimize the extent of groundwater that exceeds RGs such that 1) the resultant HI would not exceed a value of 1; 2) the cumulative ILCR would not exceed a value of 1E-5; and 3) the RGs are the same for limestone bedrock groundwater underlying each of the TNT and Red Water Pond areas. The RGs for the limestone bedrock groundwater COCs based on residential use are shown in Table 3-1.

Overburden/Shale RGs. The limestone bedrock groundwater RGs were adopted as overburden/shale RGs. Alternative RGs were developed for those overburden/shale COCs that were not identified as limestone bedrock groundwater COCs at any of TNT or Red Water Pond Areas. The alternate RGs had to be developed because overburden/shale groundwater was not quantitatively evaluated in the groundwater BHHRA (Section 3.2). With the exception of toluene, the groundwater RBSCs were used as the RGs for each of these compounds identified as COCs in the overburden/shale only. The MCL for toluene (1 mg/L) was used as the RG for

toluene. The RGs for the overburden/shale groundwater COCs based on residential use are shown in Table 3-1.

3.5 Groundwater Protection and Mitigation Strategies

Source removal of contaminants in soil has been completed at TNTB and the PRRWP Area, and is planned for TNTA and TNTC (Section 1.5). This FS primarily addresses groundwater protection and mitigation that is in addition to this soil source removal. A site-specific groundwater model was run based on soil and groundwater concentrations of 2,4-DNT, 2,6-DNT, and TNT measured in samples collected from the five AOCs. This model was used as a tool in the derivation of the strategies employed in this FS for groundwater protection and mitigation. The model does not include a natural biotic or abiotic degradation component because adequate data was not collected to characterize the degree to which these phenomena may be occurring. As discussed in Section 1.7, the lack of these degradation components bias the model toward overestimating future groundwater concentrations, particularly with respect to the strong reducing conditions in the limestone water-bearing zone.

This groundwater model was run assuming that all soil remediation at TNTB (completed 2006), the PRRWP Area (completed 2008), TNTA (planned), and TNTC (planned) has been completed. Further soil remediation beyond that planned and completed to date is not warranted based on the model results (Section 1.7). Therefore, the groundwater protection and mitigation strategies described in this FS focus directly on groundwater.

3.5.1 Strategy for Limestone Bedrock Groundwater Only

Strategies for protection and mitigation of groundwater in the limestone water-bearing unit were developed based on measured bedrock groundwater concentrations of COCs and potential future groundwater concentrations that may occur through leaching and vertical transport of contaminants from the overburden/shale groundwater. It is important to recognize that even if groundwater were remediated to pristine conditions, the groundwater will eventually revert back to “natural” conditions (high dissolved solids, sulfate, metals and petroleum) present throughout the area.

Treatment of Overburden/Shale Groundwater to Protect Bedrock. Potential future bedrock concentrations of the DNT isomers and TNT were based on the site groundwater model (Appendix A). Assumptions concerning possible transport of other limestone bedrock COCs from the overburden/shale groundwater to the bedrock are based on observation of concentrations of these COCs in the overburden/shale groundwater, behavior of the model regarding the DNTs and TNT, and best professional judgment.

The areas that potentially require remediation, based on mitigation and protection of limestone bedrock groundwater, are depicted on Figure 3-1 through 3-5. These include areas where site-related contamination in the overburden/shale groundwater has been modeled or otherwise judged to potentially impact the limestone groundwater in the future at concentrations that exceed RGs. Table 3-4 provides a summary of the reasons that specific building areas were included for remediation of the overburden/shale to protect the limestone bedrock groundwater in the TNT areas. Note that Section 3.6 presents guidelines for estimating the footprints of groundwater contamination at the TNT Areas.

The strategy for treating the overburden/shale groundwater within the PRRWP and WARWP Areas for protection of the limestone bedrock groundwater is based on a review of both the model output and the analytical data. Unlike the TNT Areas, the Red Water Pond Areas do not have multiple distinguishable point sources. Also, very little to no shale exists in these areas; therefore, contamination in the overburden is not mitigated by sorption to the shale (refer to Section 2.7) and is in more direct contact with the limestone bedrock. It was noticed that concentrations of total COCs at both the WARWP and the PRRWP were either less than 20 µg/L or were substantially greater than 20 µg/L. Therefore, the areas shown on Figures 3-4 and 3-5 as the estimated area of overburden/shale required for protection of the limestone bedrock groundwater (encircled in green) are those interpreted as having concentrations greater than 20 µg/L.

Treatment of Limestone Bedrock Groundwater. Analytical results from two limestone bedrock sampling locations, BED-MW27 and BED-MW14, indicate that concentrations of nitroaromatics at these locations currently exceed RGs. BED-MW27 is located near the PBOW boundary, northeast of the PRRWP Area. Contamination (2,4-DNT at 1.6 µg/L; 2,6-DNT at 1.4 µg/L) from this well is assumed to originate from the PRRWP Area. Therefore, treatment options for this area are based on a continuous, elongated plume extending from the PRRWP Area to just beyond the PBOW boundary in the vicinity of BED-MW27. The approximate plume location for the BED-MW27 plume is depicted on Figure 3-6. As previously discussed, detections of nitroaromatics in the limestone bedrock are sporadic, likely due to the strongly reducing conditions that promote degradation. As such, a continuous groundwater plume of contamination likely does not exist; rather, contamination may be released in slugs due to increased precipitation in the PRRWP area. This release mechanism coupled with the degradation in the limestone bedrock would result in the sporadic unpredictable nature of the groundwater contamination.

BED-MW14 is located in the northeastern portion of the WARWP Area. BED-MW14 contamination (2,4-DNT at 19 µg/L) is assumed to originate from the former waste disposal ponds. Treatment options were developed for this area based on a continuous plume extending from the WARWP Area locations to the northeast, beyond BED-MW14. The approximate plume location for the BED-MW14 plume is depicted on Figure 3-7. As previously noted, the contamination in this area is sporadic in nature, the result of the vertical transport from the overburden more prevalent during times of heavier precipitation coupled with degradation processes in the limestone bedrock groundwater.

An additional limestone bedrock well, TNTA-BEDGW-018, also had a concentration of 2,6-DNT (3.6 µg/L) that exceeded the RG. This concentration was reported under the explosives analysis for the sample collected in 1998. However, 2,6-DNT was not detected in samples collected from TNTA-BEDGW-018 in 1997, 2001, or 2002, nor was it detected in the 1998 SVOC analysis. Because 2,6-DNT has generally not been detected in this well, TNTA-BEDGW-018 is not targeted for remediation in this FS.

3.5.2 Strategy for All Groundwater

Strategies for protection and mitigation of all groundwater associated with the five AOCs were developed based on measured overburden/shale concentrations, measured limestone bedrock groundwater concentrations, modeled overburden/shale concentrations, and modeled bedrock concentrations of COCs. As previously noted, even if groundwater were remediated to pristine conditions by treatment of nitroaromatics and naturally occurring constituents, the groundwater will eventually revert back to "natural" conditions (high dissolved solids, sulfate, metals, and petroleum) present throughout the area.

Treatment of Overburden/Shale Groundwater to Protect All Groundwater. All groundwater in the overburden/shale with COCs that exceed RG values is targeted for remediation under this approach. As a result, the lateral extent of groundwater targeted for remediation is greater than that resulting from the approach that targets the overburden/shale for protection of the bedrock groundwater only (Section 3.5.1). At the TNT Areas, this includes additional building areas being added for remediation of the overburden/shale groundwater based on all areas with exceedances of overburden/shale RGs (Figures 3-1 thru 3-3). Additional mitigation to include all areas which exceed RGs in the overburden/shale unit of the Red Water Pond Areas results in larger areas potentially being remediated (Figures 3-4 and 3-5).

Treatment of Limestone Bedrock Groundwater. The treatment of limestone under the strategy for protection of all groundwater is exactly the same as that described for treatment of

the limestone bedrock groundwater in Section 3.5.1. That text is repeated in the following sentences.

Analytical results from two limestone bedrock sampling locations, BED-MW27 and BED-MW14, indicate that concentrations of nitroaromatics at these locations currently exceed RGs. BED-MW27 is located near the PBOW boundary, northeast of the PRRWP Area. Contamination (2,4-DNT at 1.6 µg/L; 2,6-DNT at 1.4 µg/L) from this well is assumed to originate from the PRRWP Area. Therefore, treatment options for this area are based on a continuous, elongated plume extending from the PRRWP Area to just beyond the PBOW boundary in the vicinity of BED-MW27. The approximate plume location for the BED-MW27 plume is depicted on Figure 3-6.

BED-MW14 is located in the northeastern portion of the WARWP Area. BED-MW14 contamination (2,4-DNT at 19 µg/L) is assumed to originate from the former waste disposal ponds. Treatment options were developed for this area based on a continuous plume extending from the WARWP Area locations to the northeast, beyond BED-MW14. The approximate plume location for the BED-MW14 plume is depicted on Figure 3-7.

An additional limestone bedrock well, TNTA-BEDGW-018, also had a concentration of 2,6-DNT (3.6 µg/L) that exceeded the RG. This concentration was reported under the explosives analysis for the sample collected in 1998. However, 2,6-DNT was not detected in samples collected from TNTA-BEDGW-018 in 1997, 2001, or 2002, nor was it detected in the 1998 SVOC analysis. Because 2,6-DNT has generally not been detected in this well, TNTA-BEDGW-018 is not targeted for remediation in this FS.

3.6 Areal Extent of Contaminated Groundwater

Determination of the areal extent for groundwater was based on a combination of analytical groundwater data, analytical soil data, information concerning former manufacturing activities, information obtained from similar former ordnance works facilities, planned areas of soil remediation, and observations made based on the completed soil remediation footprints of TNTB (Section 1.5). Section 3.5 mentions that the strategy for remediating the overburden/shale groundwater for protection of the limestone bedrock groundwater results in the selection of fewer areas to remediate in the TNT Area, or smaller areas to remediate in the Red Water Pond Areas, as compared to the goal of remediating the overburden/shale groundwater itself to drinking water quality.

The following general default approach was used in estimating the areal extent of overburden/shale groundwater contamination as described in Sections 3.6.1 and 3.6.2 for the individual building areas within the TNT Areas:

- A 70-foot-square area, centered on the former drowning tank locations, was assumed to be impacted at each mono house, bi-tri house, and fortifier house location that was previously identified as having measured or predicted groundwater contamination.

- The former building footprint and a 30-foot perimeter around this footprint were assumed to be impacted at each acid fume recovery house and sweating and graining house location that was previously identified as having measured or predicted groundwater contamination.

- The footprint of the wastewater settling tank basins and a 30-foot perimeter around this footprint were assumed to be impacted at each acid wastewater settling tank location that was previously identified as having measured or predicted groundwater contamination.

- The former building and basin footprints and a 30-foot perimeter around these footprints were assumed to be impacted at each former wash house facility that was previously identified as having measured or predicted groundwater contamination.

It is emphasized that the above approach was modified at several locations based on building area-specific groundwater and soil contamination data. Most notably, this occurred at TNTA Wash House Building 146, where contamination was observed in overburden/shale well TNTA-MW11 to the northeast (Figure 3-1) and at TNTB Fortifier House 463 (Figure 3-2), where soil contamination was found farther south and, especially, farther east of the default 70-foot square centered on the drowning tank. At both of these building areas, the estimated areal extent of groundwater contamination was increased substantially. Note that areas of completed or planned soil remediation are shown on Figures 3-1 through 3-5 in pink hatching. The estimated areal extent of contamination in the two current bedrock plumes (Figures 3-6 and 3-7) is described in Section 3.6.3.

3.6.1 Areal Extent in Overburden/Shale for Protection of the Limestone Bedrock Groundwater

Table 3-5 presents the areas and volumes estimated for the extent of contamination under the assumption that the overburden/shale groundwater will not be used as a drinking water source. The results in this table represent the level of remediation required in the overburden/shale to protect the limestone bedrock groundwater. The respective extents for each of the five AOCs

under this assumption are as follows (separate remediation areas are depicted in green hatching on Figures 3-1 through 3-5):

- TNTA – 86,100 ft^2
- TNTB – 16,400 ft^2
- TNTC – 52,900 ft^2
- PRRWP Area – 320,000 ft^2
- WARWP Area – 370,000 ft^2.

This equals an overall area of 845,400 ft^2. Table 3-5 includes the square footage of the individual building areas within the TNT Areas as well as the input data used in these calculations.

3.6.2 Areal Extent in Overburden/Shale for Mitigation/Protection of All Groundwater

Table 3-6 presents the areas and volumes estimated for the extent of contamination assuming that the overburden/shale groundwater will be used as a drinking water source. Note that this assumption is more stringent than that used in Section 3.6.1; therefore, the extent of contamination is greater. The results in this table represent the level of remediation required to clean up the overburden/shale to drinking water quality. The respective extents for each of the five AOCs under this assumption are as follows (separate remediation areas are depicted in blue hatching on Figures 3-1 through 3-5):

- TNTA – 116,300 ft^2
- TNTB – 115,200 ft^2
- TNTC – 60,200 ft^2
- PRRWP Area – 440,000 ft^2
- WARWP Area – 680,000 ft^2.

This equals an overall area of 1,411,700 ft^2, or an area approximately 70 percent greater than that required for protection of the limestone bedrock groundwater only. Table 3-6 includes the square footage of the individual building areas within the TNT Areas, as well as the input data used in these calculations.

3.6.3 Estimated Areal Extent of Current Limestone Bedrock Plumes

The 2,4-DNT and 2,6-DNT plume that extends northeastward from the PRRWP Area to the vicinity of abandoned well BED-MW27 (Figure 3-6) is approximately 810,000 ft^2. The 2,4-DNT plume thought to extend from the WARWP Area to the vicinity of Well BED-MW14 (Figure 3-7) is estimated at approximately 570,000 ft^2.

3.7 Volumes of Contaminated Groundwater

The extent of contamination in the overburden/shale at the Red Water Pond Areas is generally well defined due to numerous rounds of groundwater sampling coupled with a direct-push investigation conducted at both sites. The results from these investigations indicate that the overburden/shale groundwater contamination has not appreciably migrated from the source areas (i.e., ponds). This information supports the conceptual site model in that contamination transport is interpreted to be dominated by a vertical (downward) movement of contamination from the overburden/shale to the bedrock due to the discontinuous and highly variable nature of the shallow groundwater.

For the TNT Areas, groundwater contamination is typically identified from single wells or direct-push groundwater samples. Further delineation sampling will be required to refine the volume estimates presented in this document. However, soil excavation has been completed at TNTB, which provides some indication of the areal extent of the source area soils in the vadose zone. This information, when coupled with the data from the red water ponds, suggests that groundwater contamination at these buildings will be restricted in lateral extent. Further, at the mono, bi-tri, and fortifier houses, contamination in the overburden/shale is associated with the drown tanks. These drown tanks were small, approximately 12 feet in diameter. Investigation results from PBOW RI activities, as well as investigation of similar structures at other TNT manufacturing facilities, indicate that contamination typically will not extend more than approximately 35 feet from these tanks. This was evident for most of these tanks at TNTB, where the excavation volumes of unsaturated zone soils were fairly limited, except for one building (Building 463). The extent of soil contamination at Building 463 was much larger than the others, but was likely influenced by the fact that this tank sat on a large mound, which facilitated lateral movement of contamination away from this building.

A concern at this site for contamination volume estimates is the total depth of contamination. As previously noted, most of the site geology consists of overburden soils up to about 30 feet in thickness which overlie varying thicknesses of shale, which in turn overlies the limestone bedrock. Review of available groundwater data at source area wells (e.g., TNTA-BEDGW001 and TNTB-BEDGW003) suggests that contamination does not migrate a significant amount into the competent shale. However, where the shale is very thin to absent (e.g., the red water ponds), contamination has been sporadically detected in the limestone. The sporadic nature of the detections is interpreted to be the result slow release of the contaminants from the overburden during times of higher precipitation coupled with the reducing nature of the limestone bedrock, which promotes natural degradation of nitroaromatics.

The following depth assumptions have been made in this FS to estimate the volumes of groundwater contamination in the overburden/shale within these areas that have been identified as contaminated:

1. All groundwater (when present) within the saturated overburden layer is assumed to be contaminated.

2. If the combined thickness of the saturated overburden and saturated weathered shale layers is less than 20 feet, all groundwater above the competent shale is assumed to be contaminated.

3. If the thickness of the saturated overburden plus one-half the thickness of the saturated weathered shale layer is less than 20 feet, then groundwater within the combined overburden and weathered shale layers is assumed to be contaminated to a depth of 20 feet below the water table.

4. If the thickness of the saturated overburden plus one-half the thickness of the saturated weathered shale layer is greater than 20 feet, then groundwater (when present) within the saturated weathered shale layer is assumed to be contaminated to a depth of one-half the thickness of the weathered shale layer.

The contaminated areas, shown on Figures 3-1 through 3-5, include both those identified based on protection of bedrock groundwater only (Section 3.6.1) and those that would be required to reduce the concentration of COCs to RGs is presented in Section 3.7.2. Therefore, the statement in the above assumptions, "…assumed to be contaminated" should be interpreted within the respective mitigation/protection objectives described in Sections 3.6.1 and 3.6.2. These depth assumptions were used to estimate the overburden/shale groundwater remediation volumes presented in Sections 3.7.1 and 3.7.1 Examples of the conditions under which the above four assumptions may apply are depicted on Figure 3-8.

Note that only very low concentrations of nitroaromatics have been observed in the limestone bedrock groundwater. This observation suggests that the weathered shale impedes the vertical transport of nitroaromatics (Section 2.7). Therefore, under conditions associated with above assumptions Nos. 3 and 4, it is regarded as appropriately conservative to base FS cost and materials estimates on a volume of contaminations that does not extend to the base of the weathered shale.

A discussion of the estimated volumes of overburden/shale groundwater that may be required for protection of the limestone bedrock groundwater is presented in Section 3.7.1, and those that would be required to reduce the concentration of COCs to RGs are discussed in Section 3.7.2.

The estimated volumes of the two current limestone plumes at the PRRWP Area (Figure 3-6) and the WARWP Area (Figure 3-7) are provide in Section 3.7.3.

3.7.1 Volumes in Overburden/Shale for Protection of the Limestone Bedrock Groundwater

The estimated remediation volumes of overburden/shale that would be required for protection of the limestone bedrock groundwater to meet RGs are provided in Table 3-5. These estimates are based on the areas depicted on Figures 3-1 through 3-5 and the depth-of-contamination approach described in Section 3.7. The volume for each of the areas is as follows:

- TNTA – 2,533,000 gallons
- TNTB – 25,000 gallons
- TNTC – 770,000 gallons
- PRRWP Area – 6,224,000 gallons
- WARWP Area – 13,839,000 gallons.

This equals an overall volume of 23,391,000 gallons. Table 3-6 includes the volumes of the individual building areas within the TNT Areas, as well as the input data used in these calculations.

3.7.2 Volumes in Overburden/Shale for Mitigation/Protection of All Groundwater

The estimated remediation volumes of overburden/shale that would be required for cleanup of the overburden/shale groundwater to drinking water quality are provided in Table 3-6. These estimates are based on the areas depicted on Figures 3-1 through 3-5 and the depth-of-contamination approach described in Section 3.7. The volume for each of the areas is as follows:

- TNTA – 2,833,000 gallons
- TNTB – 242,000 gallons
- TNTC – 1,372,000 gallons
- PRRWP Area – 8,558,000 gallons
- WARWP Area – 25,434,000 gallons.

This equals an overall volume of 38,439,000 gallons, or approximately 64 percent more water than that required for protection of the limestone bedrock groundwater only. Table 3-6 includes the volumes of the individual building areas within the TNT Areas as well as the input data used in these calculations.

3.7.3 Estimated Volumes of Current Limestone Bedrock Plumes

The areal extent of the current 2,4-DNT and 2,6-DNT plume extending northeastward from the PRRWP Area to the vicinity of abandoned well BED-MW27 is approximately 810,000 ft^2. The

average thickness of the contamination within the limestone bedrock groundwater at this location was estimated as 50 feet, which equals a formation volume of 40.5 million ft^3. Based on an effective porosity in the limestone of 0.2, the volume of contaminated groundwater within the PRRWP Area plume is estimated (0.2×40.5 million $ft^3 \times 7.48$ gallons/ft^3) as 61 million gallons.

The current WARWP 2,4-DNT plume thought to extend northeastward from the WARWP Area to the vicinity of well BED-MW14 is approximately 570,000 ft^2 in area. The average thickness of the contamination within the limestone bedrock groundwater at this area was estimated as 53 feet. The formation volume of this plume is thus equal to 30.2 million ft^3. Based on an effective porosity in the limestone of 0.2, the volume of contaminated groundwater within the WARWP Area plume is approximately 45 million gallons.

3.8 Applicable or Relevant and Appropriate Requirements

CERCLA Section 121 requires that on-site remedial actions comply with ARARs at the completion of the remedy. ARARs are defined in CERCLA regulation (40 Code of Federal Regulations [CFR] 300.5) as follows:

- "Applicable requirements" means those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal environmental or state environmental or facility siting laws that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance found at a CERCLA site.

- "Relevant and appropriate requirements" means those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that, while not "applicable" to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well suited to the particular site.

ARARs are identified at various points in the CERCLA cleanup process and are refined as additional information regarding site conditions is made available. When an analysis results in a determination that a requirement is both relevant and appropriate, compliance with that requirement is mandatory to the same extent as for applicable requirements.

This section identifies potential ARARs for five AOCs (TNT Areas A, B, and C and the Pentolite Road and West Area Red Water Ponds), based on the current knowledge of site

conditions. Federal and State of Ohio laws, regulations, guidance, and policy have been reviewed to determine the potential ARARs for these areas. These ARARs have been categorized in terms of location-, chemical-, and action-specific ARARs and are presented in Tables 3-7 and 3-8.

3.8.1 Location-Specific Applicable or Relevant and Appropriate Requirements

Location-specific ARARs constitute those requirements that must be met at a site due solely to its physical location or protected status. Generally, such ARARs are limited to locations afforded special legal protection (e.g., wetlands, historically significant resources, wildlife refuges, and critical species habitat).

Special Areas. National Wetlands Inventory maps of PBOW do not show wetland areas on the installation; however, jurisdictional mapping of wetlands specific to the five AOCs has not been conducted. Based on the observed ecological settings of these areas, while wetland areas may be present on site (although not confirmed by a survey), wetland requirements are not ARARs for the proposed remedial actions at the site. This is due to the fact that remedial actions will not take place within a wetlands area and are not anticipated to impact wetlands at the site.

Of the five AOCs, only the WARWP Area has the potential to be located within the 100-year and 500-year floodplain. The Executive Order governing floodplains has been determined a TBC for remedial actions at the WARWP only. However, proposed remedial actions in this area are not anticipated to impact floodplains.

Biological Resources. The Endangered Species Act and its implementing regulations are not potential ARARs for remedial action at the five AOCs because no known federally threatened or endangered species are found on PBOW. However, Ohio state-protected species regulations are determined potentially applicable to remedial action discussed in this FS, because one state-endangered bird species and one state-threatened plant species are associated with the PBOW. The Sedge wren (*Cistothorus platensis*) is a state-endangered bird species that has been documented in the general area of PBOW. Closed gentian (*Gentiana clausa*) is a state-threatened plant species observed in the western portion of TNTC.

Cultural Resources. Federal and state cultural resource requirements are identified as potential ARARs for the five AOCs at PBOW because the existence of historical and/or archaeological resources in these areas is unknown. The five AOCs have been used for industrial purposes since construction of the PBOW in the 1940s. It is, therefore, reasonable to assume that surface or near-surface archaeological resources would not be found in these areas.

Should archaeological resources or burial grounds/remains be discovered during implementation of remedial action at the site, then work will cease and the proper authorities will be consulted.

3.8.2 Chemical-Specific Applicable or Relevant and Appropriate Requirements

Chemical-specific ARARs are those requirements that are specific to a chemical or group of chemicals (e.g., arsenic, PCBs). These ARARs are concentrations of a chemical that may be found in, or discharged to, the environment. Chemical-specific ARARs typically consist of health- or risk-based values, modified as appropriate to reflect technological limitations of analysis or treatment.

The only chemical-specific ARARs identified for the five AOCs pertain to groundwater. State of Ohio primary drinking water standards are named as potential ARARs for the groundwater at PBOW, since the overburden/shale and bedrock aquifers at PBOW have been discussed as possible potential future sources of drinking water. As stated in section 2.6, based on groundwater productivity in the overburden/shale aquifer and elevated naturally occurring compounds in both the overburden/shale and bedrock aquifer, both of the groundwater units meet the Class III groundwater designation. Therefore, future use of these aquifers as a drinking water source is doubtful.

3.8.3 Action-Specific Applicable or Relevant and Appropriate Requirements

Action-specific ARARs are typically technology- or activity-based requirements or limitations placed on remedial actions. Such requirements are specific to the particular remedial action considered (e.g., excavation, in situ treatment). Action-specific ARARs are detailed in Table 3-8.

Underground Injection Control Regulations. The Ohio underground injection control (UIC) regulations address protection of groundwater from subsurface sources, to include waste disposal wells and other underground injection sources. The underground injection of chemicals/nutrients (e.g., during in situ treatment of groundwater) is regulated by the UIC program. In addition, UIC regulations specifically address the injection of treated groundwater at remediation sites. Thus, State of Ohio UIC regulations identified in Table 3-8 are identified as potential action-specific ARARs for alternatives involving an underground injection activity.

Based on groundwater analytical results representative of the underlying aquifers, groundwater extracted from the PRRWP and WARWP Areas is not expected to meet the definition of hazardous waste. State of Ohio regulations authorize the use of a Class V aquifer remediation well for the injection of nonhazardous fluids as part of a groundwater remediation project.

Air Quality. The use of a groundwater pump-and-treat (P&T) system as proposed in Alternatives 3 and 4 of this FS, will create air emissions. The emissions are anticipated to be temporary and limited to volatile organic emissions generated in the air stripping process. State of Ohio air emissions regulations are identified as ARARs for alternatives that involve use of the groundwater treatment system and result in air emissions. However, based on the estimated levels of air emissions generated by the treatment system, the system will be exempt from complying with any air emissions standards.

Hazardous Waste Management Regulations. The use of a groundwater P&T system, as proposed in Alternatives 3 and 4 of this FS, will result in the generation of solid waste in the form of spent filters, spent carbon, wastewater sludge, and/or filter cake. It is not anticipated that the treatment operation will result in the generation of hazardous waste. However, Ohio hazardous waste regulations are named potential action-specific ARARs and will be applicable to any hazardous waste generated as a result of remedial action.

Institutional Controls. State of Ohio requirements for environmental covenants are deemed ARARs for the remedial action at PBOW that involve land-use controls. The covenant statute identifies the standards for environmental covenants, including the required content, distribution, duration, and termination.

3.8.4 Other Criteria To Be Considered

Nonbinding advisories, criteria, or guidelines (known as TBCs) may be applied in instances where an ARAR does not exist for a particular contaminant or when an ARAR does not adequately address specific site conditions. Because TBCs are generally not promulgated or enforceable, they do not have the same status as ARARs. TBCs should only be considered if they are identified as appropriate based on site circumstances, shown to be protective, and are not superseded by a legally binding ARAR. SMCLs and drinking water health advisories (EPA, 2006) are non-promulgated values that are used as guidance for drinking water quality. The chemical-specific reference doses and cancer slope factors (EPA, 2007) are TBCs that were used with risk assessment methodology to develop site cleanup goals.

4.0 Screening of Remedial Action Technologies

4.1 Introduction

This section discusses the screening of the technologies and process options used to assemble the remedial alternatives for groundwater. The following steps involved in this screening are defined in *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (EPA, 1988):

- Identify volumes or areas of contaminated media to which remedial actions might be applied, taking into account the RAOs and the chemical and physical characteristics of the site (Chapter 3.0).
- Identify and screen technology process options to eliminate those that cannot be implemented at the site (Chapter 4.0).
- Assemble the representative technology process options into alternatives representing a range of treatment and disposal combinations, as appropriate (Chapter 5.0).

4.2 Identification of Groundwater Requiring Remedial Action

The areas and volumes of contaminated groundwater that require remediation are provided in Section 3.7. Groundwater plume maps for the COCs in the limestone bedrock aquifer are presented on Figures 3-6 and 3-7. Estimated areas requiring remediation in the overburden/weathered shale aquifer are presented in Tables 3-5 and 3-6.

4.3 Screening of Technology Process Options

The following sections discuss the technology screening process for groundwater. Table 4-1 summarizes the results of the preliminary screening process options. Technologies potentially applicable to the treatment of COCs in groundwater were screened for effectiveness, implementability, and relative cost. In Chapter 5.0, selected technology options are subsequently assembled into remedial alternatives for groundwater and compared to the no-action alternative.

4.3.1 Long-Term Monitoring

Effectiveness. Long-term monitoring (LTM) of groundwater would be effective in evaluating the performance of remedial technologies for groundwater, periodically assessing the status of groundwater quality across PBOW, and monitoring the migration of contaminants with respect to the property boundary and potential off-site receptors. Groundwater modeling indicates that COCs in limestone bedrock groundwater in the PRRWP Area plume may migrate off site within

150 years. The monitoring well closest to the property boundary within the PRRWP Area plume is contaminated, although the nearest off-site well is not.

Implementability. LTM is technically and administratively implementable at PBOW.

Cost. The relative cost for LTM would be low to moderate. Costs associated with LTM would consist of development of a monitoring program, installation of additional monitoring wells, sampling, analysis, data management, interpretation of results, and report preparation. The number of wells sampled and the frequency of monitoring would likely change over the course of remediation as active treatment was completed or long-term trends in groundwater data became apparent. Although the cost of an individual monitoring event would be relatively low, the life-cycle costs for LTM would be more significant if monitoring was required over a long duration.

Summary. LTM would be a cost-effective component of a remedial alternative if coupled with institutional controls and/or other active remedial technologies. LTM has been retained for inclusion in remedial alternatives in Chapter 5.0.

4.3.2 Monitored Natural Attenuation

Effectiveness. MNA is defined by EPA as the "reliance on natural attenuation processes, within the context of a carefully controlled and monitored site cleanup approach, to achieve site-specific remediation objectives within a time frame that is reasonable compared to that offered by more active methods" (EPA, 1999c). Natural attenuation mechanisms include the following in situ processes: biodegradation; dispersion; dilution; volatilization; sorption; radioactive decay; and chemical or biological stabilization, transformation, or destruction. Natural attenuation processes reduce the potential risk at a site in the following three ways:

- Transformation of contaminants to a less toxic form through destructive processes, such as biodegradation or abiotic transformations
- Reduction of contaminant concentrations whereby potential exposure levels may be reduced
- Reduction of contaminant mobility and bioavailability through sorption onto the soil or rock matrix.

EPA prefers natural attenuation processes that degrade or destroy contaminants (EPA, 1999c).

Three lines of evidence are used to evaluate the potential efficacy of MNA at contaminated sites (EPA, 1999c):

- Historical groundwater or soil chemistry data that demonstrate a clear and meaningful trend of decreasing contaminant mass and/or concentration over time
- Hydrogeologic and geochemical data that can be used to demonstrate indirectly the types of natural attenuation processes active at the site and the rate at which such processes will reduce contaminant concentrations to desired levels
- Data from field or microcosm studies that directly demonstrate the occurrence of a particular natural attenuation process at the site and its ability to degrade COCs.

Although EPA-accepted MNA protocols have been established for some petroleum hydrocarbons and chlorinated solvents, applying MNA to TNT-contaminated sites is challenging for the following reasons (USACE, 1999):

- TNT can undergo a complex array of biological and abiotic degradation, transformation, and immobilization reactions that are dependent on site-specific environmental conditions (e.g., ORP conditions, fraction of clay and organic carbon).
- Some TNT degradation products (e.g., azoxytetranitrotoluene) are more toxic than TNT and can pose health risks if they accumulate in groundwater.
- The most important attenuation mechanism for aminated TNT degradation products is immobilization. Analytical tests for directly measuring immobilized reaction products are currently not available.
- Microbial mineralization is primarily a cometabolic process, with slow reaction kinetics that prevents TNT mineralization products from accumulating in measurable amounts.

Although the groundwater data set collected at the site is suitable for determining the nature and extent of contamination, it is not adequate for a thorough evaluation of the potential effectiveness of MNA. A preliminary assessment of natural attenuation for PBOW groundwater (Appendix B) indicates that the naturally occurring petroleum hydrocarbons and hydrogen sulfide present in the limestone bedrock aquifer could promote the unassisted abiotic and anaerobic biodegradation of nitrate and nitroaromatic compounds. Analytical data indicate that nitroaromatics are detected only sporadically and at low concentrations in the limestone bedrock groundwater. This data, coupled with the strongly reducing conditions present in the limestone bedrock, indicate that natural attenuation is occurring. However, the lack of consistent detections of nitroaromatics

would make evaluation of MNA difficult. The following parameters would be required for an MNA evaluation:

- **Explosives** - TNT, 2-ADNT, 4-ADNT, 2,4-diamino-6-nitrotoluene, 2,6-amino-4-dinitrotoluene, 2,4-DNT, and 2,6-DNT.
- **Natural Attenuation Parameters** - dissolved oxygen, nitrate, ferrous iron, sulfate, sulfide, methane, oxidation reduction potential, total organic carbon, pH, alkalinity, temperature

Implementability. In contrast to natural attenuation of petroleum hydrocarbons and chlorinated solvents, natural attenuation of nitroaromatic compounds is not as well documented. In order for MNA to be accepted as a functional remedial alternative for a site, adequate site-specific evidence must be gathered to document the contribution of intrinsic biodegradation to groundwater restoration. Although USACE has developed a draft protocol for evaluating the effectiveness of MNA at explosives-contaminated sites (USACE, 1999), this protocol has not been endorsed by EPA. Therefore, there are technical and administrative obstacles to the acceptance of MNA as a technology option for groundwater contaminated with nitroaromatic compounds. Nevertheless, a case might be made in the future for including MNA as a component of the remedy for groundwater if adequate data are collected, the technology is coupled with another remedial technology, and its inclusion would lower the overall cost of remedial action.

Cost. The overall relative cost of MNA is expected to be low to moderate, with life-cycle costs depending on the length of the monitoring period. The major cost elements include development of a monitoring program, installation of additional monitoring wells, sampling, analysis, data management, interpretation of results, and report preparation. The early costs for an MNA program are typically greater than for a standard LTM program, because more wells are usually installed and sampled, the analytical program is more extensive, the frequency of sampling might be increased (at least initially), and additional data analysis is required. MNA is only cost-effective if the increased early costs are offset by avoiding or curtailing the scope of more costly active remediation or shortening the duration or frequency of monitoring in the later stages of the remedial period.

Summary. MNA would not be effective as the sole technology for groundwater at PBOW. Although conditions in portions of the limestone bedrock aquifer appear conducive to the natural biodegradation of at least some of the COCs, not enough data have been developed to conclusively support an MNA approach for groundwater, and MNA's cost-effectiveness in

comparison to a more traditional LTM program has not been demonstrated. Nevertheless, MNA has been retained for discussion in Chapter 5.0 as a potential enhancement to a future LTM program.

4.3.3 Groundwater Use Restrictions

Effectiveness. Groundwater use restrictions are an effective method of preventing human exposure to contaminated groundwater as long as they are enforced. Ultimate effectiveness hinges on the implementation of reliable administrative and legal mechanisms to preserve and enforce these restrictions over long periods of time. Groundwater use restrictions are typically most effective when used as an interim action to prevent exposures during the period between the initiation and completion of a remedial action that achieves cleanup objectives, releasing the site from restricted use.

Implementability. Groundwater use restrictions are implementable at PBOW.

Cost. The costs associated with implementing and maintaining groundwater use restrictions are low.

Summary. Groundwater use restrictions can be an effective mechanism to protect human receptors from exposure to contaminated groundwater. This technology option has been retained for inclusion in the development of remedial alternatives in Chapter 5.0.

4.3.4 In Situ Enhanced Bioremediation

In situ enhanced bioremediation (ISEB) involves the injection of a carbon substrate into an aquifer to create anaerobic conditions in the target area and promote biodegradation of COCs.

Effectiveness. Extensive research has been conducted on the biodegradation of nitroaromatic compounds in general and of TNT in particular. This research has demonstrated that TNT is amenable to biological attack by both aerobic and anaerobic organisms. Both types of organisms are reported to effect TNT degradation by reducing the nitro groups on the TNT molecule.

Figure 4-1 presents the various aerobic metabolic degradation pathways that have been proposed for TNT (Esteve-Núñez, et al., 2001). Most of the research conducted to date has demonstrated that microaerophillic bacteria tend to reduce nitro groups on the TNT molecule to hydroxylamino or amino groups. Under aerobic conditions, these derivatives either accumulate without further degradation or oxidatively polymerize to form recalcitrant azoxytetranitrotoluene

(Esteve-Núñez, et al., 2001). Some of these aerobic degradation products are more toxic than the parent TNT molecule. A few studies have suggested that an aerobic metabolic route to TNT mineralization may be reached by transforming TNT to DNT isomers via formation of an intermediate hydride-Meisenheimer complex. This might be a desirable outcome, since 2,4-DNT and 2,6-DNT have been shown to be biodegradable aerobically via dioxygenase attack (Esteve-Núñez, et al., 2001). The research on this metabolic pathway has been inconclusive, however, since some of the studies report the formation of DNT isomers (Duque, et al., 1993; Haïdor and Ramos, 1996; Martin, et al., 1997), while others do not (Vorbeck, et al., 1998; French, et al., 1998; Pak, et al., 2000). The degradation and transformation reactions in this pathway are complex, and reaction products cannot always be identified.

Another very recent study demonstrated denitration and oxidative attack of the aromatic ring structure of TNT by a mixed aerobic microbial community, with the generation of 3-methyl-4,6-dinitrocatechol (Figure 4-2) as one of the reaction products. The generation of this constituent is significant, because formation of a substituted catechol through oxygenation of the aromatic ring is a fundamental microbial strategy for aerobic degradation of aromatic hydrocarbons, as the catechol facilitates further dehydrogenation and hydroxylation reactions that lead to mineralization (Tront and Hughes, 2005). Although this result is promising, additional research is needed to identify the microbes responsible, as the mixed culture used resulted in a slow degradation rate for TNT and mixed reaction products, including the production of ADNT, that are dead-end degradation products.

Figure 4-3 presents the various anaerobic metabolic degradation pathways that have been proposed for TNT (Esteve-Núñez, et al., 2001). The first study to provide evidence for the anaerobic biodegradation potential of TNT used cell suspensions or crude extracts of *Veillonella alkalescens,* with hydrogen as an electron donor. Since then, microorganisms from the *Clostridium* and *Desulfovibrio* genera have been studied extensively to document their ability to anaerobically reduce TNT. A number of studies have demonstrated the anaerobic metabolism of TNT to triaminotoluene (TAT) via reaction intermediates such as hydroxyamino-dinitrotoluenes, ADNTs, and 2,4-diaminonitrotoluene. The reduction of the first nitro group on the TNT molecule occurs more rapidly than the succeeding nitro groups. Complete denitration of TNT to TAT requires an ORP less than minus 200 mV, a condition that exists only in anoxic environments (Esteve-Núñez, et al., 2001). Although TAT appears to be a dead-end reaction product, it is less toxic than the parent TNT compound and is strongly and seemingly irreversibly adsorbed to soil minerals. A significant advantage of anaerobic over aerobic microbial processes is that anaerobic degradation of TNT does not result in the formation of the toxic azoxy compounds that readily form in the presence of oxygen (Zhang and Bennett, 2005). Researchers

have also determined that at least one species of *Pseudomonas* can use TNT as a electron acceptor under anoxic conditions to drive the synthesis of adenosine triphosphate via oxidative phosphorylation (Esteve-Núñez, et al., 2000).

ISEB of nitroaromatics-contaminated groundwater by cometabolic reduction under anaerobic conditions is a potential process option to achieve RGs in the overburden/weathered shale aquifer. The complete reduction of TNT and other nitroaromatics requires the addition of an electron-donating substrate such as Hydrogen Release Compound®, lactate, or emulsified vegetable oil.

An additional benefit to ISEB is that it will leave the treated areas in an anaerobic condition that will likely promote degradation of residual nitroaromatic contamination through natural attenuation processes.

Implementability. The use of ISEB at PBOW would be more implementable in the overburden and weathered shale because direct-push injection technology can be cost-effectively used to deliver chemicals. Groundwater recirculation could also be used as a vehicle to deliver carbon substrate to the contaminated groundwater by extracting groundwater from the downgradient edge of a plume and metering the substrate to the water before it is reinjected at the upgradient edge of the plume. Injection systems of this type employ permanent small-diameter injection wells.

Treatment with ISEB in the unweathered shale and limestone bedrock aquifers is more difficult and less cost-effective. Direct-push injection technology cannot be used in either of these zones. The low porosity and hydraulic conductivity of the unweathered shale make it difficult to deliver chemical reagents effectively. Flow in the limestone is dominated by preferential pathways through fractures and solution cavities that make it difficult to predict where injected chemicals will go and measure the effects of treatment. COC concentrations in the limestone bedrock aquifer are relatively low (i.e., typically less than 20 µg/L), making it a low-grade target for ISEB, as the cost per pound of contaminant removed would be high. DNTs are the predominant COCs in the limestone bedrock aquifer. These constituents are more effectively degraded under aerobic conditions, although they do degrade cometabolically under anaerobic conditions. The target areas of the limestone are already anaerobic, and some of these areas are contaminated with naturally occurring petroleum hydrocarbons which could promote the natural biodegradation of some of the nitroaromatic COCs without intervention by injection of an additional carbon source (Appendix B).

A number of alternate carbon sources are available for use in ISEB, such as lactate, molasses, Hydrogen Release Compound, and emulsified vegetable oil. Each substrate has advantages and disadvantages and suitability is dependent upon site conditions, remedial objectives and strategy, and method of delivery.

The cost-effectiveness of ISEB is dependent on the concentration of competing electron acceptors (e.g., dissolved oxygen, ferrous iron, sulfate, and nitrate) that utilize the injected carbon substrate without any attending reduction in contaminant concentrations. Areas with high concentrations of competing electron acceptors may be costly to remediate.

Implementation of ISEB is not limited by the availability of adequate materials or technical expertise. Reagent suppliers and remediation contractors with experience injecting the materials are readily available. A pilot-scale treatment study prior to full-scale implementation is recommended, as it would facilitate optimization of the injection design parameters.

Cost. The cost associated with ISEB is expected to be moderate to high, depending on the size of the plumes to be treated and the concentration of competing electron acceptors. The capital costs would include injecting a carbon substrate into the target aquifer to be followed by monitoring. Operation and maintenance (O&M) costs associated with monitoring and reporting would be incurred until treatment goals were achieved.

Summary. ISEB is a potentially effective technology to treat COCs in the overburden and weathered shale aquifer. Therefore, the technology has been retained for inclusion in the development of remedial alternatives in Chapter 5.0.

4.3.5 Apatite II

This technology involves the use of a fishbone-based nutrient source known as Apatite II™ to enhance the biodegradation of TNT-contaminated groundwater.

Effectiveness. Apatite II is a natural phosphate mineral derived from fish bones. It was developed by PIMS NW, Inc. as a reagent to chemically stabilize in situ and ex situ a wide range of metals (especially lead, uranium, plutonium, zinc, and cadmium) in soil and groundwater (PIMS NW, Inc., 2006). Recent research at New Mexico State University (Martinez, et al., 2005) has tested the effect of Apatite II on the biodegradation of TNT. Apatite II is postulated to enhance the biodegradation of organic pollutants such as TNT by both acting as a nutrient and sequestering toxic trace metals that might inhibit the beneficial action of TNT-degrading microorganisms (Martinez, et al., 2005).

The study tested TNT removal efficiencies in flow-through column experiments using a TNT-degrading fungal strain, Apatite II, and a combination of the fungus and Apatite II. Four glass columns were prepared, two with 50 cubic centimeters of soil and two with 25 cubic centimeters each of soil and Apatite II. For five months, the columns were supplied 10 mg/L of TNT in water, after which two of the columns were inoculated with a TNT-degrading fungus. Tests run treating aqueous solutions of 10 mg/L of TNT demonstrated average TNT removal efficiencies of 55 percent for soil + fungi (no Apatite II), 73 percent for soil + Apatite II (no fungi) and 92 percent for soil + Apatite II + fungi, although 43 percent of the TNT was removed from the control sample (soil only).

Implementability. The application of Apatite II to TNT-contaminated groundwater is limited to the one laboratory study previously described. Additional research is needed to develop it into a full-scale remediation technology. For the treatment of groundwater, the technology would have to be coupled to a bioremediation technology to be effective. Apatite II would not be a viable stand-alone technology for the treatment of TNT-contaminated groundwater or the other PBOW limestone bedrock groundwater COCs.

Cost. Inadequate data are available about the technology to characterize full-scale remediation costs.

Summary. Although Apatite II may be a useful enhancement for technologies that use biodegradation to remove TNT from soil and groundwater, the technology is not developed enough to recommend it for a full-scale application. Therefore, Apatite II will not be retained for the development of remedial alternatives in Chapter 5.0.

4.3.6 In Situ Chemical Oxidation

In situ chemical oxidation (ISCO) involves the injection of a chemical oxidant (e.g., hydrogen peroxide, potassium permanganate, ozone) into an aquifer to chemically oxidize COCs into less toxic or nontoxic reaction products.

Effectiveness. ISCO is a potentially effective technology for the destruction of nitroaromatic compounds in groundwater, although it does not appear to be widely used for this purpose. Most of the available literature on the application of chemical oxidants for environmental remediation focus on their use in the treatment of chlorinated aliphatic hydrocarbons, such as tetrachloroethene and trichloroethene. A recent study comparing the kinetics of contaminant degradation for various contaminants with potassium permanganate showed that the second

order rate constant for TNT oxidation with permanganate (0.16 $M^{-1}s^{-1}$) is approximately 4 to 5 times lower than for trichloroethene (0.76 $M^{-1}s^{-1}$). The reduced popularity of ISCO for treatment of nitroaromatic compounds is likely due to its typically lower cost-effectiveness when compared to ISEB. This is because the unit cost of chemical reagents is higher for ISCO than for ISEB.

Implementability. ISCO is typically applied by injecting the oxidant via direct injection technology. ISCO implementation costs are highly dependant upon the natural oxidant demand of the soil within the target zone, commonly called soil oxidant demand (SOD). A high SOD means that ISCO would be costly to implement, while a low SOD means that it may be cost-effective. No SOD data are available for saturated soil at PBOW, so it is difficult to evaluate its potential cost-effectiveness at the site. ISCO would not be appropriate for treatment of portions of the limestone bedrock aquifer where high concentrations of petroleum hydrocarbons occur naturally. A potential disadvantage in the use of ISCO for PBOW groundwater is that it would leave the treated areas of the aquifer in an aerobic state. This condition would not promote the optimum biodegradation processes that cause nitroaromatic compounds to attenuate naturally.

Cost. The cost of treating groundwater using ISCO would be moderate to high, depending on the size of the areas to be treated and the SOD of the target remediation zones.

Summary. Although ISCO treatment of contaminated groundwater is potentially technically feasible, no SOD data are available for saturated soil at PBOW to estimate chemical demand. Therefore, the cost-effectiveness of ISCO cannot be adequately evaluated. Additionally, ISCO implementation costs are typically higher than those for ISEB. ISCO would also leave the treated groundwater in an aerobic condition that would inhibit the natural attenuation processes for nitroaromatic compounds that lead to nontoxic end products (see discussion of aerobic and anaerobic pathways in Section 4.3.6). Therefore, this option has not been retained for inclusion in the development of remedial alternatives in Chapter 5.0.

4.3.7 In Situ Chemical Reduction

Effectiveness. In situ chemical reduction of nitroaromatics in groundwater is a potentially feasible technology. Laboratory studies have demonstrated the successful abiotic reduction of nitroaromatic compounds by zero-valent iron (ZVI). In aqueous solution, ZVI is oxidized to ferrous iron providing electrons for reduction of nitroaromatics (Choe, et al., 2001):

$$Fe^0 \rightarrow Fe^{2+} + 2e^-$$

$$ArNO2 + 6H^+ + 6e^- \rightarrow ArNH_2 + 2H_2O$$

The reduction of nitrobenzene to aniline under reducing conditions using ZVI has been demonstrated in a number of studies (Agrawal and Tratnyek, 1994). Although the end products of nitro reduction using ZVI are aryl-amines, these compounds are subject to additional reactions in the environment, such as covalent binding to natural organic matter and adsorption onto mineral surfaces. In practice, the reaction rate of ZVI corrosion can be affected by common solutes in groundwater systems, such as carbonate. Bicarbonate will oxidize ZVI, and the resulting carbonate precipitate can form a protective layer on the metal surface, as it frequently does in water distribution systems. Laboratory studies have demonstrated a decrease in the observed rate of nitro reduction when the reaction was run in a bicarbonate buffer solution (Agrawal, et al., 1995).

Another strong reducing agent that has been used for in situ reduction of oxidized metals is sodium dithionite (chemical formula: $Na_2S_2O_4$). In groundwater, sodium dithionite may activate naturally existing iron species to a more reactive (reduced) form, resulting in the formation of a reactive zone. Similar to a ZVI application, the reduced iron may facilitate the abiotic reduction of nitroaromatics present in groundwater. Possible byproducts of the reaction are aminotoluenes.

Implementability. The use of chemical reduction at PBOW would be more implementable in the overburden and weathered shale because of the shallow depths and unconsolidated nature of the material. Further, while the overburden groundwater tends to be higher in dissolved oxygen, the deeper competent shale and limestone groundwater is strongly reducing due to the present of naturally-occurring petroleum making treatment of these zones unnecessary.

The abiotic reduction of nitroaromatic compounds using ZVI can be implemented in a couple of ways. One involves the construction of a permeable reactive wall of ZVI through which contaminated groundwater would flow. Such systems have been constructed for the purpose of remediating chlorinated ethenes and nitroaromatic compounds. The technology may be applied as a single reactive barrier to contain the spread of contaminated groundwater at the downgradient edge of a plume or it may be constructed as multiple, parallel walls to treat an entire plume.

Another way to apply ZVI technology is to inject an aqueous suspension of microscale or nanoscale ZVI particles into contaminated groundwater. These particles are very reactive due to their small size and large surface area. Although a promising innovation of ZVI technology, microscale and nanoscale ZVI particles are still in the developmental stage.

Sodium dithionite is applied as an in situ chemical reduction technology by injecting a solution of the chemical into the contaminated groundwater. Sodium dithionite reduction of nitroaromatics has not been applied at the field scale.

Cost. The cost of implementing ZVI as a reactive barrier wall is expected to be high in most applications, because significant excavation and reagent usage is required for its construction. Not enough information is available to adequately assess the cost of implementing either microscale or nanoscale ZVI or sodium dithionate.

Summary. ZVI as a barrier technology would be costly to implement at PBOW. In situ chemical reduction using microscale or nanoscale ZVI or sodium dithionate are developing technologies. Inadequate information is available to evaluate their potential cost-effectiveness. Therefore, this technology has not been retained for the development of remedial alternatives in Chapter 5.0.

4.3.8 Ex Situ Biological Treatment

Effectiveness. Ex situ biological treatment is a potentially effective technology to treat COCs in extracted groundwater. Nitrate can be denitrified to nitrogen gas under anoxic conditions. Nitroaromatic compounds may be either degraded anaerobically or aerobically, depending upon the particular constituent. TNT is most effectively degraded anaerobically, while DNTs are most effectively degraded under aerobic conditions. Biological treatment can also be used to reduce total organic carbon (TOC) by degrading other organic compounds (e.g., petroleum hydrocarbons) that may be in groundwater.

Implementability. Fluidized bed reactors are often used for small groundwater streams. Activated carbon is usually used as the fluidized media that supports the growth of microorganisms on its surface.

Cost. The cost of ex situ biological treatment is expected to be moderate to high.

Summary. The technology is technically feasible and will be retained for the development of remedial alternatives in Chapter 5.0.

4.3.9 Phytoremediation (Constructed Wetlands)

Effectiveness. Phytoremediation is not a well-developed technology for the treatment of groundwater contaminated with nitroaromatic compounds. Phytoremediation utilizes plants in treating groundwater contaminated with TNT and other nitroaromatics. Some limited success was demonstrated with the use of constructed wetlands to treat nitroaromatic-contaminated groundwater during a field demonstration at Milan Army Ammunition Plant (near Milan, Tennessee), but the effectiveness of the system dropped off in the winter months due to reduced microbial activity at the colder temperatures. This would be an even larger challenge for a system at PBOW which, because of its more northern latitude, experiences lower temperatures.

Implementability. Phytoremediation would be implementable at PBOW, because adequate space exists to construct wetland areas.

Cost. The cost of phytoremediation would be moderate to high, depending on the volume of extracted groundwater that would require treatment and the treatment area required to provide adequate residence time in the system to achieve discharge criteria.

Summary. Phytoremediation has yet to be proven a highly effective treatment process for nitroaromatic-contaminated groundwater. Therefore, this technology is not retained for inclusion in the remedial alternatives in Chapter 5.0.

4.3.10 Air Stripping

Effectiveness. Air stripping is a very effective technology for removing VOCs such as BTEX from groundwater. It can also be used to strip H_2S and precipitate reduced iron from anaerobic groundwater by air oxidation.

Implementability. The technology is easy to implement. A diffused aeration tank design would be recommended for groundwater treatment applications at PBOW due to the high concentrations of iron and other suspended solids in groundwater. The equipment may require periodic cleaning to remove calcium carbonate scale or biological growth.

Cost. The cost of air stripping is expected to be low to moderate.

Summary. Air stripping is a very cost-effective technology to remove VOCs from extracted groundwater. It will be retained for the development of remedial technologies in Chapter 5.0.

4.3.11 Granular-Activated Carbon

Effectiveness. Carbon adsorption using granular-activated carbon (GAC) is an effective and proven process technology for treating water contaminated with low concentrations (less than 20,000 µg/L) of nitroaromatic explosives (Hayes and Arthur, 2004). As the contaminated groundwater is passed through one or more beds of GAC, the nitroaromatic contaminants are adsorbed on the surface of the GAC. Periodically, the GAC becomes saturated with contaminants to the extent that the effluent groundwater no longer meets discharge limits, and the spent GAC is removed and replaced with fresh adsorbent. GAC systems are typically operated with two or more beds in series, positioned in a rotating lead-lag configuration. When the GAC is spent in the lead vessel, the valves around the vessels are repositioned to place the lag vessel into the lead position, and the GAC is replaced in the spent vessel.

Implementability. GAC systems are easy to operate and require minimal attention. The GAC in the lead carbon vessel is replaced with fresh carbon when the concentration of organic COC in wastewater entering the lead vessel and between the lead and lag vessel are equivalent or nearly so. This means that the carbon in the lead vessel is saturated with organic contaminants and must be replaced. Therefore, periodic wastewater sampling and replacement of spent carbon are the primary operating requirements. The influent wastewater to a GAC system may require pretreatment to remove gross organic contamination or suspended solids. High concentrations of organic compounds will quickly exhaust the adsorption capacity of the carbon. The carbon bed will act as a media filter if suspended solids have not been previously removed in the treatment process. These solids will plug the carbon bed, reducing flow through the unit and lowering its adsorption capacity for organic compounds.

Cost. The capital and operating costs associated with a properly designed GAC treatment system are considered to be moderate.

Summary. Carbon adsorption is a well-developed and cost-effective technology for treating low concentrations of nitroaromatic compounds. It would also serve as a polishing treatment to remove low concentrations of other nonpolar hydrocarbons (e.g., BTEX) after primary treatment. Therefore, this technology has been retained for inclusion in the development of remedial alternatives in Chapter 5.0.

4.3.12 Suspended Solids Removal

Effectiveness. Larger suspended particles can be removed from groundwater via sedimentation or filtration. Sedimentation is typically used to remove high concentrations of suspended solids. Solid particles settle in a quiescent zone of the equipment. A parallel-plate clarifier is appropriate for the flow rates encountered in most groundwater treatment systems. Larger flow applications require circular clarifiers.

Media filters are vessels filled with one or more types of granular media that filter out large particles. The filters are periodically backwashed to removed entrapped solids. Bag or cartridge filters are often used to filter flow streams with low particulate loading or as a polishing filtration step following sedimentation or media filtration.

Implementability. The above technologies are easy to implement and well developed. The settled solids from sedimentation or media filtration must usually be dewatered prior to disposal.

Cost. The capital and operating costs of suspended solids removal equipment is typically moderate.

Summary. The above technologies are very cost-effective at removing suspended solids from extracted groundwater. Therefore, the technology will be retained for the development of remedial alternatives in Chapter 5.0.

4.3.13 Groundwater Extraction

Effectiveness. Groundwater modeling indicates that extraction is a potentially feasible process option to remove and contain groundwater contaminants within the two limestone bedrock plumes at PBOW. The modeling indicates that adequate hydraulic containment in the WARWP Area and PRRWP Area plumes could be achieved with as few as three and five recovery wells, respectively (Appendix A). However, the modeling also indicates that the extraction wells would have to be operated for at least 150 years, because the model predicts that contaminants will continue to source the limestone bedrock aquifer from the overlying strata.

The effectiveness of groundwater extraction is ultimately dependent on the ability to treat and discharge the extracted groundwater. Evaluations of ex situ treatment technologies and discharge options are presented in subsequent sections.

While groundwater extraction from the bedrock aquifer may be effective, this technology will not be effective in the overburden/shale due to the intermittent nature of overburden/shale groundwater, smaller grain size, and higher organic content of the aquifer material. The discontinuous nature of the overburden/shale suggests that little to no groundwater may be present at some source areas throughout much of the year. This discontinuous nature would allow for groundwater extraction intermittently, resulting in an unreasonably long time period required to achieve RGs. In addition, the overburden/shale contains more organic material than does the bedrock, resulting in stronger sorption of contaminants and a longer time period to remove the contaminant mass.

Implementability. Groundwater extraction is technically and administratively implementable within the WARWP Area and PRRWP Area plumes of the limestone bedrock aquifer. Based on previous wells installed into the limestone bedrock, hydrogen sulfide can expect to be encountered leading to nuisance odors and well degradation. Nuisance hydrogen sulfide odor would have to be managed in a fashion to prevent public complaints, particularly for wells installed near the facility boundary. Consideration would also be given to constructing bedrock wells with materials that would withstand the degradation caused by an acidic (hydrogen sulfide) environment.

Cost. The cost of constructing the eight vertical groundwater extraction wells needed to contain groundwater within the WARWP Area and PRRWP Area plumes is low. The annual operating cost for the groundwater extraction system would be low. The present value cost of groundwater extraction would be moderate due to the extended period of operation predicted by the modeling.

Summary. Groundwater extraction is a potentially feasible technology to remove and contain contaminants in limestone bedrock groundwater. Only a few wells would be required to attain hydraulic containment. Therefore, groundwater extraction using vertical extraction wells has been retained for inclusion in the remedial alternatives in Chapter 5.0.

4.3.14 Disposal Options for Extracted Groundwater

Any remedial alternative that uses groundwater extraction as a component must be coupled with a disposal technology. This section evaluates four potential options for disposal of treated groundwater:

- Reinjection
- Direct discharge to surface water
- Discharge to an existing NASA wastewater treatment plant (WWTP) on PBOW
- Discharge to a publicly owned treatment works (POTW).

Each of these options is discussed in the following sections.

4.3.14.1 Reinjection

Effectiveness. Reinjection would be an effective disposal process for extracted groundwater from PBOW, provided the water can be cost-effectively treated prior to injection.

For both groundwater treatment systems, the treated water could be pumped to reinjection wells for disposal back into the limestone bedrock aquifer, upgradient of contamination. Provided the recovery/reinjection well network was properly designed to achieve hydraulic control, this would flush contaminants toward recovery wells and accelerate the removal of COCs. This is often considered an enhancement in a groundwater cleanup strategy, but in this case it would also mobilize naturally occurring petroleum hydrocarbons, which are not the focus of remediation. A second major disadvantage of this approach is that aerated water from the treatment processes is being reintroduced into an anaerobic aquifer. The resulting changes in ORP conditions could have significant and unintended adverse consequences.

A second and perhaps better reinjection strategy would be to reinject effluent from the groundwater treatment systems into areas of overburden groundwater that are under aerobic conditions, as long as reinjection wells are not placed so that they accelerate the lateral or vertical movement of contamination. This is sometimes accomplished by reinjecting the treated water downgradient of the plume. The optimal placement of reinjection wells at PBOW would require additional groundwater modeling and perhaps further characterization of potential reinjection areas.

Implementability. The extracted groundwater would require treatment prior to reinjection and constituents would fall into one of the following three categories as a basis for treatment:

- COCs in groundwater present at concentrations greater than the RG
- Contaminants (site related or naturally occurring) that are present at concentrations above the drinking water standards (MCLs)
- Constituents that could cause operational problems either in downstream treatment operations or in the reinjection system.

At a minimum, the following chemical constituents in extracted limestone bedrock groundwater from the WARWP Area would require treatment prior to reinjection:

- 4,6-Dinitro-2-methylphenol
- 2,4-DNT
- 3-Nitroaniline
- Nitrobenzene
- Nitrate
- TOC
- Total suspended solids (TSS).

Extracted groundwater from the WARWP Area must be treated for nitrate and the four nitroaromatic compounds listed above because they are COCs that have been detected in the groundwater. The TOC concentration in groundwater (160 to 937 mg/L in BED-MW14) most likely results from the presence of natural petroleum hydrocarbons. High levels of TOC may stimulate the growth of microorganisms in the reinjection area. Therefore, TOC should be reduced to minimize fouling problems. TSS in BED-MW14 ranges from 11 to 54 mg/L. The TSS concentration in extracted groundwater should be reduced prior to reinjection so that accelerated plugging of the reinjection wells and the surrounding formation is prevented.

An anoxic bioreactor would be required to denitrify the nitrate to nitrogen gas. The anoxic bioreactor may also partially reduce some of the nitroaromatic compounds. The low concentrations of nitroaromatic compounds present in the WARWP Area limestone groundwater would typically be treated by carbon adsorption, but the high concentrations of TOC make this impractical without pretreatment. Since the high concentrations of TOC need to be reduced to minimize fouling of the reinjection system anyway, an aerobic bioreactor would be used to remove TOC and also further reduce the concentrations of nitroaromatic compounds, as biological treatment for dinitrotoluenes is most effective under aerobic conditions (Nishino and Spain, 2001). Sequential anoxic/aerobic biological treatment may obviate the need for downstream carbon adsorption to remove nitroaromatic compounds. Primary TSS removal would be achieved by sedimentation (clarifier) or filtration (e.g., media filter). Secondary TSS removal (e.g., bag or cartridge filtration) may be required after the clarifier or media filter. The sludge generated by the primary TSS removal process would require dewatering (e.g., filter press) to make it suitable for disposal.

At a minimum, the following chemical constituents in extracted limestone bedrock groundwater from the PRRWP Area would require treatment prior to reinjection:

- 2,4-DNT
- 2,6-DNT
- Benzene
- Iron
- TSS.

Extracted groundwater from the PRRWP Area would be treated for the two listed DNTs because they are COCs that have been detected in the groundwater. Benzene would be treated because it has been detected (60 to 130 µg/L) above the Ohio drinking water standard, even though it is a naturally occurring chemical and its presence is unrelated to TNT manufacturing operations. TSS in BED-MW27 ranges from 65 to 499 mg/L. The TSS concentration in extracted groundwater must be reduced prior to reinjection so that accelerated plugging of the reinjection wells and the surrounding formation is prevented. The concentration of iron in BED-MW27 groundwater ranges from 31 to 257 mg/L. The anaerobic groundwater in the PRRWP Area may become oxygenated during extraction and treatment processes. The change in ORP conditions can oxidize the more soluble ferrous iron to insoluble ferric iron. Iron particles can plug the reinjection zone and stimulate the growth of iron-reducing bacteria that aggravate fouling problems. Therefore, the concentration of iron in extracted groundwater should also be reduced prior to reinjection.

An air stripper would remove benzene (and other VOCs) from the water and oxidize iron in the influent. The air stripper would also strip H_2S from the groundwater if present. Air pollution controls may be required to attenuate VOC or H_2S emissions from the air stripper. Such measures might add substantially to remediation costs. Primary TSS removal would be achieved by sedimentation (clarifier) or filtration (e.g., media filter). Secondary TSS removal (e.g., bag or cartridge filtration) may be required after the clarifier or media filter. The sludge generated by the primary TSS removal process would require dewatering (e.g., filter press) to make it suitable for disposal. A carbon adsoption system using GAC would effectively remove the low concentrations of nitroaromatic COCs as well as adsorbable TOC in the groundwater influent. The much lower TOC concentrations (2.6 to 3.7 mg/L) in the PRRWP Area limestone bedrock groundwater make carbon adsorption a cost-effective choice.

Although there are significant capital and operating costs associated with treatment of extracted groundwater to make it suitable for reinjection, the costs should compare favorably to those required to treat groundwater for direct discharge to surface water.

Cost. The costs for disposal of extracted groundwater by reinjection are considered to be moderate. Reinjection wells would require periodic cleaning and perhaps even replacement.

Summary. Reinjection is judged to be the most cost-effective disposal option for groundwater extracted from the limestone bedrock aquifer in the WARWP and PRRWP Areas. There is no identified access to a POTW, and the high treatment costs associated with a surface water discharge make it impractical, but reinjection will be retained for inclusion in the remedial alternatives developed in Chapter 5.0.

4.3.14.2 Surface Water Discharge

Effectiveness. As described in the previous section, all treated wastewater from NASA facilities on site is discharged to surface water. Numerous creeks and drainage channels are present across PBOW, so discharge to surface water should be a readily available option for treated limestone bedrock groundwater, provided the water can be cost-effectively treated to meet discharge requirements. Pipe Creek is located east of the WARWP Area plume and an unnamed creek is located south of the PRRWP Area plume. Discharges to surface water would require an NPDES permit from the OEPA.

Implementability. Table 4-2 presents a comparison of potential surface water criteria for constituents in the limestone bedrock groundwater that are subject to regulation under the Ohio Water Pollution Control Act. The table presents statewide, Sandusky River, and Lake Erie drainage basin surface water criteria, which are all applicable to surface discharges within PBOW. The most stringent value from all three columns is selected as the appropriate surface water criteria for each chemical constituent on the table. Tables 4-3 and 4-4 compare the selected surface water criteria identified in Table 4-2 to chemical concentrations detected within the WARWP Area (well BED-MW14) and PRRWP Area (well BED-MW27) plumes, respectively. Chemicals that have been detected at a maximum concentration above the selected surface water criteria are highlighted in the table, although the average concentration of a highlighted chemical may be below the surface water criteria. In determining if the average groundwater concentration is the appropriate value to characterize water quality for each constituent, it is important to consider the sampling techniques used to collect the samples (e.g., low-flow sampling data more reliable than grab sample data for metals) and the temporal trend in the data (i.e., higher significance to increasing trend). Based on the data presented in Table 4-3, the WARWP Area limestone bedrock groundwater would require treatment for the following chemical constituents prior to surface water discharge:

- TDS
- Cobalt

- Copper
- Nickel
- Selenium.

Copper and nickel are both amenable to treatment using conventional technologies such as alkaline precipitation (with calcium or magnesium hydroxide), coagulation with polymer addition, or flocculation, followed by removal of suspended solids by clarification and/or filtration. Cobalt and selenium are more unusual or difficult to remove, but they may coprecipitate with the other metals.

The most costly constituent to treat on the above list is TDS. Dissolved solids are removed by reverse osmosis (RO) or evaporation. RO is a membrane separation process that uses elevated pressures to generate a low TDS permeate from the influent. The dissolved solids are retained in a lower-volume reject stream, and this high TDS reject stream is typically 10 to 20 percent of the influent flow. The reject must be further treated, as it is not acceptable for discharge. The reject may be evaporated and the residual salt cake disposed of as a nonhazardous solid waste. Alternatively, the entire groundwater stream may be evaporated without pretreatment using RO, but a larger volume of water must be evaporated.

Either of these technologies would require pretreatment to remove organic compounds in the groundwater (160,000 to 937,000 µg/L TOC in WARWP Area) to prevent fouling of process equipment. The efficient operation of an RO system typically requires the influent water to be pretreated by microfiltration and/or nanofiltration to extend the useful life of RO membranes to a cost-effective duration. Both technologies involve high capital and operating costs that are generally considered unacceptable for a groundwater treatment application. Replacement of membranes (RO and upstream membrane separation technologies) is a significant operating cost for RO systems, and evaporators have intensive energy requirements.

Based on the data presented in Table 4-4, the PRRWP Area limestone bedrock groundwater would require treatment for the following chemical constituents prior to surface water discharge:

- TDS
- Iron
- Benzene
- Ethylbenzene
- Toluene
- Xylene.

Benzene, ethylbenzene, toluene, and xylenes are easily removed by air stripping. Aeration of the water would also oxidize dissolved ferrous iron to less soluble ferric hydroxide. The iron hydroxide precipitate would require removal by coagulation with polymer addition, flocculation, clarification, and/or filtration. As previously discussed for treatment of the WARWP Area limestone bedrock groundwater, TDS removal is problematic and costly.

Cost. The capital cost for construction of a surface water piping system from either the WARWP Area or PRRWP Area plumes would be low, but the pretreatment costs associated with effluent water quality compliance would be high.

Summary. Although suitable surface water bodies such as creeks and drainage channels are located reasonably near areas of contaminated limestone bedrock groundwater, the requirement to remove TDS from extracted WARWP Area and PRRWP Area groundwater prior to discharge makes surface water discharge impractical to implement. Therefore, this technology is not retained for inclusion in the remedial alternatives developed in Chapter 5.0.

4.3.14.3 Discharge to Existing NASA WWTP

Effectiveness. Discharge to an existing NASA WWTP would be similar in nature to a POTW discharge. NASA has a number of NPDES-permitted outfalls on site, and some of these outfalls presumably involve upstream wastewater treatment processes. For example, NASA's Space Power Facility WWTP discharges effluent through Outfall 2IO00002005. This WWTP apparently treats sanitary wastewater based on the effluent limits listed in the permit and may be capable of removing biodegradable organic contaminants. This may be a possible discharge point for extracted limestone bedrock groundwater if it has sufficient unused hydraulic and treatment capacity and if the addition of the groundwater stream to its influent would not cause a violation of any NPDES permit conditions. Some pretreatment of the extracted groundwater would likely be required prior to discharge to a NASA WWTP to remove constituents that would pass through untreated and cause a violation of its discharge permit.

Implementability. The feasibility of discharging extracted groundwater to a NASA WWTP cannot be evaluated at this time, because adequate information is not available about the design and operation of these plants. However, the practicality of this disposal option may warrant further investigation.

Cost. An assessment of the cost of this disposal option is not possible at this time.

Summary. There is insufficient information at this time to complete a thorough evaluation of this disposal option, so this technology is not retained for inclusion in the remedial alternatives developed in Chapter 5.0. However, additional investigation of this disposal option may be warranted if more information becomes available.

4.3.14.4 POTW Discharge

Effectiveness. Discharge to a POTW might be a cost-effective disposal option, given the composition of limestone bedrock groundwater within the WARWP and PRRWP Areas (particularly the WARWP Area plume) and provided that access to a POTW is readily available. The bedrock aquifer is contaminated with naturally occurring petroleum hydrocarbons (160,000 to 937,000 µg/L TOC in WARWP Area bedrock groundwater) that do not result from TNT manufacturing operations. Nevertheless, once contaminated groundwater is extracted from the subsurface, it must be treated for any chemical constituents that are subject to regulation, irrespective of their origin. POTWs typically receive sanitary wastewater and use aerobic biological treatment processes (e.g., aeration basins or lagoons) as a secondary treatment technology to remove biologically degradable organic matter. A primary advantage of POTW disposal is that the secondary treatment process of the POTW would treat biodegradable organic contaminants in the extracted groundwater, potentially obviating the need for this type of treatment as part of the PBOW groundwater treatment systems. Some pretreatment of extracted groundwater would likely be required prior to POTW discharge to remove constituents that would pass through the POTW untreated and cause a violation of its discharge permit. For example, pretreatment of metals is a typical requirement.

Implementability. All effluent streams from on-site NASA facilities discharge to surface water, so there is apparently no entry point into a POTW sewer conveyance within the property boundaries. However, sludge from NASA's Space Power Facility WWTP is transferred (presumably trucked) to a local POTW for treatment and/or disposal. The feasibility of piping extracted groundwater from PBOW to a local POTW may warrant further consideration.

Cost. A discharger is charged on a volumetric basis for disposal of wastewater at a POTW, and these costs are typically low to moderate depending upon the volume of wastewater. As there is no access to a POTW currently on site and no local POTW identified as a potential discharge location, an assessment of the cost to build and operate pump stations and piping systems to convey extracted groundwater to a POTW is not possible at this time.

Summary. There is no access to a POTW currently on site and no local POTW identified as a potential discharge location, so this technology is not retained for inclusion in the remedial alternatives developed in Chapter 5.0. However, additional consideration of this disposal option may be warranted if a POTW is identified within close proximity to PBOW.

5.0 Development and Detailed Analysis of Remedial Alternatives for Groundwater

The goal of this chapter is to introduce, assess, and communicate the relative costs, benefits, and limitations of the remedial alternatives for groundwater selected for detailed analysis. Evaluation criteria for the detailed analysis of remedial alternatives are described by EPA in *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (EPA, 1988). These are the nine evaluation criteria included in the NCP, Title 40 CFR, Part 300.430 (EPA, 1990). The results of the detailed analysis of remedial alternatives for groundwater will be presented in the proposed plan, decision document (DD), and other public information documents following the consideration of OEPA and community input. The comparison of remedial alternatives is presented in Chapter 6.0.

The nine evaluation criteria include the two threshold criteria, five primary balancing criteria, and two modifying criteria. These criteria cover regulatory, technical, cost, institutional, and community considerations. Generally, the two threshold criteria are as follows:

- Protection of human health and the environment
- Compliance with ARARs.

The five balancing criteria are as follows:

- Long-term effectiveness and permanence
- Short-term effectiveness
- Reduction in toxicity, mobility, and volume
- Technical and administrative implementability
- Alternative cost, including capital, O&M, and present value costs.

The final two criteria are the modifying criteria. These two criteria often are evaluated after the initial publication of the FS, and are as follows:

- State acceptance
- Community acceptance.

The first seven criteria will be evaluated in this FS. The two modifying criteria will be evaluated through working-level discussions with OEPA, as well as through the solicitation of community input from public outreach activities. These activities include publication of a proposed plan and presentation of the proposed plan at a public meeting. The purpose of the proposed plan is to present the preferred alternative to the public and provide an opportunity to receive public input

as part of the remedial decision process. Such comment would be received specifically during the public meeting and a public comment period of at least 30 days, in addition to comments received during regularly scheduled PBOW Restoration Advisory Board meetings. The public comment would form the basis of the modifying criterion, community acceptance. Once all of the FS criteria have been adequately considered and a final remedy pathway is selected, a final remediation alternative will be presented in a DD. The DD will serve as the basis for additional remedial design and action.

In developing the groundwater alternatives, a range of remedial alternatives were developed and evaluated that meet remedial action objectives, but do so in either more or less aggressive fashions. This presents decision makers with an array of remedial approaches to consider when balancing the various evaluation criteria. The following four remedial alternatives were selected for detailed evaluation:

- Alternative GW-1: No further action
- Alternative GW-2: Groundwater monitoring and institutional controls
- Alternative GW-3: ISEB/P&T for mitigation/protection of the limestone bedrock groundwater, groundwater monitoring, and institutional controls
- Alternative GW-4: ISEB/P&T for mitigation/protection of the overburden/shale and limestone bedrock groundwater, groundwater monitoring, and institutional controls.

The description and evaluation of each of these alternatives is presented in the following sections. Cost tables for Alternatives GW-2 through GW-4 are presented in Tables 5-1 through 5-3 (no costs are attributable to the no-further-action alternative). The present value of O&M costs for each alternative are calculated in Table 5-4 and a summary and comparison of total present value costs for the remedial alternatives are presented in Table 5-5.

5.1 Alternative GW-1 – No Action

5.1.1 Description

A no-action alternative is required by the NCP to be carried forward as a baseline for detailed comparison. Under this alternative, no further remedial action or monitoring would be conducted for contaminated groundwater at the site. Note that completed (TNTB and PRRWP Area) and planned soil removal (TNTA and TNTC) represent source removal actions with respect to protection of groundwater (see Section 1.5). Decontamination efforts, beginning in

1945 (see Section 1.3), were also completed that removed potential groundwater sources. Therefore, GW-1 is a no-further-action alternative rather than a no-action alternative.

5.1.2 Overall Protection of Human Health and the Environment

Alternative GW-1 would not protect human health from site-related contamination that would be left in place and no restrictions would be placed on its potential future use. Adverse human health effects could be incurred by a future on-site resident who might install a well and use the groundwater as household drinking water. However, adverse human health risks are also attributable to naturally occurring constituents in PBOW groundwater. Even in the absence of site-related COCs, PBOW groundwater is not suitable for potable use. In addition, COCs in groundwater could also migrate off site in the limestone aquifer and potentially pose a human health threat to a resident who may use this off-site groundwater as drinking water. Under GW-1, no assessment of whether U.S. Department of Defense (DOD)-related contamination is migrating off site could be made because there is no monitoring component of this alternative. However, as noted in Section 2.7, the strongly reducing conditions in the limestone bedrock appears to be effective in degrading nitroaromatics, although additional information is required to more definitely determine the potential for natural attenuation at the site. Available groundwater analytical data indicates that site-related contamination is limited to on-site areas.

Based on previous investigations, groundwater within the overburden/shale is discontinuous, seasonally dependent and of relatively low quality based on concentrations of chloride, sulfate, sodium, and TDS that exceed SMCLs. While SMCLs are not regulatory enforceable, they are used as a guide to determine acceptable drinking water based on taste, smell, color, or appearance. Similarly, high concentrations of sulfate, as well as hydrogen sulfide and naturally occurring petroleum, are present in limestone bedrock, making it undesirable as a source for potable water. Even without site-related contamination, groundwater consumption results in an unacceptable risk to current or future receptors due to the naturally occurring petroleum and metals. A survey of current off-site use of groundwater was conducted by USACE. The result of the survey indicated that, while private wells were present in downgradient areas, they are not used for potable water. Thus, the poor water quality and limited yield in the overburden/shale and poor water quality in the limestone in effect deter use as a potable source for drinking water. This results in an incomplete exposure pathway for off-site groundwater, although there will always be a potential for future exposure in the absence of any land-use restrictions in the area.

Contaminated groundwater does not present a threat to ecological receptors or other environmental media, since impacted groundwater does not discharge to surface water.

5.1.3 Compliance with Applicable or Relevant and Appropriate Requirements

Alternative GW-1 would not comply with the Ohio drinking water standards for nitrate in both groundwater units and toluene in the overburden/shale groundwater. These are the only chemical-specific ARARs for this water unit, since there are no primary drinking water standards for any of the other COCs in groundwater. Note that the Ohio standards for nitrate and toluene would only apply in the overburden/shale groundwater if this groundwater is regarded as a potential drinking water source; Section 2.6 presents information to suggest that this groundwater does not represent a viable drinking water source. Location- and action-specific ARARs are not applicable to this alternative, because no action would be taken.

5.1.4 Long-Term Effectiveness

Alternative GW-1 would not be effective because it would not protect human health.

5.1.5 Reduction of Toxicity, Mobility, or Volume

This alternative does not employ any remedial component that would reduce the toxicity, mobility, or volume of contaminants in groundwater.

5.1.6 Short-Term Effectiveness

This alternative does not involve implementation of a remedial action, so there would be no implementation-related impacts to workers, the environment, or the community.

5.1.7 Implementability

There are no technical implementation issues associated with this alternative.

5.1.8 Cost

There is no cost associated with this alternative.

5.2 Alternative GW-2 – Groundwater Monitoring and Institutional Controls

5.2.1 Description

Alternative GW-2 is composed of the following remedial components:

- ***Institutional controls to restrict the use of groundwater at the site.*** The objective of this component is to prevent the exposure of on-site receptors to contaminated groundwater as long as it poses a threat.

- ***Long-term groundwater monitoring.*** The objective of this component is to periodically assess groundwater quality across the site to ensure that groundwater contamination does not threaten potential off-site drinking water supplies.

- ***MNA.*** The objective of this component is to collect and evaluate the potential for natural attenuation to be occurring in the limestone bedrock to complement the LTM data showing spatial and temporal changes in the extent of contamination.

This alternative would include no active remedial action to reduce the concentration of COCs in groundwater. The groundwater use restrictions would prevent use of all groundwater in contaminated areas. These use restrictions would be in place as long as the concentrations of COCs are greater than the RGs. Land-use controls consist of legal mechanisms designed to control exposure to chemicals in soil and groundwater and can include deed notices, easements, well drilling prohibitions, and zoning restrictions. Land-use controls would be implemented and enforced under Ohio's Environmental Covenants Act. A land-use control implementation plan (LUCIP) would be required to implement and enforce the specific groundwater use prohibitions. The attached EPA Federal Facility Land-Use Control ROD Checklist (Appendix D) or similar document would be completed as part of the DD and would guide the development of the LUCIP.

Additional monitoring wells would be required to accomplish the above monitoring objective. For cost estimating purposes, the following assumptions are made concerning groundwater monitoring:

- No new wells would be constructed in the overburden/weathered shale zone, because this aquifer would not be actively restored and, thus, would not in the foreseeable future serve as a future source of drinking water.

- A total of 29 new wells would be constructed in the limestone bedrock aquifer.

- A total of 33 wells in the limestone bedrock zone would be analyzed for COCs once per year for 150 years.

The actual monitoring requirements would be negotiated between USACE and OEPA when an LTM program is established. These requirements will likely be different than the assumptions previously presented above. Monitoring requirements may change over time as well. For example, later in the remedial period, fewer wells might be sampled in the limestone bedrock or sampling frequency might be decreased if COCs concentrations in groundwater exhibit a long-term decreasing trend. Alternatively, additional sampling may be required in areas if an increasing trend in COC concentrations were observed.

MNA is included as a component of long-term groundwater monitoring for Alternative GW-2, although it is recognized that not enough data are available to conclusively determine its effectiveness as a remedial technology. However, the presence of naturally occurring petroleum hydrocarbons in portions of the limestone bedrock aquifer may stimulate the anaerobic biodegradation of nitroaromatic COCs (Appendix B). Further evaluation of MNA as a possible enhancement to the groundwater monitoring program is warranted based on the analytical data collected for the site. This data indicate that nitroaromatics are only detected sporadically within the limestone bedrock. MNA, if shown to be occurring, could shorten the required monitoring period or significantly decrease the frequency of monitoring in the future.

If groundwater monitoring results indicate that contamination may migrate off site at unacceptable levels, additional action would be taken to mitigate this threat.

5.2.2 Overall Protection of Human Health and the Environment

Alternative GW-2 would prevent human exposure to contaminated groundwater by prohibiting use of on-site groundwater while the concentrations of COCs exceed the RGs. Groundwater monitoring would protect off-site groundwater users by periodically evaluating limestone bedrock groundwater quality. This would enable additional remedial action to be taken should COCs in groundwater threaten potential off-site drinking water.

Contaminated groundwater does not present a threat to ecological receptors or other environmental media, because impacted groundwater does not discharge to surface water.

5.2.3 Compliance with Applicable or Relevant and Appropriate Requirements

The compliance of Alternative GW-2 with all ARARs is uncertain, but possible. The location-, chemical-, and action-specific ARARs that were considered for Alternative GW-2 are presented in Tables 3-7 and 3-8. The alternative would not comply with the chemical-specific ARAR for nitrate in the immediate future. The concentration of nitrate in the WARWP Area limestone bedrock plume is greater than the Ohio drinking water standard of 10 mg/L. Nitrate is the only bedrock COC with an Ohio primary drinking water standard and, therefore, the only chemical-specific ARAR for the limestone aquifer. However, naturally occurring petroleum hydrocarbons in the WARWP Area limestone bedrock groundwater are elevated, and geochemical conditions in this groundwater unit may promote the natural anaerobic biological denitrification of nitrate to nitrogen gas over an extended period of time (Appendix B). Long-term groundwater monitoring would confirm this. If nitrate did not naturally attenuate over time, remedial measures could be taken to treat the nitrate or a waiver for this ARAR could be sought.

Concentrations of nitrate exceed the Ohio drinking water standards for nitrate (10 mg/L) in overburden/shale groundwater in the PRRWP Area and WARWP Area plumes. However, site nitrate concentrations also exceed the maximum nitrate concentration detected among PBOW background wells. Toluene exceeds the Ohio drinking water standard at one TNTA location in a single sample collected using direct-push technology. These are the only potential chemical-specific ARARs for this water unit, since there are no primary drinking water standards for any of the other COCs in groundwater. The lone toluene exceedance (1,350 µg/L) was detected in a TNTA Building Area 111 direct-push location that was only marginally above the Ohio standard (1 mg/L or 1,000 µg/L). Note that the Ohio standards would only be ARARs if the overburden/shale groundwater is regarded as a potential drinking water source; Section 2.6 presents information to suggest that this groundwater does not represent a viable drinking water source.

The only action-specific regulatory requirements triggered by implementation of Alternative GW-2 are those that pertain to the management of hazardous waste. In the event that hazardous waste is generated during monitoring activities, such waste would require management in accordance with these ARARs. The action-specific ARARs pertaining to hazardous waste management only apply if the prerequisites for the particular ARAR are satisfied.

5.2.4 Long-Term Effectiveness

Alternative GW-2 would effectively manage the residual risks through groundwater use restrictions to prevent on-site exposure and groundwater monitoring to guard against off-site exposure to contaminated groundwater. The institutional controls and groundwater monitoring system need to be robust, because groundwater modeling predicts that concentrations of COCs in limestone bedrock groundwater will remain above RGs for more than 150 years. The natural reducing conditions in the limestone bedrock groundwater may lead to natural attenuation of the concentrations of nitroaromatics over time (refer to Section 2.7).

5.2.5 Reduction of Toxicity, Mobility, or Volume

This alternative does not employ any active remedial component that would permanently or significantly reduce the toxicity, mobility, or volume of contaminants in groundwater, although the concentrations of COCs in limestone bedrock groundwater may be expected to naturally attenuate over time (Appendix B).

5.2.6 Short-Term Effectiveness

This alternative does not involve implementation of a remedial action (besides installation of monitoring wells), so there would be no implementation-related impacts to workers, the environment, or the community. On-site workers would be protected by groundwater use restrictions that would remain in place until groundwater RGs were met. Also, on-site workers would be protected during installation of monitoring wells by following the site health and safety plan. The potential effects of fugitive hydrogen sulfide emissions on workers and the public will be considered when locating new well sites. The long-term groundwater monitoring program would protect the community by providing advanced warning of any groundwater contamination that might threaten nearby water supplies. Based on groundwater modeling results, it would take more than 150 years for the concentrations of COCs in the limestone bedrock aquifer to fall below RGs under this alternative. If the groundwater modeling of contaminant transport is overly conservative, the recovery period for the bedrock aquifer may be reduced, although it is unlikely that COCs in overburden/shale groundwater will attenuate to RGs in the foreseeable future without remedial action. Natural attenuation processes in the limestone bedrock aquifer may also act to accelerate groundwater cleanup (Appendix B), although the presence of naturally occurring petroleum hydrocarbons in the vicinity of PBOW would preclude its use as a potential future source of drinking water.

5.2.7 Implementability

The components of Alternative GW-2 are technically and administratively implementable. Nothing in the implementation of the components of this alternative precludes additional action if necessary.

5.2.8 Cost

The capital and annual O&M costs for Alternative GW-2 are presented in Table 5-1. Table 5-4 shows the present value calculation of O&M costs using a 3.1 percent discount rate (USACE and EPA, 2000). Table 5-5 presents a summary of the estimates for capital cost, present value of O&M cost, and total present value cost. The capital cost of Alternative GW-2 is $547,000. The present value of annual O&M costs over the 150-year remedial duration is $1,455,000. The total present value of capital and O&M costs is $2,002,000, with an estimated range of $1,401,000 (minus 30 percent) to $3,003,000 (plus 50 percent).

5.3 Alternative GW-3 – In Situ Enhanced Bioremediation/Pump and Treat for Mitigation/Protection of the Limestone Bedrock Aquifer

5.3.1 Description

Alternative GW-3 is composed of the following remedial components:

- ***ISEB within the overburden and weathered shale aquifer to reduce the concentrations of COCs to RGs within 12 targeted areas of the aquifer.*** The objective of this component is to protect the underlying limestone bedrock aquifer from contamination in the overburden/weathered shale zone. Restoration of the entire overburden/shale aquifer to drinking water quality is not an objective.

- ***P&T in the WARWP and PRRWP Areas of the limestone bedrock aquifer to reduce the concentrations of COCs to RGs.*** The objective of this component is to reduce the concentrations of COCs to drinking water quality.

- ***Long-term groundwater monitoring.*** The objectives of this component are to verify the effectiveness of remedial technologies and assess groundwater quality across the site so that groundwater contamination does not threaten potential off-site drinking water supplies.

- ***Institutional controls to restrict the use of groundwater at the site.*** The objective of this component is to prevent the exposure of on-site receptors to contaminated groundwater as long as it poses a threat.

5.3.1.1 ISEB in Overburden/Shale Groundwater

The target area for remediation in the overburden/weathered shale zone for Alternative GW-3 is shown in Table 3-5. The total target area is 829,000 ft^2 over 12 separate overburden/shale plumes. The objective of this component of the remedial alternative is to prevent contaminants from migrating to the underlying limestone bedrock aquifer, thereby protecting the bedrock as a potential future drinking water source.

To simplify the preliminary design and cost estimation process for the FS, the overburden/shale plume areas within each site (i.e., TNTA, TNTB, TNTC, PRRWP Area, and WARWP Area) were combined and treated as one plume. A plume area-weighted average was calculated for plume thickness (Table 3-5) and contaminant concentrations (Appendix E) were calculated accordingly as representative of groundwater across each site.

Although a number of substrates could be used as a carbon source to stimulate anaerobic biodegradation in the aquifer, the preliminary design of the ISEB technology is based on

injection of emulsified vegetable oil. Emulsified vegetable oil is a suitable choice for plumes within these sites, because the concentrations of COCs within the overburden/weathered shale zone are relatively high and the oil would provide a dissolved source of carbon over an extended period of time. The injected oil initially adsorbs onto the soil within the treatment zone and gradually dissolves into groundwater. The use of emulsified oil makes it practical to treat only a portion of the plume (with the exception of the WARWP Area plume, as discussed below) and thereby minimize injection costs. Since the adsorbed oil is a reservoir of carbon substrate, the emulsified oil may be injected within a series of barriers oriented perpendicular to the direction of groundwater flow. Contaminants are treated as groundwater flows through the reaction barriers, where oil is released into solution.

The preliminary design basis of the ISEB component of Alternative GW-3 is presented in Table 5-6. Calculations supporting the preliminary design are presented in Appendix E. Tables E-1 through E-5 present the plume area-weighted average concentrations of COCs by site. These values are used along with the average concentrations of the competing electron acceptors (Table E-6) to determine the emulsified vegetable oil required for biodegradation. For convenience, a spreadsheet provided by EOS Remediation, Inc., was used to estimate the quantity of emulsified oil required to effect remediation at each site (Tables E-7 through E-11). Table E-12 presents other supporting ISEB design calculations that supplement those in Tables E-7 through E-11.

The injection points along each barrier are assumed to be 10 feet apart. The number of barriers within each plume varies. An estimated 4,609 injection points are required to treat the plume areas under this alternative. The majority of these points are required within the PRRWP Area plume (81 percent of the total). Although this is the largest plume, the high number of injection points and large mass of emulsified oil required here (1,032,000 pounds) result principally from the high concentration of sulfate (5,263 mg/L) present within this plume. The sulfate concentration in the PWRWP plume is almost an order of magnitude higher than in any other plume on PBOW. The nitrate concentration is also higher in the PRRWP Area plume (419 mg/L) than elsewhere. Although TNT is biodegradable by some bacteria under nitrate- and sulfate-reducing conditions, reaction rates are typically higher under methanogenic conditions (Krumholz et al., 1997) and the degradation of sequential intermediate reaction products require increasingly lower reducing conditions (Spain, 1995). The emulsified oil requirement calculated here is a rough estimate, and a pilot test would be required to more accurately estimate substrate requirements.

For costing purposes, it is assumed that one injection crew would work full-time until the injection is completed. Although the work could be completed more rapidly by using multiple crews, funding considerations may prevent a significantly expedited remediation schedule.

5.3.1.2 P&T with Reinjection in Limestone Bedrock Aquifer

The second component of Alternative GW-3 is groundwater extraction and treatment within the WARWP Area and PRRWP Area limestone bedrock plumes shown on Figures 3-6 and 3-7. Groundwater extraction is targeted in these areas only because the groundwater modeling predicts that concentrations of COCs will not exceed RGs in other areas (Appendix A). Therefore, the objective of this component is to eventually restore the bedrock aquifer to drinking water quality so that the groundwater use restrictions may eventually be removed and the property may be released for unrestricted use. It is important to couple ISEB in the overburden/shale groundwater with P&T in the limestone bedrock, because the downward migration of untreated nitroaromatic compounds in the upper aquifer otherwise could be accelerated by P&T.

Groundwater modeling was performed to estimate the number of groundwater extraction wells required and the sustained pumping rate that could be maintained at each well. Modeling of two groundwater extraction scenarios was completed for both the WARWP Area and PRRWP Area plumes to determine the sensitivity of contaminant concentrations in groundwater to the number of extraction wells (Appendix A). The groundwater modeling indicated that contaminant reduction in the limestone bedrock plumes would not be significantly accelerated by the larger number of recovery wells. Therefore, for remedial costing purposes in this FS, the following recovery well configuration was selected based on the modeling work:

- WARWP Area plume: three recovery wells at 6 gpm total flow
- PRRWP Area plume: five recovery wells at 10.5 gpm total flow.

The analytical data for limestone bedrock wells BED-MW14 (WARWP Area) and BED-MW27 (PRRWP) were evaluated to determine what type of treatment would be required prior to disposal under various discharge scenarios. POTW, surface water, and reinjection disposal scenarios were considered for treated groundwater. As discussed in Chapter 4.0, the reinjection option was retained because the POTW and surface water discharge options were not practical. A discussion of the constituents that would require treatment prior to reinjection is presented in Section 4.3.4.4.

The following treatment train is proposed for the WARWP Area treatment system (Figure 5-1):

- Anoxic denitrification fluid bed reactor
- Aerobic bioreactor
- Coagulant metering system
- Flash mix tank with high-speed agitator
- Flocculation tank with low-speed agitator
- Parallel plate clarifier with clarified water pump and sludge pump
- Duplex bag filters with filter feed pump
- Sludge holding tank
- Filter press with feed pump
- Sump pump.

The anoxic denitrification fluid bed reactor would biologically reduce nitrate to nitrogen gas and may reduce nitroaromatic COCs to less toxic reaction products. The aerobic bioreactor would reduce the TOC concentration and may contribute to the further biodegradation of nitroaromatic COCs. The coagulant metering system, flash mix tank, flocculation tank, and parallel plate clarifier are used together to reduce the concentration of TSS. The duplex bag filters would remove additional particulate matter that overflows the clarifier. The sludge holding tank is an accumulation point for settled solids from the clarifier. The sludge would be dewatered in the filter press and discharged into a hopper for off-site disposal. The filtrate from the press would drain to the area sump and would be returned to the front end of the treatment process. The treated water would be pumped to reinjection wells for disposal in the limestone bedrock aquifer.

The following additional unit operation may be required for a WARWP Area groundwater treatment system:

- Dual-bed granular activated carbon system.

GAC units are commonly used to remove low levels of nitroaromatic compounds from water. The GAC unit would only be required if the anaerobic denitrification system and the aerobic bioreactor did not reduce the concentrations of nitroaromatic COCs below the RGs.

The following treatment train is proposed for the PRRWP Area treatment system (Figure 5-2):

- Aeration tank (air stripper)
- Coagulant metering system
- Flash mix tank with high-speed agitator
- Flocculation tank with low-speed agitator
- Parallel plate clarifier with clarified water pump and sludge pump

- Duplex bag filters with feed pump
- Dual bed GAC system
- Sludge holding tank
- Filter press with feed pump
- Sump pump.

The aeration tank would strip VOCs (including benzene) from the water and oxidize iron in the influent. The aeration tank would also strip H_2S if present from the groundwater. The coagulant metering system, flash mix tank, flocculation tank, and parallel plate clarifier are used together to reduce the concentration of TSS. The duplex bag filters would remove additional particulate matter that overflows the clarifier. The GAC system would remove low concentrations of nitroaromatic COCs, as well as adsorbable TOC, in the groundwater influent. Adsorption of organic compounds that are not COCs would increase carbon utilization costs, but the TOC concentration in the PRRWP Area groundwater (2.6 to 3.7 mg/L) is much lower than in the WARWP Area plume. The sludge holding tank is an accumulation point for settled solids from the clarifier. The sludge would be dewatered in the filter press and discharged into a hopper for off-site disposal. The filtrate from the press would drain to the area sump and would be returned to the front end of the treatment process. The treated water would be pumped to reinjection wells for disposal of the treated water in the limestone bedrock aquifer.

The following additional unit operations may be required for a PRRWP Area groundwater treatment system:

- Oil/water separator
- H_2S wet scrubber.

A naturally occurring light nonaqueous-phase liquid (LNAPL) petroleum hydrocarbon has been detected during sampling of BED-MW27. The thickness of the LNAPL has ranged from a sheen to as much as 0.5 feet on the surface of the groundwater. Under constant pumping conditions, the LNAPL may disappear. If not, an oil/water separator may be required on the front end of the groundwater treatment train to remove free-phase petroleum hydrocarbons. H_2S has been detected in the vapor space of BED-MW27 at a concentration greater than 50 parts per million vapor in air. H_2S nuisance odors from the air stripper may be managed by appropriate design of the air stripper stack or by locating the PRRWP Area groundwater treatment system as far as practical from the PBOW property boundary. If the H_2S cannot be managed by these approaches, a wet scrubber may be required to remove the H_2S from the air stripper emissions. The concentration of H_2S in groundwater has not been measured, so H_2S emissions cannot be estimated at this time.

The reinjection system for the WARWP Area and PRRWP Area treatment systems would consist of five and seven reinjection wells, respectively, each pumping at approximately 2 gpm. The reinjection wells would be located upgradient of the plumes, within 200 feet. The reinjection system requirements have been estimated based on what is currently known about the hydrology using previous groundwater modeling at these sites, although no modeling has been performed to specify the reinjection system.

5.3.1.3 Groundwater Monitoring

The third component of Alternative GW-3 is groundwater monitoring. Groundwater monitoring under this alternative has two objectives. The first objective is to evaluate the performance of the active remedial systems implemented, ISEB and P&T. The second objective is to assess the overall quality of groundwater across PBOW in the limestone bedrock since it would be regarded as the only potential drinking water source under this alternative.

Additional monitoring wells would be required to accomplish these objectives. For cost estimating purposes, the following assumptions are made concerning groundwater monitoring:

- A total of 11 new wells would be constructed in the overburden/weathered shale zone in areas where remedial action is proposed.
- A total of 29 new wells would be constructed in the limestone bedrock.
- A total of 19 wells in the overburden/weathered shale zone would be analyzed for COCs and MNA parameters once per year for 5 years after ISEB implementation is complete. No additional monitoring is proposed in the overburden/weathered shale zone after the first 5 years.
- A total of 33 wells in the limestone bedrock zone would be analyzed for COCs once per year for 150 years.

The actual monitoring requirements would be negotiated between USACE and OEPA when an LTM program is established. These requirements would likely be different from the assumptions presented above. Monitoring requirements may change over time as well. For example, later in the remedial period, fewer wells might be sampled in the limestone bedrock, or sampling frequency might be decreased if COC concentrations in groundwater exhibited a long-term decreasing trend. Alternatively, additional sampling may be required in areas if an increasing trend in COC concentrations is observed.

MNA is not included formally as a component of long-term groundwater monitoring for Alternative GW-3 because not enough data are available to conclusively determine its effectiveness as a remedial technology. MNA analysis is only proposed for the ISEB target areas to help evaluate the technology's effectiveness immediately after the implementation period. However, the presence of naturally occurring petroleum hydrocarbons in portions of the bedrock aquifer may stimulate the anaerobic biodegradation of nitroaromatic COCs (Appendix B). Further evaluation of MNA as a possible enhancement to the groundwater monitoring program may be warranted, if it would shorten the required monitoring period or significantly reduce the frequency of monitoring in the future.

5.3.1.4 Institutional Controls

The final component of Alternative GW-3 is groundwater use restrictions. These restrictions would prevent use of all groundwater in contaminated areas until such time as the concentrations of COCs fall below the RGs. Land-use controls consist of legal mechanisms designed to control exposure to chemicals in soil and groundwater and can include deed notices, easements, well drilling prohibitions, and zoning restrictions. Land-use controls would be implemented and enforced under Ohio's Environmental Covenants Act. A LUCIP would be prepared to implement and enforce specific groundwater use prohibitions. The attached EPA Federal Facility Land-Use Control ROD Checklist (Appendix D) or similar document would be completed as part of the DD and would guide the development of the LUCIP.

5.3.2 Overall Protection of Human Health and the Environment

Alternative GW-3 would prevent human exposure to contaminated groundwater by prohibiting use of on-site groundwater while the concentrations of COCs exceed the RGs. Groundwater monitoring would protect off-site groundwater users by periodically evaluating limestone bedrock groundwater quality. This would enable additional remedial action to be taken should COCs in groundwater threaten potential off-site drinking water. Targeted use of ISEB within the overburden/shale aquifer would reduce the concentrations of COCs and prevent the migration of COCs to the limestone bedrock aquifer. P&T within the bedrock aquifer of the WARWP and PRRWP Areas would reduce the concentration of COCs in these plumes and prevent the off-site migration of contaminated groundwater in these areas.

Contaminated groundwater does not present a threat to ecological receptors or other environmental media, because impacted groundwater does not discharge to surface water.

5.3.3 Compliance with Applicable or Relevant and Appropriate Requirements

The location-, chemical-, and action-specific ARARs that were considered for Alternative GW-3 are presented in Tables 3-7 and 3-8. Nitrate is the only limestone bedrock COC with a chemical-specific ARAR. The P&T system in the WARWP Area would reduce the concentration of nitrate in limestone bedrock groundwater to below the Ohio standard. The other bedrock COCs do not have an Ohio drinking water standard or other chemical-specific ARAR.

Concentrations of nitrate exceed the Ohio drinking water standards in overburden/shale groundwater in the PRRWP Area and WARWP Area plumes. Toluene exceeds the Ohio drinking water standard at one TNTA location in a single sample collected using direct-push technology. These are the only potential chemical-specific ARARs for this water unit, because there are no primary drinking water standards for any of the other COCs in groundwater. ISEB treatment in the PRRWP Area and WARWP Area should successfully denitrify the nitrate to levels less than the Ohio standard. The lone toluene exceedance (1,350 µg/L) was detected in a TNTA Building Area 111 direct-push location that was only marginally above the Ohio standard (1,000 µg/L). The Building 111 Area would be treated with ISEB under this alternative. Although toluene was not targeted for ISEB, some anaerobic degradation of toluene would be possible. This alternative also includes monitoring of the overburden/shale; this monitoring would be used to determine whether toluene concentrations would still exceed the Ohio drinking water standard. Note that the Ohio standards would only be ARARs if the overburden/shale groundwater is regarded as a potential drinking water source; Section 2.6 presents information to suggest that this groundwater does not represent a viable drinking water source.

The location-specific ARARs identified in Table 3-7 are applicable to this remedial alternative only in cases where the prerequisites are satisfied. For example, historical and archaeological resource protection requirements are named as potential ARARs for this alternative, even though no such resources have been identified at the site to date. Because the five AOCs were used for industrial purposes during the 1940s and extensive remedial and investigative activities have occurred since that time, the potential for discovery of such resources is remote. However, if protected resources were discovered during intrusive remedial activities, they would be afforded protection under these ARARs.

Action-specific regulatory requirements triggered by implementation of Alternative GW-3 include UIC, hazardous waste management, and air quality requirements (Table 3-8). As with the location-specific ARARs, the action-specific ARARs only apply if the prerequisites for the particular ARAR are satisfied. For example, ARARs concerning hazardous waste management would apply only if hazardous waste were generated and/or managed on site as a result of the

remedial action. Based on the estimated levels of air emissions generated by the groundwater treatment systems, the systems should not require any air pollution controls. The UIC program requirements are an ARAR for reinjection of treated groundwater. The requirements of the UIC program should be met by treating the groundwater prior to reinjection.

5.3.4 Long-Term Effectiveness

Alternative GW-3 would reduce the magnitude of residual risk at the site by reducing the concentrations of COCs in both the overburden/shale and limestone bedrock aquifers through treatment. While concentrations of COCs remain above RGs, the residual risks would be managed through groundwater use restrictions to prevent on-site exposure and groundwater monitoring to guard against off-site exposure to contaminated groundwater. The institutional controls and groundwater monitoring system need to be robust, because groundwater modeling predicts that concentrations of COCs in bedrock groundwater will remain above RGs for at least 150 years, even with active remediation in place for soil and groundwater. It is noted that the natural reducing conditions in the limestone bedrock aquifer may result in natural attenuation of the nitroaromatic COCs over time (refer to Section 2.7).

The long-term effectiveness of the P&T system may not meet the objectives stated in Section 5.3.1 with respect to unrestricted use of groundwater. The technology would reduce and/or contain the mass of contamination within groundwater, but release of the site for unrestricted use would require the aquifer to meet drinking water quality throughout its entirety. The P&T system may never restore groundwater within the limestone bedrock to drinking water quality. The presence of naturally-occurring constituents, such as petroleum hydrocarbons, may render portions of this aquifer permanently undesirable for use as drinking water. For these reasons, restoration of all limestone groundwater to drinking water quality and release of the aquifer for unrestricted use may not be a feasible objective.

5.3.5 Reduction of Toxicity, Mobility, or Volume

Remedial technologies used as part of alternative GW-3 should irreversibly and permanently reduce the toxicity, mobility, and volume of COCs in groundwater. Injection of a carbon substrate into the overburden/shale groundwater during the implementation of ISEB would biologically convert nitrate and nitroaromatic COCs to less toxic or nontoxic reaction products. Nonmineralized reaction products may be incorporated into the soil matrix through subsequent irreversible transformation and covalent binding reactions.

The treatment operations of the P&T systems also provide irreversible and permanent treatment of COCs. The anoxic denitrification and aerobic bioreactors in the WARWP Area treatment

system would biologically convert nitrate and nitroaromatic contaminants in extracted groundwater to nontoxic or less toxic reaction products. The carbon adsorption system in the PRRWP Area treatment system would remove nitroaromatic contaminants in extracted groundwater by adsorption onto GAC. The adsorbed organic contaminants would be thermally destroyed off site upon regeneration of the spent carbon by the GAC vendor. In addition to the spent carbon, both P&T systems would generate a nonhazardous filter cake that would require off-site disposal.

Alternative GW-3 would treat an estimated 23.4 million gallons of groundwater over an area of 968,000 ft^2 in the overburden/shale groundwater and a current pore space of 106 million gallons of groundwater over an area of 1,380,000 ft^2 in the limestone bedrock aquifer.

5.3.6 Short-Term Effectiveness

On-site workers would be protected by groundwater use restrictions that would remain in place until groundwater RGs are met. On-site workers would be protected during installation of monitoring wells by following the site health and safety plan and would be equipped with the necessary personal protective equipment. The work conducted would conform to all USACE safety requirements. The P&T systems are not projected to generate any emissions that would be a health risk to site workers or the public, but air emissions will be routinely evaluated to ensure air pollution controls are met and human endangerment is not a consequence. The long-term groundwater monitoring program would protect the community by providing advanced warning of any groundwater contamination that might threaten off-site water. The groundwater monitoring conducted immediately after implementation of ISEB to evaluate the performance of the technology in the overburden/shale aquifer would include analysis of naturally occurring, ORP-sensitive metals that can be mobilized under reducing conditions.

The estimated time to complete substrate injection in the overburden/shale groundwater is approximately 4.3 years using one direct-push rig with a crew working full time. This work could be accomplished more rapidly using multiple rigs/crews, although funding constraints might preclude a more expedited schedule. The limestone bedrock aquifer P&T system could be designed and constructed in approximately 2 years. In the case of both technologies, additional groundwater characterization and technology pilot studies are recommended to optimize the treatment technologies before full-scale implementation. Therefore, the total elapsed time necessary to have the technologies completely implemented would be longer.

The initial 5-year stage of the groundwater monitoring program would test the effectiveness of ISEB treatment in the overburden/shale groundwater after it is completed. After that period of

time, it is assumed that groundwater monitoring would be restricted to the bedrock aquifer. Groundwater modeling has estimated that the P&T systems in the WARWP and PRRWP Areas would have to operate for at least 150 years. The remedial period is extensive because the model predicts that there will continue to be some contribution to bedrock contamination from overlying zones. If the groundwater modeling predictions about contaminant transport are overly conservative, the remedial period for the P&T system may be less. Natural attenuation processes in the limestone bedrock aquifer (Appendix B) may also act to reduce the operating period of the P&T systems. The estimated volumes of bedrock groundwater requiring treatment at the WARWP and PRRWP Areas is 45 million and 61 million gallons, respectively. At the projected capture rate of the two P&T systems (6 gpm for WARWP Area and 10.5 gpm for PRRWP Area), the WARWP Area and PRRWP Area P&T systems would capture approximately 10.5 and 13.6 pore volumes, respectively, in 150 years.

5.3.7 Implementability

The components of Alternative GW-3 appear to be technically and administratively implementable, albeit at a potentially high cost. Additional data should be collected prior to full-scale implementation of the ISEB and P&T technologies to ensure that they will be effectively implemented. Groundwater plumes at target areas for groundwater remediation should have well-defined boundaries. The distribution of COCs and potential competing electron acceptors should be well understood so that the demand for carbon substrate can be predicted and the configuration of injection points can be designed effectively for ISEB areas. Of particular concern are the concentrations of sulfate and nitrate throughout the ISEB target area at the PRRWP Area overburden/shale plume. The available data indicate that sulfate would exert a high demand on carbon substrate within this plume, leading to a potentially costly ISEB implementation. The distribution of contaminants and competing electron acceptors should be better defined so that a cost-effective ISEB implementation can be performed. ISEB pilot test(s) are also recommended to optimize the injection requirements. In addition, the degradability of all contaminants would be confirmed because some of the nitroaromatics (e.g., dinitrotoluenes) are more easily degraded under aerobic conditions.

The unit operations proposed for the WARWP Area and PRRWP Area P&T systems are relatively complicated and costly for groundwater treatment systems with flow rates of 10 gpm or less. This is particularly true of the proposed WARWP Area P&T system. These systems are complicated because constituents other than the target contaminants for groundwater remediation require treatment to meet operational or discharge requirements. High levels of TOC, TSS, iron, and TDS increase the complexity of the treatment process or limit the options for discharge. The high TOC is assumed to be naturally occurring petroleum hydrocarbons. Given the potential

cost of these systems, it is important that the type and distribution of groundwater constituents (including nontarget constituents) be well defined before the treatment system is designed and constructed. The groundwater quality within the WARWP Area and PRRWP Area plumes should be characterized under pumping conditions by sampling at the end of a pump test. The pump test would also verify aquifer characteristics and the sustainable groundwater pumping rate. The groundwater model could then be used to refine the number and location of groundwater extraction and reinjection wells. Treatability tests may be required to support the design of the treatment systems and confirm the biodegradability of the undefined organics in the groundwater.

As previously discussed, funding constraints may not allow the project to be executed all at one time. Nevertheless, the work could be easily broken into various phases. It may be preferable to complete the ISEB component before the groundwater treatment systems are operated to avoid drawing contamination from the upper aquifer into the limestone bedrock. A phased approach to remedial action would also facilitate the intermediate evaluation of individual stages or components. This would allow adjustments and fine tuning of later stages of remediation that could result in cost savings on the total project.

Nothing in the implementation of the components of this alternative precludes additional action if necessary.

5.3.8 Cost

The capital and annual O&M costs for Alternative GW-3 are presented in Table 5-2. Table 5-4 shows the present value calculation of O&M costs using a 3.1 percent discount rate (USACE and EPA, 2000). Table 5-5 presents a summary of the estimates for capital cost, present value of O&M cost, and total present value cost. The capital cost of Alternative GW-3 is $8,900,000. The present value of annual O&M costs over the 150-year remedial duration is $6,984,000. The total present value of capital and O&M costs is $15,884,000 with an estimated range of $11,119,000 (minus 30 percent) to $23,826,000 (plus 50 percent).

5.4 Alternative GW-4 – In Situ Enhanced Bioremediation/Pump and Treat for Mitigation/Protection of the Overburden/Shale and Bedrock Aquifers

5.4.1 Description

Alternative GW-4 is composed of the following remedial components:

- ***ISEB within the overburden and weathered shale aquifer to reduce the concentrations of COCs to RGs within 27 contaminated areas of the aquifer.*** The objective of this component is to reduce the concentrations of COCs to drinking water quality in these areas so that the aquifer may eventually be released for unrestricted use.

- ***P&T in the WARWP Area and PRRWP Area plumes in the limestone bedrock aquifer to reduce the concentrations of COCs to RGs.*** The objective of this component is to reduce the concentrations of COCs to drinking water quality so that the aquifer may eventually be released for unrestricted use.

- ***Long-term groundwater monitoring.*** The objectives of this component are to verify the effectiveness of remedial technologies and assess groundwater quality across the site so that groundwater contamination does not threaten potential off-site drinking water.

- ***Institutional controls to restrict the use of groundwater at the site.*** The objective of this component is to prevent the exposure of on-site receptors to contaminated groundwater until it no longer poses a threat.

5.4.1.1 ISEB in Overburden/Shale Groundwater

The target area for remediation in the overburden/weathered shale zone for Alternative GW-4 is shown in Table 3-6. The total target area is 1,411,700 ft^2 over 27 separate plumes. The objective of this component is to reduce the concentrations of COCs to drinking water quality in these areas so that the aquifer may eventually be released for unrestricted use.

To simplify the preliminary design and cost estimation process for the FS, the plume areas within each site (i.e., TNTA, TNTB, TNTC, PRRWP Area and WARWP Area) were combined and treated as one plume. A plume area-weighted average was calculated for plume thickness (Table 3-6), and contaminant concentrations (Appendix E) were calculated accordingly as representative of groundwater across each site.

Although a number of substrates could be used as a carbon source to stimulate anaerobic biodegradation in the aquifer, the preliminary design of the ISEB technology is based on injection of emulsified vegetable oil. Emulsified vegetable oil is a suitable choice for plumes within these sites, because the concentrations of COCs within the overburden/weathered shale zone are relatively high and the oil would provide a dissolved source of carbon over an extended period of time. The injected oil initially adsorbs onto the soil within the treatment zone and gradually dissolves into groundwater. The use of emulsified oil makes it practical to treat only a portion of the plume (with the exception of the WARWP Area plume) and thereby minimize injection costs. Since the adsorbed oil is a reservoir of carbon substrate, the emulsified oil may

be injected within a series of barriers oriented perpendicular to the direction of groundwater flow. Contaminants are treated as groundwater flows through the reaction barriers, where oil is released into solution.

The preliminary design basis of the ISEB component of Alternative GW-4 is presented in Table 5-7. Calculations supporting the preliminary design are presented in Appendix E. Tables E-13 through E-17 present the plume-area-weighted average concentrations of COCs by site. These values are used along with the average concentrations of the competing electron acceptors (Table E-6) to determine the emulsified vegetable oil required for biodegradation. For convenience, a spreadsheet provided by EOS Remediation, Inc., was used to estimate the quantity of emulsified oil required to effect remediation at each site (Tables E-18 through E-22). Table E-23 presents other supporting ISEB design calculations that supplement those in Tables E-18 through E-22.

The injection points along each barrier are assumed to be 10 feet apart. The number of barriers within each plume varies. An estimated total of 8,173 injection points are required to treat the plume areas under this alternative. The majority of these points are required within the PRRWP Area plume (84 percent of the total). Although this is the largest plume, the high number of injection points and large mass of emulsified oil required here (1,905,000 pounds) result principally from the high concentration of sulfate (5,263 mg/L) present within this plume. The sulfate concentration in the PWRWP plume is almost an order of magnitude higher than in any other plume on PBOW. The nitrate concentration is also higher in the PRRWP Area plume (253 mg/L) than elsewhere. Although TNT is biodegradable by some bacteria under nitrate- and sulfate-reducing conditions, reaction rates are typically higher under methanogenic conditions (Krumholz, et al., 1997) and the degradation of sequential intermediate reaction products require increasingly lower reducing conditions (Spain, 1995). The emulsified oil requirement calculated here is a rough estimate, and a pilot test would be required to more accurately estimate substrate requirements.

For costing purposes, it is assumed that one injection crew would work full time until the injection is completed. Although the work could be completed more rapidly by using multiple crews, funding considerations may prevent a significantly expedited remediation schedule.

5.4.1.2 P&T With Reinjection in Limestone Bedrock Aquifer

The second component of Alternative GW-4 is groundwater extraction and treatment within the PRRWP Area and WARWP Area limestone bedrock plumes (Figures 3-6 and 3-7). Groundwater extraction is targeted in these areas only because the groundwater modeling predicts that concentrations of COCs will not exceed RGs in other areas (Appendix A).

Therefore, the objective of this component is to eventually restore the overburden/shale zone and the limestone bedrock aquifer to drinking water quality so that the groundwater use restrictions may be removed and the property may eventually be released for unrestricted use. It is important to couple ISEB in the overburden/shale groundwater with P&T in the limestone bedrocks because the downward migration of untreated nitroaromatic compounds in the upper aquifer could otherwise be accelerated by P&T.

The P&T systems in this alternative are identical to those proposed for Alternative GW-3. Refer to Section 5.3.1.2 for a detailed discussion of the P&T component of this alternative.

5.4.1.3 Groundwater Monitoring

The third component of Alternative GW-4 is groundwater monitoring. Groundwater monitoring under this alternative has two objectives. The first objective is to evaluate the performance of the active remedial systems implemented, ISEB and P&T. The second objective is to assess the overall quality of groundwater across PBOW in the limestone bedrock since it would be the only potential drinking water source under this alternative.

Additional monitoring wells would be required to accomplish these objectives. For cost estimating purposes, the following assumptions are made concerning groundwater monitoring:

- A total of 26 new wells would be constructed in the overburden/weathered shale zone in areas where remedial action is proposed.
- A total of 29 new wells would be constructed in the limestone bedrock.
- A total of 35 wells in the overburden/weathered shale zone would be analyzed for COCs and MNA parameters once per year for 5 years after ISEB implementation is complete. No additional monitoring is proposed in the overburden/weathered shale zone after the first 5 years.
- A total of 33 wells in the limestone bedrock zone would be analyzed for COCs once per year for 150 years.

The actual monitoring requirements would be negotiated between USACE and OEPA when an LTM program is established. These requirements would likely be different from the assumptions presented above. Monitoring requirements may change over time as well. For example, later in the remedial period, fewer wells might be sampled in the bedrock, or sampling frequency might be decreased if COC concentrations in groundwater exhibit a long-term decreasing trend.

Alternatively, additional sampling may be required in areas if an increasing trend in COC concentrations is observed.

MNA is not included formally as a component of long-term groundwater monitoring for Alternative GW-4 because not enough data are available to conclusively determine its effectiveness as a remedial technology. MNA analysis is only proposed for the ISEB target areas to help evaluate the technology's effectiveness immediately after the implementation period. However, the presence of naturally occurring petroleum hydrocarbons in portions of the limestone bedrock aquifer may stimulate the anaerobic biodegradation of nitroaromatic COCs (Appendix A). Further evaluation of MNA as a possible enhancement to the groundwater monitoring program may be warranted if it would shorten the required monitoring period or significantly reduce the frequency of monitoring in the future.

5.4.1.4 Institutional Controls

The final component of Alternative GW-4 is groundwater use restrictions. These restrictions would prevent use of all groundwater in contaminated areas until such time as the concentrations of COCs fall below the RGs. Land-use controls consist of legal mechanisms designed to control exposure to chemicals in soil and groundwater and can include deed notices, easements, well drilling prohibitions, and zoning restrictions. Land use controls would be implemented and enforced under Ohio's Environmental Covenants Act. A LUCIP would be prepared to implement and enforce specific groundwater use prohibitions. The attached EPA Federal Facility Land-Use Control ROD Checklist (Appendix D) or similar document would be completed as part of the DD and would guide the development of the LUCIP.

5.4.2 Overall Protection of Human Health and the Environment

Alternative GW-4 would prevent human exposure to contaminated groundwater by prohibiting use of on-site groundwater while the concentrations of COCs exceed the RGs. Groundwater monitoring would protect off-site groundwater users by periodically evaluating limestone bedrock groundwater quality throughout the plumes. This would enable additional remedial action to be taken should COCs in groundwater threaten potential off-site drinking water. Implementation of ISEB within the overburden/shale groundwater would reduce the concentrations of COCs across the aquifer and prevent the migration of COCs to the bedrock aquifer. P&T within the limestone bedrock aquifer of the WARWP and PRRWP Areas would reduce the concentrations of COCs in these areas and prevent the off-site migration of contaminated groundwater in these areas.

Contaminated groundwater does not present a threat to ecological receptors or other environmental media, because impacted groundwater does not discharge to surface water.

5.4.3 Compliance with Applicable or Relevant and Appropriate Requirements

This alternative would comply with all ARARs. The location-, chemical-, and action-specific ARARs that were considered for Alternative GW-4 are presented in Tables 3-7 and 3-8. The alternative would comply with the Ohio drinking water standard for nitrate that is the sole chemical-specific ARAR. The P&T system in the WARWP Area would reduce the concentration of nitrate in limestone bedrock groundwater to below the Ohio standard. The other bedrock COCs do not have an Ohio drinking water standard or other chemical-specific ARAR.

Concentrations of nitrate exceed the Ohio drinking water standards for nitrate in overburden/shale groundwater in the PRRWP Area and WARWP Area plumes. Toluene exceeds the Ohio drinking water standard at one TNTA location in a single sample collected using direct-push technology. These are the only potential chemical-specific ARARs for this water unit, since there are no primary drinking water standards for any of the other COCs in groundwater. ISEB treatment in the PRRWP Area and WARWP Area should successfully denitrify the nitrate to levels less than the Ohio standard. The lone toluene exceedance (1,350 µg/L) was detected in a TNTA Building Area 111 direct-push location and was only marginally above the Ohio standard (1,000 µg/L). The Building 111 Area would be treated with ISEB under this alternative. Although toluene was not targeted for ISEB, some anaerobic degradation of toluene would be possible. This alternative also includes monitoring of the overburden/shale; this monitoring would be used to determine whether toluene concentrations still exceed the Ohio drinking water standard. Note that the Ohio standards would only be ARARs if the overburden/shale groundwater is regarded as a potential drinking water source; Section 2.6 presents information to suggest that this groundwater does not represent a viable drinking water source.

The location-specific ARARs identified in Table 3-7 are applicable to this remedial alternative only in cases where the prerequisites are satisfied. For example, historical and archaeological resource protection requirements are named as potential ARARs for this alternative even though no such resources have been identified at the site to date. Because the five AOCs were used for industrial purposes during the 1940s and extensive remedial and investigative activities have occurred since that time, the potential for discovery of such resources is remote. However, if protected resources were to be discovered during intrusive remedial activities, they would be afforded protection under these ARARs.

Action-specific regulatory requirements triggered by implementation of Alternative GW-4 include UIC, hazardous waste management, and air quality requirements (Table 3-8). As with the location-specific ARARs, the action-specific ARARs only apply if the prerequisites for the particular ARAR are satisfied. For example, ARARs concerning hazardous waste management would apply only if hazardous waste is generated and/or managed on site as a result of the remedial action. Based on the estimated levels of air emissions generated by the groundwater treatment systems, the systems should not require any air pollution controls. The UIC program requirements are an ARAR for reinjection of treated groundwater. The requirements of the UIC program should be met by treating the groundwater prior to reinjection.

5.4.4 Long-Term Effectiveness

Alternative GW-4 would reduce the magnitude of residual risk at the site by reducing the concentrations of COCs in both the overburden/shale and limestone bedrock aquifers through treatment. While concentrations of COCs remain above RGs, the residual risks would be managed through groundwater use restrictions to prevent on-site exposure and groundwater monitoring to guard against off-site exposure to contaminated groundwater. The institutional controls and groundwater monitoring system need to be robust, because groundwater modeling predicts that concentrations of COCs in bedrock groundwater would remain above RGs for at least 150 years even with active remediation in place for soil and groundwater. It is noted that the natural reducing conditions in the limestone bedrock aquifer may naturally attenuate the nitroaromatic COCs over time (refer to Section 2.7).

The long-term effectiveness of the ISEB and P&T systems may not meet the objectives stated in Section 5.4.1 with respect to unrestricted use of groundwater. The technologies will reduce and/or contain the mass of contamination within groundwater, but release of the site for unrestricted use would require the aquifers to meet drinking water quality throughout their entirety. ISEB would greatly reduce the mass of contamination in the overburden/shale groundwater, but complete restoration of this unit to drinking water quality may require a completely uniform distribution of injected reagents throughout the contaminated zone, which would not be possible. The P&T system may never restore groundwater within the limestone bedrock to drinking water quality. The presence of naturally occurring constituents, such as petroleum hydrocarbons, may render portions of this aquifer permanently undesirable for use as drinking water. For these reasons, restoration of all groundwater to drinking water quality and release of these areas for unrestricted use may not be a feasible objective.

5.4.5 Reduction of Toxicity, Mobility, or Volume

Remedial technologies used as part of alternative GW-4 should irreversibly and permanently reduce the toxicity, mobility, and volume of COCs in groundwater. Injection of a carbon substrate into the overburden/shale groundwater during the implementation of ISEB would biologically convert nitrate and nitroaromatic COCs to less toxic or nontoxic reaction products. Nonmineralized reaction products may be incorporated into the soil matrix through subsequent irreversible transformation and covalent binding reactions.

The treatment operations of the P&T systems also provide irreversible and permanent treatment of COCs. The anoxic denitrification and aerobic bioreactors in the WARWP Area treatment system would biologically convert nitrate and nitroaromatic contaminants in extracted groundwater to nontoxic or less toxic reaction products. The carbon adsorption system in the PRRWP Area treatment system would remove nitroaromatic contaminants in extracted groundwater by adsorption onto GAC. The adsorbed organic contaminants would be thermally destroyed off site upon regeneration of the spent carbon by the GAC vendor. In addition to the spent carbon, both P&T systems would generate a nonhazardous filter cake that would require off-site disposal. Further, the natural reducing conditions in the limestone bedrock aquifer may naturally attenuate the nitroaromatic COCs over time (refer to Section 2.7).

Alternative GW-4 would treat 38.4 million gallons of groundwater over an area of 1,411,700 ft^2 in the overburden/shale groundwater and a current pore space of 106 million gallons of groundwater over an area of 1,380,000 ft^2 in the limestone bedrock aquifer.

5.4.6 Short-Term Effectiveness

On-site workers would be protected by groundwater use restrictions that would remain in place until groundwater RGs were met in both the limestone and overburden/shale groundwater. Remediation workers would be equipped with the necessary personal protective equipment and would conform to all USACE safety requirements. The P&T systems are not projected to generate any emissions that would be a health risk to site workers or the public but air emissions will be routinely evaluated to ensure air pollution controls are met and human endangerment is not a consequence. The long-term groundwater monitoring program would protect the community by providing advance warning of any groundwater contamination that might threaten off-site groundwater. The groundwater monitoring conducted immediately after implementation of ISEB to evaluate the performance of the technology in the overburden/shale aquifer would include analysis of naturally occurring ORP-sensitive metals that can be mobilized under reducing conditions.

The estimated time to complete substrate injection in the overburden/shale aquifer is approximately 7.8 years using one direct-push rig with a crew working full time. This work could be accomplished more rapidly using multiple rigs/crews, although funding constraints might preclude a more expedited schedule. The limestone bedrock aquifer P&T system could be designed and constructed in approximately 2 years. In the case of both technologies, additional groundwater characterization and technology pilot studies are recommended to optimize the treatment technologies before full-scale implementation. Therefore, the total elapsed time necessary to have the technologies completely implemented would be longer.

The initial 5-year stage of the groundwater monitoring program would test the effectiveness of ISEB treatment in the overburden/shale groundwater after it is completed. After that period of time, it is assumed that groundwater monitoring would be restricted to the limestone bedrock aquifer. Groundwater modeling has estimated that the P&T systems in the WARWP and PRRWP Areas would have to operate for at least 150 years. The remedial period is extensive, because the model predicts that there would continue to be some contribution to bedrock contamination from overlying zones. If the groundwater modeling predictions about contaminant transport are overly conservative, the remedial period for the P&T system may be less. Natural attenuation processes in the bedrock aquifer (Appendix D) may also act to reduce the operating period of the P&T systems. The estimated volume of limestone bedrock groundwater requiring treatment at the WARWP and PRRWP Areas is 45 million and 61 million gallons, respectively. At the projected capture rate of the two P&T systems (6 gpm for WARWP Area and 10.5 for PRRWP Area), the WARWP Area and PRRWP Area P&T systems would capture approximately 10.5 and 13.6 pore volumes, respectively, in 150 years.

5.4.7 Implementability

The components of Alternative GW-4 appear to be technically and administratively implementable, albeit at a potentially high cost. Additional data should be collected prior to full-scale implementation of the ISEB and P&T technologies to ensure that they would be effectively implemented. Groundwater plumes at target areas for groundwater remediation should have well-defined boundaries. The distribution of COCs and potential competing electron acceptors should be well understood so that the demand for carbon substrate can be predicted and the configuration of injection points can be designed effectively for ISEB areas. Of particular concern is the concentration of sulfate and nitrate throughout the ISEB target area at the PRRWP Area overburden/shale plume. The available data indicate that sulfate would exert a high demand on carbon substrate within this plume, leading to a potentially costly ISEB implementation. The distribution of contaminants and competing electron acceptors should be better defined so that a cost-effective ISEB implementation can be performed. ISEB pilot test(s)

are also recommended to optimize the injection requirements. In addition, the degradability of all contaminants would be confirmed because some of the nitroaromatics (e.g., dinitrotoluenes) are more easily degraded under aerobic conditions.

The unit operations proposed for the WARWP Area and PRRWP Area P&T systems are relatively complicated and costly for groundwater treatment systems with flow rates of 10 gpm or less. This is particularly true of the proposed WARWP Area P&T system. These systems are complicated because constituents other than the target contaminants for groundwater remediation require treatment to meet operational or discharge requirements. High levels of TOC, TSS, iron, and TDS increase the complexity of the treatment process or limit the options for discharge. The high TOC is assumed to be naturally occurring petroleum hydrocarbons. Given the potential cost of these systems, it is important that the type and distribution of groundwater constituents (including nontarget constituents) be well defined before the treatment system is designed and constructed. The groundwater quality within the WARWP and PRRWP Area plumes should be characterized under pumping conditions by sampling at the end of a pump test. The pump test would also verify aquifer characteristics and the sustainable groundwater pumping rate. The groundwater model could then be used to refine the number and location of groundwater extraction and reinjection wells. Treatability tests may be required to support the design of the treatment systems and confirm the biodegradability of the undefined organics (i.e., TOC) in the groundwater.

As previously discussed, funding constraints may not allow the project to be executed all at one time. Nevertheless, the work could be easily broken into various phases. It may be preferable to complete the ISEB component before the groundwater treatment systems are operated to avoid drawing contamination from the upper aquifer into the limestone bedrock. A phased approach to remedial action would also facilitate the intermediate evaluation of individual stages or components. This would allow adjustments and fine tuning of later stages of remediation that could result in cost savings on the total project.

Nothing in the implementation of the components of this alternative precludes additional action if necessary.

5.4.8 Cost

The capital and annual O&M costs for Alternative GW-4 are presented in Table 5-3. Table 5-4 shows the present value calculation of O&M costs using a 3.1 percent discount rate (USACE and EPA, 2000). Table 5-5 presents a summary of the estimate for capital cost, present value of O&M cost and total present value cost. The capital cost of Alternative GW-4 is $12,555,000.

The present value of annual O&M costs over the 150-year remedial duration is $7,059,000. The total present value of capital and O&M costs is $19,614,000, with a range of $13,730,000 (minus 30 percent) to $29,421,000 (plus 50 percent).

6.0 Comparative Analysis of Remedial Alternatives

This chapter provides a comparative analysis of the remedial alternatives developed in Chapter 5.0. The comparisons are based on the first seven of the nine NCP evaluation criteria and the overall feasibility of the alternatives in achieving and maintaining RAOs for groundwater. These seven criteria are as follows:

- Threshold criteria
  - Overall protection of human health and the environment
  - Compliance with ARARs.

- Primary balancing criteria
  - Long-term effectiveness and permanence
  - Reduction of toxicity, mobility, or volume through treatment
  - Short-term effectiveness
  - Implementability
  - Cost.

Table 6-1 summarizes this analysis. The last two criteria, known as the modifying criteria, are state acceptance and community acceptance. These two criteria are typically determined after presentation to the state and community and thus are not discussed in this FS.

6.1 Protection of Human Health and the Environment

Alternatives GW-2 through GW-4 all provide protection for human health and the environment based on the implementation of legally enforceable on-site groundwater use restrictions. In addition to groundwater use restrictions, Alternative GW-4 is intended to meet drinking water quality in both the overburden/shale groundwater and the limestone bedrock groundwater after remediation is complete. Once these goals were met, the land-use restrictions could be removed. GW-3 is intended for mitigation (via P&T) and protection (via targeted ISEB in the overburden/shale) of the limestone bedrock groundwater only. Under Alternative GW-3, the land-use restrictions would remain in effect into the foreseeable future. Alternative GW-2 would likewise be protective of on-site exposure to humans through groundwater use restrictions. The monitoring program would be designed to determine whether contaminated groundwater was migrating past the property boundary. If PBOW-related contamination were to be found in off-site groundwater, a determination would be made at that time concerning the potential for additional actions.

Even with active P&T, the site groundwater model predicts that Alternatives GW-3 and GW-4 would not reduce the COC concentrations to drinking water quality within 150 years. It is

possible that the reducing conditions in the limestone bedrock groundwater may naturally attenuate the COCs in a reduced time frame. Note that the predictive modeling does not account for abiotic or biotic degradation (see Section 1.7). Alternatives GW-2 through GW-4 would provide a monitoring program that would be designed to determine whether contaminated groundwater was migrating past the property boundary. Alternative GW-1 is not protective from site-related contaminants under the assumption that the groundwater could be used as a potable source, because no further action would be taken to reduce the concentrations of COCs in groundwater, prevent or identify the migration of contaminated groundwater off site, or prevent human exposure to contaminated groundwater. However, even in the absence of site-related contamination, adverse human health risks are anticipated from consumption of PBOW groundwater due to naturally-occurring petroleum and inorganics. Thus, any action to address site-related COCs would not render groundwater suitable for potable use at this site.

No unacceptable ecological risks are presented by groundwater contamination at the site.

6.2 Compliance with Applicable or Relevant and Appropriate Requirements

Chemical-specific ARARs are not available for any of the COCs except nitrate and toluene, for which Ohio public drinking water standards are promulgated. Nitrate is the only COC with a chemical-specific ARAR in the limestone bedrock groundwater, and it is a bedrock COC only in the WARWP Area. Nitrate is also an overburden/shale COC in the PRRWP and WARWP Areas; toluene is an overburden/shale COC in TNTA. If it were determined that the overburden/shale groundwater were not a suitable drinking water source at these AOCs due to inadequate water yield and/or poor quality due to naturally occurring chemicals (refer to Section 2.6), then these Ohio drinking water standards would not be ARARs. Alternatives GW-4 and GW-3 would comply with ARARs through use of the P&T at the WARWP. Alternative GW-2 would not comply unless monitoring showed that nitrate in WARWP bedrock groundwater was naturally attenuating. GW-1 would not comply with this ARAR; even if natural attenuation were effective, GW-1 has no monitoring component to demonstrate its effectiveness.

Alternative GW-4, through use of ISEB to meet drinking water quality in the overburden/shale, is the only alternative that would meet the chemical-specific Ohio public drinking water standards for nitrate and toluene in the overburden/shale groundwater. As mentioned, if it was determined that the overburden/shale is not a potential drinking water source at these AOCs, then these standards would not qualify as ARARs.

Alternatives GW-2 through GW-4 would also comply with all location- and action-specific ARARs. Location- and action-specific ARARs do not apply to Alternative GW-1 because no action would be taken.

6.3 Long-Term Effectiveness and Permanence

The evaluation of long-term effectiveness and permanence for a given alternative depends on whether or not the overburden/shale and limestone are deemed to be Class III aquifers. Alternative GW-4 potentially provides the greatest reduction in residual risk by treating contaminated groundwater above RGs in both the overburden/weathered shale and limestone bedrock aquifers. The reduction of residual risk under Alternative GW-3 is potentially less than that under Alternative GW-4 because not all areas above RGs in the overburden/weathered shale aquifer would be treated. If it is determined that the overburden/shale groundwater does not represent a potential drinking water source within the AOCs, then the residual risks associated with GW-4 and GW-3 would be essentially equal, with both alternatives being protective of the limestone bedrock aquifer. Alternatives GW-1 and GW-2 do not reduce the residual risk at the site, but Alternatives GW-2 through GW-4 would manage the residual risk through groundwater use controls and groundwater monitoring. Alternative GW-1 does not implement any controls to manage residual risk or ensure the protection of human health and the environment. Groundwater modeling predicts concentrations of COC in limestone bedrock will remain above the RGs for at least 150 years.

None of the alternatives may completely restore groundwater to drinking water quality such that the site could be released for unrestricted use. Restoration of the overburden/weathered shale aquifer may be limited by an inability to achieve completely uniform distribution of treatment chemicals in situ. The presence of naturally occurring contaminants, such as petroleum hydrocarbons, in limestone bedrock groundwater may render portions of the aquifer undesirable for use as drinking water.

6.4 Reduction of Toxicity, Mobility, or Volume Through Treatment

Alternative GW-4 provides the greatest reduction of toxicity, mobility, or volume by treating 38.4 million gallons of overburden/weathered shale groundwater and a pore volume of 106 million gallons in the limestone bedrock groundwater. In comparison, Alternative GW-3 treats 23.7 million gallons of overburden/weathered shale groundwater and a pore volume of 106 million gallons of limestone bedrock groundwater. Alternatives GW-1 and GW-2 do not employ any form of treatment.

Alternatives GW-3 and GW-4 use ISEB to treat overburden/shale groundwater and a groundwater P&T system to contain, remove, and treat limestone bedrock groundwater. All of the treatment technologies result in the irreversible conversion or destruction of the COCs.

6.5 Short-Term Effectiveness

Alternative GW-1 has no short-term impact because no action would be taken. Remedial durations for the ISEB portions of GW-3 and GW-4 are expected to last 4.3 years and 7.8 years, respectively. According to the site groundwater model, contamination within the limestone bedrock groundwater zone will require more than 150 years for remediation to RGs, even with active P&T under Alternatives GW-3 and GW-4; attainment of drinking RGs is anticipated to take longer under GW-2. It is noted that natural attenuation may shorten this duration (refer to Section 2.6). The inability to quantify the impact of natural attenuation processes in the groundwater modeling effort may result in overly conservative projections about the time required to achieve RGs.

6.6 Implementability

Alternatives GW-2 through GW-4 are all technically implementable. All of the technologies are well developed, and equipment, specialists, and materials are readily available. All three alternatives can be easily evaluated over time by periodic groundwater monitoring. Alternatives GW-3 and GW-4 would require approval by OEPA to inject chemicals into the subsurface.

6.7 Cost

There is no cost associated with Alternative GW-1, as no action would be taken. The total present value costs of the remedial alternatives are presented below from lowest to highest:

- Alternative GW-1: $0
- Alternative GW-2: $2,002,000
- Alternative GW-3: $15,884,000
- Alternative GW-4: $19,614,000.

Capital and annual O&M costs are detailed for each of the active groundwater alternatives in Tables 5-1 through 5-3. The present value of O&M costs for the various alternatives are calculated in Table 5-4. A summary of capital, O&M and present value costs for the alternatives is presented in Table 5-5.

7.0 Conclusions

7.1 Remedial Action Objectives

This FS included an evaluation of pertinent information in the administrative record for groundwater underlying and associated with the TNT and Red Water Pond Areas. Based on this information, the following RAOs were identified for groundwater associated with these five AOCs:

1. Prevent on-site human exposure to groundwater containing COCs at concentrations that exceed RGs for residential drinking water.

2. Prevent human exposure to downgradient off-site groundwater containing COCs at concentrations that exceed RGs for residential drinking water.

Groundwater is not currently used on site, off-site migration of contamination has not been detected, and groundwater is not known to be used as drinking water in households surrounding PBOW. Therefore, no current exposure to contaminants in PBOW groundwater exists. As long as NASA owns the property, it is expected that RAO No. 1 would be met. However, controls are not currently in place to protect potential future off-site users of groundwater.

7.2 Development and Evaluation of Remedial Alternatives

A broad range of remedial alternatives was developed in the FS that allow the project risk managers to assess the relative cost effectiveness of different remedial strategies that employ varying degrees of active remediation. Each of these was developed under the assumption that groundwater would potentially be used as a potable source. However, based on naturally occurring constituents in the background wells, this water does not appear suitable for potable use.

These alternatives were developed and the targeted areas for groundwater remediation were identified using a site-specific leaching and groundwater fate and transport model as well as groundwater analytical results. The following remedial alternatives were developed and evaluated for contaminated groundwater at PBOW:

- Alternative GW-1: No further action
- Alternative GW-2: Groundwater monitoring, MNA, and institutional controls
- Alternative GW-3: ISEB/P&T for mitigation/protection of the limestone bedrock groundwater

- Alternative GW-4: ISEB/P&T for mitigation/protection of the overburden/shale and limestone bedrock groundwater.

These remedial alternatives were evaluated against seven criteria as described in Chapter 5.0, and some general conclusions are presented below.

Alternative GW-1 does not protect human health and may not comply with Ohio drinking water standard ARARs for toluene and nitrate under the assumption that site groundwater could be used as a potable water source. This would represent a failure to meet the two threshold criteria required under CERCLA, protection of human health and the environment and compliance with ARARs. However, even if DOD-related constituents are excluded from the evaluation, use of this water would exceed OEPA and EPA criteria for potable purposes and would not be protective of human health because of naturally occurring chemicals. Given the natural conditions of the groundwater, and its meeting of Class III (nondrinking) criteria, State drinking water standards would not be ARARs. If Alternative GW-1 were employed, an assessment of whether DOD-related contamination is migrating off site could not be made because there is no monitoring component of this alternative.

Alternative GW-2 protects human health and the environment by establishing groundwater use restrictions to prevent exposure to contaminated groundwater on site. Long-term groundwater monitoring would protect the surrounding community by providing advanced notice of any potential off-site movement of contamination, allowing additional remedial action to be taken if necessary. The alternative may or may not comply with all ARARs, as the concentrations of nitrate and toluene in groundwater are above Ohio drinking water standards. It is possible that the concentrations of these chemicals may attenuate with time. MNA is included under this alternative. Alternative GW-2 does not include an active treatment component. The total present value cost of the alternative is estimated to range from $1.4 to $3.0 million over 150 years.

Alternative GW-3 protects human health and the environment by establishing groundwater use restrictions and a long-term groundwater monitoring program as in Alternative GW-2. This alternative also includes treatment of groundwater in the overburden/weathered shale and limestone bedrock aquifers. The objective of this treatment is to reduce the concentration of COCs in the limestone bedrock aquifer to drinking water quality, although groundwater modeling projects that this would take more than 150 years. Despite this objective, the aquifer is contaminated with naturally occurring constituents, such as petroleum hydrocarbons and H_2S,

that may make the limestone bedrock groundwater unsuitable as potential drinking water in the vicinity of the TNT and Red Water Pond Areas. The treatment strategy would not ensure that all areas within the overburden/weathered shale aquifer would meet drinking water quality in the foreseeable future. The suitability of the overburden/shale unit as a potential drinking water source is doubtful due to its low yield and marginal quality (e.g., elevated concentrations of naturally-occurring chloride, sulfate, TDS, and sodium). The treatment components of this alternative include a combination of ISEB in the overburden/weathered shale aquifer and P&T in the limestone bedrock aquifer. Groundwater treatment should ensure compliance with all ARARs, including Ohio drinking water standards. The total present value cost of the alternative is estimated to range from $11.1 to $23.8 million over 150 years.

Alternative GW-4 protects human health and the environment by establishing groundwater use restrictions and a long-term groundwater monitoring program, as in Alternatives GW-2 and GW-3. The objective of this treatment is to reduce the concentrations of COCs in both the overburden/weathered shale and limestone bedrock aquifer to drinking water quality, although groundwater modeling projects that this would take more than 150 years in the limestone. The treatment components of this alternative include a combination of ISEB in the overburden/weathered shale aquifer and P&T in the limestone bedrock aquifer. The ISEB component in the overburden/weathered shale would be applied over a larger area than in Alternative GW-3. As mentioned in the preceding paragraph, the contamination of both aquifers by naturally occurring constituents and the low yield of the overburden/weathered shale groundwater may make both aquifers unsuitable sources of drinking water even in the absence of any contamination by TNT operations. Groundwater treatment should ensure compliance with all ARARs, including Ohio drinking water standards. The total present value cost of the alternative is estimated to range from $13.8 to $29.4 million over 150 years.

7.3 Other Considerations

The following general observations are presented to give the project risk managers some additional perspective on remedial action for groundwater at PBOW:

- Although one of the objectives of Alternatives GW-3 and GW-4 is to restore the limestone bedrock aquifer to drinking water quality, portions of the aquifer are contaminated by naturally occurring petroleum hydrocarbons and H_2S and the concentration of TDS is elevated. Therefore, this aquifer may never be a viable drinking water source due to natural contamination that is unrelated to previous TNT manufacturing operations at PBOW.

- The petroleum hydrocarbons present in the limestone bedrock aquifer and the anaerobic environment induced by this contamination have created conditions in

the aquifer that are conducive to the natural biodegradation of nitrate and nitroaromatic compounds without any human intervention.

- The ability of ISEB technology to reductively transform nitroaromatic compounds is well documented. However, the ultimate effectiveness of any in situ technology is the ability to get complete contact between contaminants and chemical reagents. Although the implementation of ISEB in the overburden/weathered shale aquifer would significantly reduce the mass of contamination, it is uncertain whether the aquifer could be returned to conditions such that it would be suitable or desirable for use as drinking water.

- The relatively complicated nature of the proposed P&T systems for the limestone bedrock aquifer substantially result from the necessity to treat constituents that are not related to TNT manufacturing operations, such as petroleum hydrocarbons, iron, and TSS. The natural levels of TDS in the groundwater make the normally low-cost option of direct discharge to surface water essentially impractical.

- The target remedial areas for ISEB in Alternative GW-3 and P&T in Alternatives GW-3 and GW-4 were selected largely on the basis of groundwater modeling predictions. While groundwater modeling is a useful tool to help assess future contaminant transport, it is limited by the amount and type of data available. To overcome the inherent uncertainties present in any groundwater modeling effort, conservative assumptions are used to estimate values that may not be well defined. These assumptions tend to overestimate the transport of contamination, particularly when the model is projecting values over extended time frames. Some of the bias in estimating parameters are additive, causing a further bias in the results. Specifically, the leaching component of the model is likely biased high. When the leaching data is coupled with the groundwater fate and transport model that lacks a degradation component, the result is the simulations produce higher groundwater concentrations and larger plumes than are likely to occur. The areas projected to require treatment may, therefore, be overestimated. This is further substantiated by the fact that nitroaromatics have only been sporadically detected in the limestone bedrock groundwater.

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TABLES

Table 1-1

Previous Environmental Investigations and Activities
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

Date	Contractor	Area				
		TNT Area A	TNT Area B	TNT Area C	WARWP Area	PRRWP Area
September - December 1945	U.S. Army	Decontamination				
1954 - 1958	Ravenna Arsenal	Decontamination				
~1963	Government Services Administration	Decontamination				
1977	NASA					Ditch diversion including excavation, removal, and backfilling resulting from observed reddish brown water.
1983	OEPA				Preliminary Assessment	
1984	Battelle Laboratories				1 surface soil sample from spoils area	
May 1985	Resident Department of Interior Fisheries Research Unit				Placed tap nets in western pond to evaluate aquatic life	
June - August 1985	Ohio Army National Guard				34 sediment samples from western pond	
December 1986	Ohio Army National Guard				surface water samples from Pipe Creek	
December 1987	Ohio Army National Guard				surface water samples from Pipe Creek	

Table 1-1

Previous Environmental Investigations and Activities
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

Date	Contractor	Area				
		TNT Area A	TNT Area B	TNT Area C	WARWP Area	PRRWP Area
1989	Shaw				Contamination Evaluation	
					5 surface soil samples; 1 overburden gw well installed and sampled	6 soil samples; 1 surface water sample; 1 overburden gw well installed and sampled
1991	SAIC				Preliminary Assessment	
1993	MK	**Site inspection**				
		1 soil sample; 1 collocated surface water and sediment sample pair; 3 overburden gw samples	2 surface soil samples; 2 collocated surface water and sediment sample pairs; install and sample 2 overburden gw wells	2 surface soil samples; 2 collocated surface water and sediment sample pairs	3 collocated surface water and sediment sample pairs; 3 overburden gw wells installed and sampled	sediment and surface soil samples
1994	D&M	**TNT Areas site investigation**			**Focused Remedial Investigation**	
		36 soil samples from 28 borings; installed 2 overburden and 2 bedrock wells; 7 gw samples from 5 overburden and 2 bedrock wells	34 soil samples from 26 borings; 2 overburden gw samples	30 soil samples from 26 borings; installed 4 overburden and 1 bedrock wells; 3 gw samples from 2 overburden and 1 bedrock well	40 total (surface and subsurface) soil samples; 12 sediment samples; 5 surface water samples; installed and sampled 2 overburden and 2 bedrock wells	63 total (surface and subsurface) soil samples; installed and sampled 3 overburden and 1 bedrock well
September - October 1996	Shaw	**Sitewide groundwater investigation**				
		5 overburden and 2 bedrock gw samples	2 overburden gw samples	4 overburden and 1 bedrock gw samples	7 overburden and 2 bedrock gw samples	4 overburden and 2 bedrock gw samples
November 1997		**Sitewide groundwater investigation**				
		5 overburden and 2 bedrock gw samples	2 overburden and 2 bedrock gw samples	6 overburden and 1 bedrock gw samples	5 overburden and 1 bedrock gw samples	4 overburden and 1 bedrock gw samples
May 1998		**Sitewide groundwater investigation**				
		5 overburden and 2 bedrock gw sample	2 overburden and 2 bedrock gw samples	6 overburden and 1 bedrock gw sample	5 overburden and 1 bedrock gw sample	4 overburden and 2 bedrock gw sample

Table 1-1

Previous Environmental Investigations and Activities
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

Date	Contractor	Area				
		TNT Area A	TNT Area B	TNT Area C	WARWP Area	PRRWP Area
1998	Shaw	**Remedial Investigation**				
			391 field screening and 40 confirmation soil samples; 2 surface water; 5 sediment samples		19 surface soil; 37 subsurface soil; 14 direct-push gw; 6 surface water; 6 sediment samples	20 surface soil; 39 subsurface soil; 20 direct-push gw samples
June - October 2000		427 field screening and 39 confirmation soil samples; 10 surface water; 15 sediment; 9 overburden piezometer gw samples		383 field screening and 40 confirmation soil; 10 surface water; 15 sediment, 9 overburden piezometer samples		
2001	Shaw	**Baseline Ecological Risk Assessment (BERA)**			**Screening Level Ecological Risk Assessment and BERA**	
2001	Shaw	**Baseline Human Health Risk Assessment (BHRRA) for soil, surface water, and sediment**				**BHRRA for soil**
July 2001	Shaw	**Remedial Investigation, continued**				**RI, cont**
		2 direct-push overburden gw samples; 1 bedrock gw well installed	2 direct-push overburden gw samples; 2 bedrock gw wells installed	2 direct-push overburden gw samples; 1 bedrock gw well installed		1 bedrock well installed
September - October 2001	Shaw	**Expanded Groundwater Remedial Investigation - "Dry season" groundwater sampling**				
		1 overburden and 3 bedrock gw samples	1 overburden and 4 bedrock gw samples	2 overburden and 2 bedrock gw samples	1 bedrock gw sample	2 bedrock gw samples
April 2002	Shaw	**Remedial Investigation, continued - "Wet season" groundwater sampling**				
		2 overburden and 3 bedrock wells	2 overburden and 4 bedrock wells	3 overburden and 2 bedrock wells	1 bedrock well	2 bedrock wells
September 2002	WTI		Removal of contaminated soil began. Contaminated soil was excavated, treated, and disposed off site.			
December 2002	Shaw				FFS for soil	

Table 1-1

Previous Environmental Investigations and Activities
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

Date	Contractor	Area				
		TNT Area A	TNT Area B	TNT Area C	WARWP Area	PRRWP Area
January 2003	WTI					Planned "Hot Spot" removed, treated and disposed off site. Additional organic layer delineation began.
2003	Shaw	FFS for soil and sediment		FFS for soil and sediment		
April 2005	Shaw				Preliminary Draft Proposed Plan	
August 2005	Shaw				Preliminary Draft Decision Document	
October 2004	Shaw		Draft Proposed Plan and Decision Document			
August 2005	Shaw	Preliminary Draft Proposed Plan and Decision Document		Preliminary Draft Proposed Plan and Decision Document		
September 2006	Shaw	**Baseline Human Health Risk Assessment for Groundwater**				

Notes:
DM = Dames & Moore, Inc.
FFS = Focused feasibility study
gw = groundwater
MK = Morrison-Knudsen Ferguson Corporation
NASA = National Aeronautics and Space Administration
OEPA = Ohio Environmental Protection Agency
PRRWP - Pentolite Road Red Water Pond
SAIC = Science Applications International, Inc.
Shaw = Shaw Environmental, Inc.
WARWP = West Area Red Water Ponds

Table 3-1

Remedial Goal Options for Bedrock Groundwater
TNT and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

Chemicals of Concern for Both Limestone Bedrock and Overburden/Shale Groundwater[a]	Remedial Goal Option (µg/L)
2,4,6-Trinitrotoluene	*3*
2,4-Dinitrotoluene	*0.5*
2,6-Dinitrotoluene	*0.5*
2-Amino-4,6-dinitrotoluene	*1*
4-Amino-2,6-dinitrotoluene	*1*
2-Nitrotoluene	*0.6*
4-Nitrotoluene	*4*
Nitrobenzene	*0.5*
4,6-Dinitro-2-methylphenol	2
3-Nitroaniline	2
Nitrate	10,000
Additional Chemicals of Concern for Overburden/Shale Groundwater Only[b]	**Remedial Goal Option (µg/L)**
1,3,5-Trinitrotoluene	109
1,3-Dinitrobenzene	0.4
3-Nitrotoluene	122
2,4-Dinitrophenol	7.3
4-Nitrophenol	4.9
3-Nitroaniline	1.1
Dibenzofuran	1.2
Fluorene	24
Toluene	1,000

Notes: µg/L = micrograms per liter; RGO = remedial goal option

[a] Remedial Goal Options (RGO) for the limestone bedrock chemicals of concern (COC) were derived based on back-calculations from the groundwater risk assessment (Shaw, 2006) as described in Section 3.4 of the text. The RGO for nitrate equals the maximum contaminant level (MCL) for drinking water (EPA, 2006).

[b] RGOs for the additonal overburden/shale groundwater COCs are the risk-based screening concentrations found in the risk assessment (Shaw, 2006). The exception is the toluene RGO which equals the MCL (EPA, 2006).

Sources:

Shaw Environmental, Inc., 2006, *Baseline Human Health Risk Assesment of Groundwater* , Final, Plumbrook Ordnance Works, Sandusky, Ohio, September.

U.S. Environmental Protection Agency (EPA), 2006, *2006 Edition of the* Drinking Water Standards and Health Advisories, Office of Water, August, EPA 822-R-06-013.

Table 3-2

Groundwater Contaminants of Concern
Delaware Limestone Bedrock Unit
TNT and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

TNT Area A	TNT Area B	TNT Area C	PRRWP Area	WARWP Area
Nitroaromatics	***Nitroaromatics***	***Nitroaromatics***	***Nitroaromatics***	***Nitroaromatics***
2,4,6-Trinitrotoluene	2,4,6-Trinitrotoluene	2,4,6-Trinitrotoluene	2,4,6-Trinitrotoluene	2,4-Dinitrotoluene
2,4-Dinitrotoluene	2,4-Dinitrotoluene	2,4-Dinitrotoluene	2,4-Dinitrotoluene	2,6-Dinitrotoluene
2,6-Dinitrotoluene	2,6-Dinitrotoluene	2,6-Dinitrotoluene	2,6-Dinitrotoluene	Nitrobenzene
2-Amino-4,6-dinitrotoluene	2-Amino-4,6-dinitrotoluene	2-Amino-4,6-dinitrotoluene	2-Amino-4,6-dinitrotoluene	
4-Amino-2,6-dinitrotoluene	4-Amino-2,6-dinitrotoluene	4-Amino-2,6-dinitrotoluene	4-Amino-2,6-dinitrotoluene	***SVOCs***
2-Nitrotoluene			Nitrobenzene	4,6-Dinitro-2-methylphenol
4-Nitrotoluene				3-Nitroaniline
Nitrobenzene				
				Wet Chemistry
				Nitrate

Notes:
SVOCs - Semivolitale organic compounds
PRRWP - Pentolite Road Red Water Pond
WARWP - West Area Red Water Pond

Table 3-3

Groundwater Contaminants of Concern
Overburden/Shale
TNT and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

TNT Area A	TNT Area B	TNT Area C	PRRWP Area	WARWP Area
Nitroaromatics	***Nitroaromatics***	***Nitroaromatics***	***Nitroaromatics***	***Nitroaromatics***
2,4,6-Trinitrotoluene	2,4,6-Trinitrotoluene	2,4,6-Trinitrotoluene	2,4,6-Trinitrotoluene	2,4-Dinitrotoluene
2,4-Dinitrotoluene	2,4-Dinitrotoluene	2,4-Dinitrotoluene	2,4-Dinitrotoluene	2,6-Dinitrotoluene
2,6-Dinitrotoluene	2,6-Dinitrotoluene	2,6-Dinitrotoluene	2,6-Dinitrotoluene	Nitrobenzene
2-Amino-4,6-dinitrotoluene	2-Amino-4,6-dinitrotoluene	2-Amino-4,6-dinitrotoluene	2-Amino-4,6-dinitrotoluene	*1,3,5-Trinitrobenzene*
4-Amino-2,6-dinitrotoluene	4-Amino-2,6-dinitrotoluene	4-Amino-2,6-dinitrotoluene	4-Amino-2,6-dinitrotoluene	*1,3-Dinitrobenzene*
2-Nitrotoluene	*1,3-Dinitrobenzene*	*1,3-Dinitrobenzene*	Nitrobenzene	*2,4,6-Trinitrotoluene*
4-Nitrotoluene		*2-Nitrotoluene*	*1,3,5-Trinitrobenzene*	*2-Amino-4,6-dinitrotoluene*
Nitrobenzene		*3-Nitrotoluene*	*1,3-Dinitrobenzene*	*4-Amino-2,6-dinitrotoluene*
1,3-Dinitrobenzene [a]		*4-Nitrotoluene*		*3-Nitrotoluene*
3-Nitrotoluene			***SVOCs***	
			2,4-Dinitrophenol	***SVOCs***
VOCs			*3-Nitroaniline*	4,6-Dinitro-2-methylphenol
Toluene			*4,6-Dinitro-2-methylphenol*	3-Nitroaniline
			4-Nitrophenol	*2,4-Dinitrophenol*
			Dibenzofuran	
			Fluorene	***Wet Chemistry***
				Nitrate
			Wet Chemistry	
			Nitrate	

Notes:
SVOCs - Semivolitale organic compounds
VOCs - Volatile organic compound
PRRWP - Pentolite Road Red Water Pond
WARWP - West Area Red Water Pond

[a] Analytes shown in italics are chemicals of concern (COCs) for overburden/shale groundwater only. Other chemicals are COCs in both the overburden/shale and limestone bedrock groundwater.

Table 3-4

Basis for Areal Extent of Contamination in Overburden/Shale and Its Potential Impact to Bedrock Groundwater
Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

Site Area	Building #	Building Type	Estimated Areal Extent (ft^2)	Basis for Estimated Areal Extent of Contamination in OB/Shale Groundwater	Potential Impact to Limestone Bedrock?	Basis for OB/Shale Contamination to Potentially Impact Bedrock
TNTA	111	Mono house	4900	70 feet centered around drowning tank	Yes	Model indicates 2,4-DNT and 2,6-DNT contamination to bedrock
	112	Bi-tri house	4900	70 feet centered around drowning tank	No	Not applicable
	116	Wash house	15500	30-foot boundary around buildings and overburden/shale groundwater sample location GW-04.	No	Not applicable
	119	Acid & fume recovery	13000	30 feet around building, including soil remediation area	Yes	Model indicates 2,6-DNT contamination to bedrock
	126	Wash house	16300	30 feet around buildings and basin	Yes	Model indicates TNT contamination to bedrock
	131	Mono house	4900	70 feet centered around drowning tank	No	Not applicable
	132	Bi-tri house	4900	70 feet centered around drowning tank	No	Not applicable
	146	Wash house	47000	30 feet around building and basin; extended north and east to include contaminated groundwater (TNTA-MW11)	Yes	TNT present at 11,500 µg/L in OB/shale; combined ADNTs present at 2,800 µg/L
	185	DNT nitrating house	4900	70 feet centered around drowning tank	Yes	Model indicates 2,4-DNT and 2,6-DNT contamination to bedrock
TNTB	412	Bi-tri house	8100	30 feet around norther portion of building, extended northward to include soil remediation area	No	Not applicable
	417	Wastewater settling tanks	44500	rectangular area around tanks to include soil remediation areas and contaminated groundwater (MK-MW17)	No	Not applicable
	452	Bi-tri house	5800	30 feet around building, extended to include soil remediation area	No	Not applicable
	453	Fortifier house	4900	70 feet centered around drowning tank	No	Not applicable
	456	Wash house	14000	30 feet around buildings and basin, modified based on soil remediation area	No	Not applicable
	463	Fortifier house	16600	70 feet around drowning tank, greatly enlarged south and east to include soil remediation area	No	Not applicable
	466	Wash house	16400	30 feet around building and basin, modified to include Northwest Nailhouse soil remediation area	Yes	TNT present in remediation pit water at 2,480 µg/L
	472	Bi-tri house	4900	70 feet centered around drowning tank	No	Not applicable

Table 3-4

Basis for Areal Extent of Contamination in Overburden/Shale and Its Potential Impact to Bedrock Groundwater
Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

Site Area	Building #	Building Type	Estimated Areal Extent (ft^2)	Basis for Estimated Areal Extent of Contamination in OB/Shale Groundwater	Potential Impact to Limestone Bedrock?	Basis for OB/Shale Contamination to Potentially Impact Bedrock
TNTC	603	Fortifier house	4900	70 feet centered around drowning tank	No	Not applicable
	611	Mono house	4900	70 feet centered around drowning tank	No	Not applicable
	616	Wash house	16700	30 feet around buildings and basin	Yes	Model indicates TNT and 2,6-DNT contamination to bedrock
	681	Mono house	4900	70 feet centered around drowning tank	Yes	2-Nitrotoluene and 4-nitrotoluene are present in OB/shale groundwater at 2310 µg/L and 1290 µg/L, respectively
	682	Bi-tri house	10000	30 feet around buildings and 70-feet centered around drowning tank, modified slightly to include soil remediation area	Yes	Model indicates TNT contamination to bedrock
	683	Fortifier house	4900	70 feet centered around drowning tank	Yes	Model indicates TNT contamination to bedrock
	692	Bi-tri house	9000	30 feet around buildings and 70-feet centered around drowning tank, modified slightly to include soil remediation area	No	Not applicable
	693	Fortifier house	4900	70 feet centered around drowning tank	No	Not applicable

Notes:

ft^2 = square feet; OB/Shale = Overburden/shale; 2,4-DNT = 2,4-dinitrotoluene; 2,6-DNT = 2,6-dinitrotoluene; TNT = 2,4,6-trinitrotoluene

The red water pond areas do not have associated point sourvce building areas as do the TNT areas. The estimated areal extent of the red water pond areas is thus based soley on the analytical results of samples collectd within these respective areas.

Table 3-5

Area and Volume Estimates - Overburden/Shale Groundwater Contamination
Protection of Bedrock Groundwater Only[a]
TNT and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

Site Area	Building #	Area (ft^2)	Depth to Water Table[b] (ft)	Overburden Layer Thickness (ft)	Weathered Shale Thickness (ft)	Thickness of Contaminated OB/WS Water[c] (ft)	Volume of Contaminated Groundwater[d] (gallons)
TNTA Area A	111	4,900	6	9.4	48.25	27.5	201,586
	119	13,000	14	10	49.4	20.7	402,574
	126	16,300	9	8	4	3	73,154
	146	47,000	4	7.1	42.4	24.3	1,708,582
	185	4,900	20	9.4	55.9	20	146,608
Totals		**86,100**					**2,532,504**
TNT Area B	466	16,400	5	5.3	0.7	1	24,534
Totals		**16,400**					**24,534**
TNT Area C	616	16,700	8	10	3	5	124,916
	681	4,900	14	16.3	27.5	20	146,608
	682	10,000	8	15.6	31.9	23.6	352,308
	683	4,900	9	11.3	25	20	146,608
Totals		**36,500**					**770,440**
WARWP Area	--	**320,000**	6	19	0	13.0	**6,223,360**
PRRWP Area	--	**370,000**	6	31	0	25.0	**13,838,000**
Combined Total Area:		**829,000**	**Combined Total Water Volume:**				**23,388,838**

Notes: ft = feet; ft^2 = square feet; OB/WS = overburden/weathered shale; WARWP = West Area Red Water Pond; PRRWP = Pentolite Road Red Water Pond

[a] Based on protection of the limestone bedrock groundwater to residential drinking water quality.
[b] Based on measured or estimated depth durings the wet period of the year.
[c] Refer to Section 3.7 of the text for assumptions concerning thickness of the contamination within the overburden shale water.
[d] Calculated as: Area (ft^2) x thickness of contamination (ft) x effective porosity (0.2) x 7.48 (gallons/ft^3).

Table 3-6

Area and Volume Estimates - Overburden/Shale Groundwater Contamination
Mitigation/Protection of All Groundwater[a]
TNT and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

Site Area	Building #	Area (ft^2)	Depth to Water Table[b] (ft)	Overburden Layer Thickness (ft)	Weathered Shale Thickness (ft)	Thickness of Contaminated OB/WS Water[c] (ft)	Volume of Contaminated Groundwater[d] (gallons)
TNTA	111	4900	6	9.4	48.25	27.5	201,783
	112	4900	9.5	9	2	1.5	10,996
	116	15500	8	9	2	3	69,569
	119	13000	14	10	49.4	20.7	402,601
	126	16300	9	8	4	3	73,159
	131	4900	6	12	4	10	73,309
	132	4900	16	7.1	43.5	20	146,618
	146	47000	4	7.1	42.4	24.3	1,708,696
	185	4900	20	9.4	55.9	20	146,615
TNTA Totals		**116300**					**2,833,345**
TNTB	412	8100	6	7	0	1	12,118
	417	44500	4	3.5	1.5	1	66,576
	452	5800	15	15.3	0.8	1.1	9,545
	453	4900	14	16	1	3	21,993
	456	14000	3	3.5	0.5	1	20,945
	463	16600	8	10.6	0.7	3.3	81,956
	466	16400	5	5.3	0.7	1	24,536
	472	4900	5	4.4	1.2	0.6	4,399
TNTB Totals		**115200**					**242,069**
TNTC	603	4900	8	8	3	3	21,993
	611	4900	4	11	12	19	139,287
	616	16700	8	10	3	5	124,924
	681	4900	14	16.3	27.5	20	146,618
	682	10000	8	15.6	31.9	23.6	352,332
	683	4900	9	11.3	25	20	146,618
	692	9000	8	11	25	20	269,298
	693	4900	7	16.3	28.1	23.4	171,176
TNTC Totals		**60200**					**1,372,245**
WARWP	--	**440,000**	6	19	0	13	**8,557,692**
PRRWP	--	**680,000**	6	31	0	25	**25,433,700**
Combined Total Area:		**1,411,700**		**Combined Total Water Volume:**			**38,439,052**

Notes: ft = feet; ft^2 = square feet; OB/WS = overburden/weathered shale; WARWP = West Area Red Water Pond; PRRWP = Pentolite Road Red Water Pond

[a] Based on protection of the limestone bedrock groundwater to residential drinking water quality.
[b] Based on measured or estimated depth durings the wet period of the year.
[c] Refer to Section 3.7 of the text for assumptions concerning thickness of the contamination within the overburden shale water.
[d] Calculated as: Area (ft^2) x thickness of contamination (ft) x effective porosity (0.2) x 7.48 (gallons/ft^3).

Table 3-7

Potential Location- and Chemical-Specific Applicable or Relevant and Appropriate Requirements
Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

Description	Requirement(s)	Prerequisite(s)	Federal Citation	OH Citation	Comments
LOCATION-SPECIFIC					
Wetlands and Floodplains					
Executive Order 11988	Floodplain Management	Actions within a floodplain	NA	NA	**TBC** if remedial action is taken within a floodplain. Portions of the west area of the PBOW are within the 100-year floodplain.
Endangered Species					
Endangered Plant Species	Prohibits removal or destruction of endangered plant species.	Presence of state-protected species or their critical habitat	NA	ORC 1518.02 OAC 1501-31-23.01, A-B	**Applicable** if remedial action has the potential to impact state-protected species on site. One state-endangered bird species and one state-threatened plant species are associated with the PBOW.
Endangered Animal Species	Prohibits removal or destruction of endangered animal species.		NA	ORC 1531.25 OAC 1501-18-1.03, A	
Cultural Resources					
Archaeological Resource Protection Act and its implementing regulations	May not excavate, remove, damage, or otherwise alter or deface such resources unless by permit or exception	Action that would impact archaeological resources on public land	16 USC 470aa-470mm 43 CFR 7.4(a) 43 CFR 7.5(b)(1)		**Applicable** if cultural or historical resources are discovered on site during remedial activity.
	Must protect any archaeological resources discovered.	Excavation activities that inadvertently discover archaeological resources			
Native American Graves Protection and Repatriation Act and its implementing regulations	Must stop activities in the area of discovery and make a reasonable effort to secure and protect the objects discovered.	Excavation activities that inadvertently discover such resources on federal lands or under federal control	25 USC 3001 – 3013 43 CFR 10.4		
	Must consult with Indian tribe likely to be affiliated with the objects to determine further disposition per 40 CFR 10.5(b)				
National Historic Preservation Act and its implementing regulations	Must take action to recover and preserve artifacts.	Alteration of terrain that threatens significant scientific, prehistoric, or archaeological data.	16 USC 470 36 CFR 65		

Table 3-7

Potential Location- and Chemical-Specific Applicable or Relevant and Appropriate Requirements
Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

Description	Requirement(s)	Prerequisite(s)	Federal Citation	OH Citation	Comments
CHEMICAL-SPECIFIC					
Maximum Contaminant Levels	Ohio Primary Drinking Water Regulations	Groundwater which is a current or future drinking water source	40 CFR 141.62	OAC 3745-81-11 A OAC 3745-81-12 D	**Relevant and Appropriate** to groundwater that is a current or future drinking water source.
Drinking Water Standards and Health Advisories	Provides non-promulgated secondary maximum contaminant levels based on aesthetic qualities such as taste, odor, and appearance. Also provides nonpromulated health-based advisories. .	Presence of site contamination	EPA 822-R-04-013, 2006	NA	**TBC.** Numeric values may be used as guidance only to support development of cleanup standards for site contaminants or for the evaluation of aquifer water quality.

CFR - Code of Federal Regulations
NA - Not applicable
OAC - Ohio Administrative Code (regulation)
ORC - Ohio Revised Code (statute)
USC - U.S. Code

Table 3-8

Potential Action-Specific Applicable and Relevant and Appropriate Requirements
TNT and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works Sandusky, Ohio

Requirement		Prerequisite(s)	Federal Citation	OH Citation	Applicable Alternative	Comments
Groundwater Protection						
Underground Injection Control Program	Defines underground injection well classes and provides procedures for construction, operation, and permitting of wells.	Construction and operation of an injection well(s)	NA	OAC 3745-34-13	GW-3/GW-4	**Applicable** to alternatives involving underground injection of treated groundwater and/or other substances.
Air Quality						
Air Quality Program	Regulates air emission sources.	Emission of air contaminants.	NA	OAC 3745-15-05	GW-3/GW-4	**Applicable** to air emissions from groundwater treatment system. However, estimated emissions from system fall below "deminimis" thresholds, qualifying system for a regulatory exemption.
Hazardous Waste Management						
Hazardous Waste Identification and Generator Requirements	Requires a hazardous waste determination be made for all solid waste. Details the requirements for generator management of hazardous waste.	Hazardous waste as defined in the regulations	40 CFR 262	OAC 3745-51 OAC 3745-52	GW-3/GW-4	**Applicable** to alternatives involving generation of hazardous waste.
Institutional Controls						
Uniform Environmental Covenants Act	Standards for environmental covenants	Site use restrictions	NA	ORC 5301.80 to 5301.92	GW-2 GW-3/GW-4	**Applicable to** alternatives that require covenants.

GW-1 - No action No action

GW-2 - Groundwater Monitoring and Land-Use Controls (LUC)

GW-3/GW-4 - In-situ Enhanced Bioremediation (ISEB), Groundwater Extraction and Treatment, GW monitoring, and Land-Use Controls

CFR - Code of Federal Regulations

GW - Groundwater

NA - Not applicable

OAC - Ohio Administrative Code (regulation)

ORC - Ohio Revised Code (statute)

Table 4-1

Summary of Preliminary Screening Process Options for Groundwater Remediation
TNT and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

General Response Action	Remedial Technology	Process Option	Effectiveness	Implementability	Relative Cost	Retained	Comments
No Action	None	None	Poor	Good	None	Yes	Retained for comparison per the NCP
Institutional Controls	Monitored Natural Attenuation	Monitoring	Good	Unknown	Low to Moderate	Yes	Potentially applicable in conjunction with other technologies. Additional site specific data required.
	Groundwater Use Restrictions	Controls on future use of groundwater	Fair	Excellent	Low	Yes	Does not meet RGs but bedrock groundwater not suitable for potable water source
	Long-Term Monitoring	Monitoring	Good	Fair	Low to Moderate	Yes	Cost effective if combined with institutional controls, natural attenuation or other active remediation.
In Situ Treatment	Bioremediation	Enhanced Bioremediation (anaerobic)	Excellent	Poor	Moderate to High	Yes	Effective for the overburden/shale groundwater only.
		Apatite II (anaerobic/aerobic)	Good	Poor	Unknown	No	Developing technology not available for full application.
	Chemical	Chemical Oxidation	Good	Poor	Moderate to High	No	Unable to estimate costs adequately.
		Chemical Reduction	Good	Poor	High	No	Unable to evaluate cost effectiveness.
Ex Situ Treatment	Bioremediation	Ex Situ Biological Treatment	Good	Good	Moderate to High	Yes	Potentially effective to treat COCs in groundwater.
		Phytoremediation (Constructed Wetlands)	Poor	Excellent	Moderate to High	No	Technology not proven for nitroaromatics.
	Physical	Air Stripping	Good	Excellent	Low to Moderate	Yes	Cost effective for VOC removal.
		Granular Activated Carbon	Excellent	Good	Moderate	Yes	Cost effective for treating nitroaromatics and VOCs
		Suspended Solids Removal	Good	Excellent	Moderate	Yes	Effective for removing suspended solids.
Containment	Groundwater Extraction	Pumping Wells	Poor	Fair	Low	Yes	Potentially effective to remove and treat contaminated groundwater.
Groundwater Disposal Options	Discharge	Reinjection	Good	Poor	Moderate	Yes	Most cost effective disposal for Red Water Ponds areas.
		Existing Surface Water Body	Excellent (Creeks nearby all sites)	Poor	Low	No	Groundwater requires pretreatment prior to discharge.
	Treatment	NASA WWTP	Poor	Unknown	Unknown	No	Groundwater requires pretreatment prior to discharge. Operation and design of plants not available.
		POTW	Poor	Poor	Unknown	No	Groundwater requires pretreatment prior to discharge. POTW piping currently no present.

Table 4-2

Potential Surface Water Critera for Discharge of Treated Water from P&T Systems
Constituents in WARWP and PRRWP Area Groundwater
Former Plum Brook Ordnance Works, Sandusky, Ohio

	Statewide		Lake Erie Drainage Basin			Sandusky River Basin		
Criteria	**Antidegradation** BADCT 30-day average (µg/L)	**Aesthetic Conditions** OMZM	**Human Health** Non-Drinking (µg/L)	**Aquatic Life** OMZA (µg/L)	**Wildlife** OZMA (µg/L)	**Aquatic Life Warmwater Habitat** OMZA (µg/L)	IMZM (µg/L)	**Water Supply Agricultural** OMZA (µg/L)
MBAS (Foaming agents)		0.50 mg/L	NE					
Oil and grease		10 mg/L	NE					
pH								6.5 - 9.0
Dissolved Oxygen								5 mg/L
Dissolved Solids			NE	1,500,000				
Chlorides			NE	NE				
Fluoride			NE	NE				2000
Nitrates + Nitrites			NE	NE				100,000
Benzene	5		310	160				
Carbon disulfide			NE	15				
Chlorobenzene			3,200	47				
Ethylbenzene	5		8,900	61				
Methylene chloride			2,600	1,900				
Toluene	5		51,000	62				
Xylenes (total)	5		83,000	27				
Bis(2-ethylhexyl)phthalate			32	8.4				
2,4-dimethylphenol			8,700	15				
2-Methylnapthalene			NL	NL				
2-Methylphenol			NE	67				
4-Methylphenol			NE	53				
Napthalene			1,200	21				
Phenanthrene			NE	2.3				
Phenol			2,400	400				
2-Amino-4,6-dinitrotoluene				18				
4-Amino-2,6-dinitrotoluene				11				
1,3-Dinitrobenzene				22				
2,4-Dinitrotoluene				44				
2,6-Dinitrotoluene				81				
HMX				220				
Nitrobenzene				380				
2-Nitrotoluene				71				
3-Nitrotoluene				42				
4-Nitrotoluene				46				
2,4-Dinitrophenol			2800					
RDX				79				
Tetryl				NE				
1,3,5-trinitrobenzene				11				
2,4,6-trinitrotoluene				13				
Antimony			780	190				
Arsenic			580	150 (TR)		150	680	100
Barium			160,000	260				
Beryllium [1]			130	100				100
Cadmium [1]			730	7.3		7.3	9	50
Chromium (total) [1]			14,000	270		270	3600	100
Cobalt				24				
Copper [1]			64,000	30		30	28	500
Cyanide (free)			48,000	5.2		12	92	
Cyanides			48,000	NE				
Iron			NE	NE				5000

Table 4-2

Potential Surface Water Critera for Discharge of Treated Water from P&T Systems
Constituents in WARWP and PRRWP Area Groundwater
Former Plum Brook Ordnance Works, Sandusky, Ohio

	Statewide		Lake Erie Drainage Basin			Sandusky River Basin		
Criteria	**Antidegradation** BADCT 30-day average (µg/L)	**Aesthetic Conditions** OMZM	**Human Health** Non-Drinking (µg/L)	**Aquatic Life** OMZA (µg/L)	**Wildlife** OZMA (µg/L)	**Aquatic Life Warmwater Habitat** OMZA (µg/L)	**Aquatic Life Warmwater Habitat** IMZM (µg/L)	**Water Supply Agricultural** OMZA (µg/L)
Lead [1]			NE	37		37	240	100
Magnesium			NE	NE				
Manganese			61,000	NE				
Mercury			0.0031	0.91	0.0013	0.91	3.4	10
Nickel [1]			43,000	170		170	940	200
Selenium			3,100	5		5		50
Silver			11,000	1.3				
Thallium			4	17				
Vanadium			NE	44				
Zinc [1]			35,000	390		390	240	25,000

Shaded criteria are the most stringent of each designated use. These criteria are chosen as ARARs for surface discharge at the WARWP and PRRWP areas. [OAC 3745-1-01(B)]

[1] Criteria for this constituent under aquatic life warmwater habitat are hardness dependent. Criteria in table are based on a water hardness of 400 mg/L.

BADCT = Best available demonstrated control technology
IMZM = inside mixing zone maximum (end-of-pipe maximum effluent limitation)
NE = No existing criteria
NL = Chemical is not criteria list
OMZA = outside mixing zone average (ambient average)
OMZM = outsife mixing zone maximum (ambient maximum)
TR = total recoverable
WARWP = West Area Red Water Ponds
PRRWP = Pentolite Road Red Water Pond
ARAR = Applicable or relevant and appropriate requirement
mg/L = Milligrams per liter
µg/L = Micrograms per liter

NOTES:

(1) Industrial water supply criteria are specific to industry. No numeric criteria promulgated in water quality standards regulations.

(2) Primary contact recreation criteria are not ARARs since they consist of bacterial standards (fecal coliform and E. Coli) and bacteria are not a site contaminant. [OAC 3745-1-07(Table 7-13)]

(3) Biological numeric criteria at OAC 3745-1-07(Table 7-15) are relevant and appropriate, but are not concentration-based numerical criteria specific to a constituent. Rather, the numbers in Table 7-15 represent an index of the 'health' of the aquatic ecosystem, as compared to pre-established reference sites using professional judgement.

ASSUMPTIONS:

(1) Treated groundwater from WARWP area will be discharged to Pipe Creek.
(2) Treated groundwater from PRRWP area will be discharged to nearby drainage ditch or tributary to Plum Brook.
(3) No waterbody used for the discharge of treated groundwater from either area will have more stringent WQC than the warmwater habitat criteria.
(4) Receiving waters in both areas are not exempt from WQS due to low-flow. [OAC 3745-1-01(D)]
(5) Anti-degradation rules are ARARs for surface water discharge at WARWP and PRRWP.

Table 4-3

Monitoring Well BED-MW14 Groundwater Results
Pentolite Road Red Water Pond Area
Former Plum Brook Ordnance Works, Sandusky, Ohio

LOCATION_CODE						PB-BED-MW14			PB-BED-MW14			PB-BED-MW14			PB-BED-MW14			PB-BED-MW14			PB-BED-MW14			PB-BED-MW14			PB-BED-MW14		
SAMPLE_NO						PB-BED-MW14			5170			5900			5905			5905R			BD3018			BD3018R			CB3022		
SAMPLE_DATE						14-Dec-94			17-Oct-96			18-Nov-97			16-May-98			18-May-98			28-Sep-01			5-Oct-01			8-Apr-02		
FK_DEPTH						0 - 0 Ft			0 - 0 Ft			0 - 0 Ft			0 - 0 Ft			0 - 0 Ft			21_62 - 21_91 Ft			37 - 37 Ft			35 - 37 Ft		
SAMPLE_PURPOSE						REG			REG			REG			REG			REG			REG			REG			REG		
Parameter	Units	Filtered	MCL	SW ARAR	Mean Detection	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ
Amino-2,6-dinitrotoluene, 4-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Amino-2,6-dinitrotoluene, 4-	µg/L	Y	NE						-	-	-																		
Amino-2-nitrotoluene, 4-	µg/L	N	NE			-	-	-																					
Amino-4,6-dinitrotoluene, 2-	µg/L	N	NE			-	-	-													-	-	-				-	-	-
Amino-4-nitrotoluene, 2-	µg/L	N	NE	NE		11																							
Dinitrobenzene, 1,3-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Dinitrobenzene, 1,3-	µg/L	Y	NE						-	-	-																		
Dinitrotoluene, 2,4-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Dinitrotoluene, 2,4-	µg/L	Y	NE						-	-	-																		
Dinitrotoluene, 2,6-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Dinitrotoluene, 2,6-	µg/L	Y	NE						-	-	-																		
Dinitrotoluene, 3,4-	µg/L	N	NE			-	-	-																					
HMX	µg/L	N	NE						-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
HMX	µg/L	Y	NE						-	-	-																		
Nitrobenzene	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Nitrobenzene	µg/L	Y	NE						-	-	-																		
Nitrotoluene, 2-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Nitrotoluene, 2-	µg/L	Y	NE						-	-	-																		
Nitrotoluene, 3-	µg/L	N	NE	42		2.8			-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Nitrotoluene, 3-	µg/L	Y	NE						-	-	-																		
Nitrotoluene, 4-	µg/L	N	NE			-	-	-													-	-	-				-	-	-
RDX	µg/L	N	NE						-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
RDX	µg/L	Y	NE						-	-	-																		
Tetryl	µg/L	N	NE						-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Tetryl	µg/L	Y	NE						-	-	-																		
Trinitrobenzene, 1,3,5-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Trinitrobenzene, 1,3,5-	µg/L	Y	NE						-	-	-																		
Trinitrotoluene, 2,4,6-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Trinitrotoluene, 2,4,6-	µg/L	Y	NE						-	-	-																		
Dissolved Oxygen	µg/L	N	NE	5 [1]											5,500														
Oxidation Reduction Potential	mV	N	NE	NE											-10.8														
pH	pH units	N	NE	6.5-9.0											7.7														
Specific Conductivity	mS/cm	N	NE	NE											2.4														
Temperature	C	N	NE	NE											13														
Turbidity	NTU	N	NE	NE											36														
Alkalinity	µg/L	N	NE	NE								210,000			500,000						482,000	J	J				481,000	J	
Chloride	µg/L	N	NE	NE								79,000			3,000						72,200						75,600		J
Cyanide, total	µg/L	N	200	5.2 [2]					20			16			44						-	-	-				38		
Hardness	µg/L	N	NE	NE								640,000			730,000						1,200,000						1,230,000		
Nitrate	µg/L	N	10,000	NE		3.3									24,000									22,000			79,300		
Nitrate-Nitrite	µg/L	N	NE	100,000								300																	
Sulfate	µg/L	N	NE	NE								610,000			630,000						1,440,000						2,660,000	J	
Total dissolved solids	µg/L	N	NE	**1,500,000**								**2,500,000**			**2,300,000**						**3,570,000**						**7,360,000**		
Total organic carbon	µg/L	N	NE	NE								190,000			160,000						617,000						937,000		
Total suspended solids	µg/L	N	NE	NE								37,000			23,000						11,000						54,000		
Turbidity	NTU	N	NE	NE																				4.2	J	J	-	-	-
Aluminum	µg/L	N	NE						-	-	-	374		J	-	-	-				64.9	B	B				87.5	B	B

Table 4-3

Monitoring Well BED-MW14 Groundwater Results
Pentolite Road Red Water Pond Area
Former Plum Brook Ordnance Works, Sandusky, Ohio

LOCATION_CODE						PB-BED-MW14			PB-BED-MW14			PB-BED-MW14			PB-BED-MW14			PB-BED-MW14			PB-BED-MW14			PB-BED-MW14			PB-BED-MW14		
SAMPLE_NO						PB-BED-MW14			5170			5900			5905			5905R			BD3018			BD3018R			CB3022		
SAMPLE_DATE						14-Dec-94			17-Oct-96			18-Nov-97			16-May-98			18-May-98			28-Sep-01			5-Oct-01			8-Apr-02		
FK_DEPTH						0 - 0 Ft			0 - 0 Ft			0 - 0 Ft			0 - 0 Ft			0 - 0 Ft			21_62 - 21_91 Ft			37 - 37 Ft			35 - 37 Ft		
SAMPLE_PURPOSE						REG			REG			REG			REG			REG			REG			REG			REG		
Parameter	Units	Filtered	MCL	SW ARAR	Mean Detection	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ
Aluminum	µg/L	Y	NE						246			-	-	-	-	-	-				54.9	B	B				94.8	B	B
Antimony	µg/L	N	6	190		-	-	-	-	-	-	-	-	-	-	-	-				-	-	-				-	-	-
Antimony	µg/L	Y	6			-	-	-	-	-	-	-	-	-	-	-	-				-	-	-				-	-	-
Arsenic	µg/L	N	10	100		-	-	-	-	-	-	-	-	-	-	-	-				6.1	B	J				9.5	B	J
Arsenic	µg/L	Y	10			-	-	-	-	-	-	-	-	-	-	-	-				5.5	B	J				9	B	J
Barium	µg/L	N	2,000	260					-	-	-	-	-	-	-	-	-				49.5	B	J				51.4	B	J
Barium	µg/L	Y	2,000						-	-	-	-	-	-	-	-	-				50.8	B	J				51.4	B	J
Beryllium	µg/L	N	4	100		-	-	-	-	-	-	-	-	-	-	-	-				-	-	-				-	-	-
Beryllium	µg/L	Y	4			-	-	-	-	-	-	-	-	-	-	-	-				-	-	-				-	-	-
Cadmium	µg/L	N	5	7.3		-	-	-	-	-	-	-	-	-	-	-	-				-	-	-				-	-	-
Cadmium	µg/L	Y	5			-	-	-	-	-	-	-	-	-	-	-	-				-	-	-				-	-	-
Calcium	µg/L	N	NE						210,000			152,000			99,000						215,000						325,000		
Calcium	µg/L	Y	NE						132,000			120,000			149,000						223,000						321,000		
Chromium	µg/L	N	100	100		-	-	-	12.3			10.2			-	-	-				1.6	B	J				3.4	B	J
Chromium	µg/L	Y	100			-	-	-	11.6			-	-	-	-	-	-				1.9	B	J				3	B	J
Cobalt	µg/L	N	NE	**24**					**69.1**			-	-	-	-	-	-				**102**						**267**		
Cobalt	µg/L	Y	NE						53.8			-	-	-	65.4						105						265		
Copper	µg/L	N	1,300	**30**	28.8	-	-	-	-	-	-	-	-	-	-	-	-				**30.7**						**94.8**		
Copper	µg/L	Y	1,300			-	-	-	-	-	-	-	-	-	-	-	-				27						92		
Iron	µg/L	N	NE	5000					450			923			427		J				164						438		
Iron	µg/L	Y	NE						-	-	-	-	-	-	269						145						417		
Lead	µg/L	N	15	37		-	-	-	-	-	-	-	-	-	-	-	-				-	-	-				3.6		
Lead	µg/L	Y	15			-	-	-	-	-	-	-	-	-	-	-	-				-	-	-				3.6		
Magnesium	µg/L	N	NE						125,000		J	70,700			59,700						146,000						230,000		
Magnesium	µg/L	Y	NE						97,700			82,500			99,900						153,000						229,000		
Manganese	µg/L	N	NE			-	-	-	47.5			54			32						65.2						136		
Manganese	µg/L	Y	NE			-	-	-	25			29.1			32.6						68						136		
Mercury	µg/L	N	2	0.0013		-	-	-	-	-	-	-	-	-	-	-	-				-	-	-				-	-	-
Mercury	µg/L	Y	2			-	-	-	0.25			-	-	-	-	-	-				-	-	-				-	-	-
Nickel	µg/L	N	NE	**170**	92.5	-	-	-	68.1			42.3			45.5						111						**278**		
Nickel	µg/L	Y	NE			-	-	-	53.5			40.7			71.3						117						276		
Potassium	µg/L	N	NE						38,300			44,700			49,000						42,100						56,800		J
Potassium	µg/L	Y	NE						64,500			40,500			32,400						43,800		J				57,000		J
Selenium	µg/L	N	50	**5**	4.7	-	-	-	-	-	-	-	-	-	-	-	-				**5.5**						**7.8**		
Selenium	µg/L	Y	50			-	-	-	-	-	-	-	-	-	-	-	-				8.2		B				7.4		
Silver	µg/L	N	NE	1.3		-	-	-	-	-	-	-	-	-	-	-	-				-	-	-				-	-	-
Silver	µg/L	Y	NE			-	-	-	-	-	-	-	-	-	-	-	-				-	-	-				-	-	-
Sodium	µg/L	N	NE						471,000		J	311,000			269,000						629,000						1,020,000		
Sodium	µg/L	Y	NE						346,000		J	360,000			365,000						662,000						1,010,000		
Thallium	µg/L	N	2	17		0.5			-	-	-	-	-	-	-	-	-				5	B	B				-	-	-
Thallium	µg/L	Y	2			-	-	-	-	-	-	-	-	-	-	-	-				7.2	B	B				-	-	-
Vanadium	µg/L	N	NE	44					-	-	-	-	-	-	-	-	-				2.4	B	B				5.5	B	J
Vanadium	µg/L	Y	NE						-	-	-	-	-	-	-	-	-				2.4	B	J				5.8	B	J
Zinc	µg/L	N	NE	390		28			36		UJ	39.8			42.2		B				10.8	B	J				64.8		
Zinc	µg/L	Y	NE			-	-	-	26			32.4			53.9		B				12.6	B	J				68.2		J
Aldrin	µg/L	N	NE						-	-	-																		
Aroclor 1016	µg/L	N	0.5						-	-	-	-	-	-				-	-	-									
Aroclor 1221	µg/L	N	0.5						-	-	-	-	-	-				-	-	-									

Table 4-3

Monitoring Well BED-MW14 Groundwater Results
Pentolite Road Red Water Pond Area
Former Plum Brook Ordnance Works, Sandusky, Ohio

LOCATION_CODE						PB-BED-MW14			PB-BED-MW14			PB-BED-MW14			PB-BED-MW14			PB-BED-MW14			PB-BED-MW14			PB-BED-MW14			PB-BED-MW14		
SAMPLE_NO						PB-BED-MW14			5170			5900			5905			5905R			BD3018			BD3018R			CB3022		
SAMPLE_DATE						14-Dec-94			17-Oct-96			18-Nov-97			16-May-98			18-May-98			28-Sep-01			5-Oct-01			8-Apr-02		
FK_DEPTH						0 - 0 Ft			0 - 0 Ft			0 - 0 Ft			0 - 0 Ft			0 - 0 Ft			21_62 - 21_91 Ft			37 - 37 Ft			35 - 37 Ft		
SAMPLE_PURPOSE						REG			REG			REG			REG			REG			REG			REG			REG		
Parameter	Units	Filtered	MCL	SW ARAR	Mean Detection	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ
Aroclor 1232	µg/L	N	0.5						-	-	-	-	-	-				-	-	-									
Aroclor 1242	µg/L	N	0.5						-	-	-	-	-	-				-	-	-									
Aroclor 1248	µg/L	N	0.5						-	-	-	-	-	-				-	-	-									
Aroclor 1254	µg/L	N	0.5						-	-	-	-	-	-				-	-	-									
Aroclor 1260	µg/L	N	0.5						-	-	-	-	-	-				-	-	-									
BHC, alpha-	µg/L	N	NE						-	-	-																		
BHC, beta-	µg/L	N	NE						-	-	-																		
BHC, delta-	µg/L	N	NE						-	-	-																		
BHC, gamma-	µg/L	N	0.2						-	-	-																		
Chlordane, alpha-	µg/L	N	NE						-	-	-																		
Chlordane, gamma-	µg/L	N	NE						-	-	-																		
DDD, 4,4'-	µg/L	N	NE						-	-	-																		
DDE, 4,4'-	µg/L	N	NE						-	-	-																		
DDT, 4,4'-	µg/L	N	NE						-	-	-																		
Dieldrin	µg/L	N	NE						-	-	-																		
Endosulfan I	µg/L	N	NE						-	-	-																		
Endosulfan II	µg/L	N	NE						-	-	-																		
Endosulfan sulfate	µg/L	N	NE						-	-	-																		
Endrin	µg/L	N	2						-	-	-																		
Endrin aldehyde	µg/L	N	NE						-	-	-																		
Endrin ketone	µg/L	N	NE						-	-	-																		
Heptachlor	µg/L	N	0.4						-	-	-																		
Heptachlor epoxide	µg/L	N	0.2						-	-	-																		
Methoxychlor	µg/L	N	40						-	-	-																		
Toxaphene	µg/L	N	3						-	-	-																		
Acenaphthene	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Acenaphthylene	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Anthracene	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Benzo(a)anthracene	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Benzo(a)pyrene	µg/L	N	0.2			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Benzo(b)fluoranthene	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Benzo(ghi)perylene	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Benzo(k)fluoranthene	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Benzoic acid	µg/L	N	NE			-	-	-																					
Benzyl alcohol	µg/L	N	NE			-	-	-																					
Bis(2-chloroethoxy)methane	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Bis(2-chloroethyl)ether	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Bis(2-chloroisopropyl)ether	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Bis(2-ethylhexyl)phthalate	µg/L	N	6	8.4		-	-	-	1	J	J	-	-	-				-	-	-	-	-	-				-	-	-
Bromophenyl phenyl ether, 4-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Butyl benzyl phthalate	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Carbazole	µg/L	N	NE						-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Chloro-3-methylphenol, 4-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Chloroaniline, 4-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Chloronaphthalene, 2-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Chlorophenol, 2-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-

Table 4-3

Monitoring Well BED-MW14 Groundwater Results
Pentolite Road Red Water Pond Area
Former Plum Brook Ordnance Works, Sandusky, Ohio

LOCATION_CODE						PB-BED-MW14			PB-BED-MW14			PB-BED-MW14			PB-BED-MW14			PB-BED-MW14			PB-BED-MW14			PB-BED-MW14			PB-BED-MW14		
SAMPLE_NO						PB-BED-MW14			5170			5900			5905			5905R			BD3018			BD3018R			CB3022		
SAMPLE_DATE						14-Dec-94			17-Oct-96			18-Nov-97			16-May-98			18-May-98			28-Sep-01			5-Oct-01			8-Apr-02		
FK_DEPTH						0 - 0 Ft			0 - 0 Ft			0 - 0 Ft			0 - 0 Ft			0 - 0 Ft			21_62 - 21_91 Ft			37 - 37 Ft			35 - 37 Ft		
SAMPLE_PURPOSE						REG			REG			REG			REG			REG			REG			REG			REG		
Parameter	Units	Filtered	MCL	SW ARAR	Mean Detection	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ
Chlorophenyl phenyl ether, 4-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Chrysene	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Dibenz(a,h)anthracene	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Dibenzofuran	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Dichlorobenzene, 1,2-	µg/L	N	600			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Dichlorobenzene, 1,3-	µg/L	N	600			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Dichlorobenzene, 1,4-	µg/L	N	75			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Dichlorobenzidine, 3,3'-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Dichlorophenol, 2,4-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Diethyl phthalate	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Dimethyl phthalate	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Dimethylphenol, 2,4-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Di-n-butyl phthalate	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Dinitro-2-methylphenol, 4,6-	µg/L	N	NE	NE		-	-	-	-	-	-	-	-	-				28	J	NJ	-	-	-				-	-	-
Dinitrophenol, 2,4-	µg/L	N	NE	NE		-	-	-	-	-	-	-	-	-				14	J	J	-	-	-				-	-	-
Dinitrotoluene, 2,4-	µg/L	N	NE	44		-	-	-	1.7	J	J	-	-	-				16			-	-	-				19		
Dinitrotoluene, 2,6-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Di-n-octyl phthalate	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Fluoranthene	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Fluorene	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Hexachlorobenzene	µg/L	N	1			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Hexachlorobutadiene	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Hexachlorocyclopentadiene	µg/L	N	50			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Hexachloroethane	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Indeno(1,2,3-cd)pyrene	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Isophorone	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Methylnaphthalene, 2-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Methylphenol, 2-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Methylphenol, 3-	µg/L	N	NE			-	-	-																					
Methylphenol, 4-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Naphthalene	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Nitroaniline, 2-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Nitroaniline, 3-	µg/L	N	NE	NE		-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				150		
Nitroaniline, 4-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Nitrobenzene	µg/L	N	NE	380		-	-	-	-	-	-	-	-	-				5.8	J	J	-	-	-				-	-	-
Nitrophenol, 2-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Nitrophenol, 4-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
n-Nitroso-di-n-propylamine	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
n-Nitrosodiphenylamine	µg/L	N	NE						-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Pentachlorophenol	µg/L	N	1			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Phenanthrene	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Phenol	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Pyrene	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Trichlorobenzene, 1,2,4-	µg/L	N	70			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Trichlorophenol, 2,4,5-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-
Trichlorophenol, 2,4,6-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-	-	-	-				-	-	-

Table 4-3

Monitoring Well BED-MW14 Groundwater Results
Pentolite Road Red Water Pond Area
Former Plum Brook Ordnance Works, Sandusky, Ohio

LOCATION_CODE						PB-BED-MW14			PB-BED-MW14			PB-BED-MW14			PB-BED-MW14			PB-BED-MW14			PB-BED-MW14			PB-BED-MW14			PB-BED-MW14		
SAMPLE_NO						PB-BED-MW14			5170			5900			5905			5905R			BD3018			BD3018R			CB3022		
SAMPLE_DATE						14-Dec-94			17-Oct-96			18-Nov-97			16-May-98			18-May-98			28-Sep-01			5-Oct-01			8-Apr-02		
FK_DEPTH						0 - 0 Ft			0 - 0 Ft			0 - 0 Ft			0 - 0 Ft			0 - 0 Ft			21_62 - 21_91 Ft			37 - 37 Ft			35 - 37 Ft		
SAMPLE_PURPOSE						REG			REG			REG			REG			REG			REG			REG			REG		
Parameter	Units	Filtered	MCL	SW ARAR	Mean Detection	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ	Result	Q	VQ
Acetone	µg/L	N	NE	NE		-	-	-	-	-	-	-	-	-				-	-	-				9.4	J	B	-	-	-
Benzene	µg/L	N	5	5 [3]		-	-	-	-	-	-	1.1						-	-	-				-	-	-	-	-	-
Bromodichloromethane	µg/L	N	80			-	-	-	-	-	-	-	-	-				-	-	-				-	-	-	-	-	-
Bromoform	µg/L	N	80			-	-	-	-	-	-	-	-	-				-	-	-				-	-	-	-	-	-
Bromomethane	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-				-	-	-	-	-	-
Butanone, 2-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-				-	-	-	-	-	-
Carbon disulfide	µg/L	N	NE	15		-	-	-	-	-	-	1.3						0.25	J	J				-	-	-	-	-	-
Carbon tetrachloride	µg/L	N	5			-	-	-	-	-	-	-	-	-				-	-	-				-	-	-	-	-	-
Chlorobenzene	µg/L	N	100	47		-	-	-	1.1	J	J	-	-	-				-	-	-				-	-	-	-	-	-
Chloroethane	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-				-	-	-	-	-	-
Chloroethyl vinyl ether, 2-	µg/L	N	NE			-	-	-																					
Chloroform	µg/L	N	80			-	-	-	-	-	-	-	-	-				-	-	-				-	-	-	-	-	-
Chloromethane	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-				-	-	-	-	-	-
Dibromo-3-chloropropane, 1,2-	µg/L	N	0.2			-	-	-																					
Dibromochloromethane	µg/L	N	80			-	-	-	-	-	-	-	-	-				-	-	-				-	-	-	-	-	-
Dibromoethane, 1,2-	µg/L	N	0.05			-	-	-																					
Dichloroethane, 1,1-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-				-	-	-	-	-	-
Dichloroethane, 1,2-	µg/L	N	5			-	-	-	-	-	-	-	-	-				-	-	-				-	-	-	-	-	-
Dichloroethene, 1,1-	µg/L	N	7			-	-	-	-	-	-	-	-	-				-	-	-				-	-	-	-	-	-
Dichloroethene, 1,2-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-				-	-	-	-	-	-
Dichloroethene, cis-1,2-	µg/L	N	70			-	-	-																					
Dichloropropane, 1,2-	µg/L	N	5			-	-	-	-	-	-	-	-	-				-	-	-				-	-	-	-	-	-
Dichloropropene, cis-1,3-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-				-	-	-	-	-	-
Dichloropropene, trans-1,3-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-				-	-	-	-	-	-
Ethylbenzene	µg/L	N	700	5 [3]		1.6			-	-	-	0.59	J	J				-	-	-				-	-	-	-	-	-
Hexanone, 2-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-				-	-	-	-	-	-
Methyl-2-pentanone, 4-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-				-	-	-	-	-	-
Methylene chloride	µg/L	N	5	1900		-	-	-	-	-	-	-	-	-				-	-	-				1.4	J	B	1.9	J	B
Styrene	µg/L	N	100			-	-	-	-	-	-	-	-	-				-	-	-				-	-	-	-	-	-
Tetrachloroethane, 1,1,2,2-	µg/L	N	NE			-	-	-	-	-	-	-	-	-				-	-	-				-	-	-	-	-	-
Tetrachloroethene	µg/L	N	5			-	-	-	-	-	-	-	-	-				-	-	-				-	-	-	-	-	-
Toluene	µg/L	N	1,000	5 [3]		3			1.5	J	J	1.7		B				-	-	-				-	-	-	-	-	-
Trichloroethane, 1,1,1-	µg/L	N	200			-	-	-	-	-	-	-	-	-				-	-	-				-	-	-	-	-	-
Trichloroethane, 1,1,2-	µg/L	N	5						-	-	-	-	-	-				-	-	-				-	-	-	-	-	-
Trichloroethene	µg/L	N	5			-	-	-	-	-	-	-	-	-				-	-	-				-	-	-	-	-	-
Vinyl acetate	µg/L	N	NE			-	-	-																					
Vinyl chloride	µg/L	N	2			-	-	-	-	-	-	-	-	-				-	-	-				-	-	-	-	-	-
Xylenes, total	µg/L	N	10,000	**5 [3]**		**14**			2.7	J	J	3.9						-	-	-				-	-	-	-	-	-

ARAR = Applicable or relevant and appropriate requirement.
NE = No criteria found in regulation.
Bold and shaded cells indicate constituent concentrations in excess of the SW ARAR. The SW ARAR is the most stringent criteria promulgated for each designated use of the waterbody.

[1] Dissolved oxygen criteria is the minimum value acceptable in the surface water body (i.e., outside mixing zone minimum average).

[2] Potential SW ARAR listed is free cyanide. Analtyical results are listed as total cyanide.

[3] Potential SW ARAR listed is the thirty-day average effluent limit for VOCs using best available demonstrated control technology, as required in the Ohio Anti-degradation rules [OAC 3745-1-05(A)(3)(f)].

Table 4-4

Monitoring Well BED-MW27 Groundwater Results
West Area Red Water Ponds Area
Former Plum Brook Ordnance Works, Sandusky, Ohio

LOCATION_CODE					PB-BED-MW27			PB-BED-MW27			PB-BED-MW27		
SAMPLE_NO					BD3032			CB3012			CD3009		
SAMPLE_DATE					9-Oct-01			9-Apr-02			18-Oct-02		
FK_DEPTH								85 - 88 Ft					
SAMPLE_PURPOSE					REG			REG			REG		
Parameter	Units	Filtered	MCL	SW ARAR	Result	Qual	ValQual	Result	Qual	ValQual	Result	Qual	ValQual
Amino-2,6-dinitrotoluene, 4-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Amino-4,6-dinitrotoluene, 2-	µg/L	N	NE	18	-	-	-	-	-	-	0.19	J	J
Dinitrobenzene, 1,3-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Dinitrotoluene, 2,4-	µg/L	N	NE	44	1.5			0.58			0.98		
Dinitrotoluene, 2,6-	µg/L	N	NE	81	1.1			0.59			1.4		
HMX	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Nitrobenzene	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Nitrotoluene, 2-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Nitrotoluene, 3-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Nitrotoluene, 4-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
RDX	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Tetryl	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Trinitrobenzene, 1,3,5-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Trinitrotoluene, 2,4,6-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Alkalinity	µg/L	N	NE	NE	473,000	J	J	488,000	J		493,000		
Chloride	µg/L	N	NE	NE	260,000			194,000			206,000		
Cyanide, total	µg/L	N	200	5.2 [1]	-	-	-	-	-	-	-	-	-
Hardness	µg/L	N	NE	NE	1,910,000			1,750,000			1,660,000		
Nitrate	µg/L	N	10,000	100,000	-	-	-	-	-	-	-	-	-
Sulfate	µg/L	N	NE	NE	1,280,000			868,000			1,110,000		
Total dissolved solids	µg/L	N	NE	**1,500,000**	**2,560,000**			**2,280,000**			**2,210,000**		
Total organic carbon	µg/L	N	NE	NE	3,700			3,500			2,600		
Total suspended solids	µg/L	N	NE	NE	200,000			499,000			65,000		
Turbidity	NTU	N	NE	NE	188			1,470			67.4		
Aluminum	µg/L	N	NE	NE	152	B	J	232		B	105	B	J
Aluminum	µg/L	Y	NE		58	B	B	59	B	J	76.3	B	B
Antimony	µg/L	N	6	190	-	-	-	-	-	-	-	-	-
Antimony	µg/L	Y	6		-	-	-	-	-	-	-	-	-
Arsenic	µg/L	N	10	100	4	B	B	-	-	-	-	-	-
Arsenic	µg/L	Y	10		-	-	-	5.2	B	J	-	-	-
Barium	µg/L	N	2,000	260	133	B	J	93.8	B	J	86.2	B	J
Barium	µg/L	Y	2,000		126	B	J	83.6	B	J	81.4	B	J
Beryllium	µg/L	N	4	100	-	-	-	-	-	-	-	-	-
Beryllium	µg/L	Y	4		-	-	-	-	-	-	-	-	-
Cadmium	µg/L	N	5	7.3	-	-	-	1.1	B	J	0.25	B	J
Cadmium	µg/L	Y	5		-	-	-	-	-	-	-	-	-
Calcium	µg/L	N	NE		462,000			370,000			371,000	J	
Calcium	µg/L	Y	NE		427,000			378,000			364,000		

Table 4-4

Monitoring Well BED-MW27 Groundwater Results
West Area Red Water Ponds Area
Former Plum Brook Ordnance Works, Sandusky, Ohio

LOCATION_CODE					PB-BED-MW27			PB-BED-MW27			PB-BED-MW27		
SAMPLE_NO					BD3032			CB3012			CD3009		
SAMPLE_DATE					9-Oct-01			9-Apr-02			18-Oct-02		
FK_DEPTH								85 - 88 Ft					
SAMPLE_PURPOSE					REG			REG			REG		
Parameter	Units	Filtered	MCL	SW ARAR	Result	Qual	ValQual	Result	Qual	ValQual	Result	Qual	ValQual
Chromium	µg/L	N	100	100	7.1	B	J	24.4			1.6	B	J
Chromium	µg/L	Y	100		-	-	-	1.4	B	J	-	-	-
Cobalt	µg/L	N	NE	24	3.1	B	J	10.9	B	J	1.6	B	J
Cobalt	µg/L	Y	NE		-	-	-	-	-	-	-	-	-
Copper	µg/L	N	1,300	30	13.3	B	J	6.3	B	B	-	-	-
Copper	µg/L	Y	1,300		-	-	-	-	-	-	-	-	-
Iron	µg/L	N	NE	**5000**	**43,100**			**257,000**		J	**31,600**		
Iron	µg/L	Y	NE		144			189		J	159		
Lead	µg/L	N	15	37	-	-	-	-	-	-	-	-	-
Lead	µg/L	Y	15		-	-	-	-	-	-	-	-	-
Magnesium	µg/L	N	NE	NE	166,000			165,000			178,000		
Magnesium	µg/L	Y	NE		162,000			168,000			177,000		
Manganese	µg/L	N	NE	NE	680			4,660			1,250		
Manganese	µg/L	Y	NE		141			1,460			816		
Mercury	µg/L	N	2	0.0013	-	-	-	-	-	-	-	-	-
Mercury	µg/L	Y	2		-	-	-	-	-	-	-	-	-
Nickel	µg/L	N	NE	170	12.4	B	J	17.7	B	J	6.4	B	J
Nickel	µg/L	Y	NE		2	B	J	-	-	-	-	-	-
Potassium	µg/L	N	NE		41,500			30,400			27,600	J	J
Potassium	µg/L	Y	NE		42,200		J	32,100			27,800	J	J
Selenium	µg/L	N	50	5	-	-	-	-	-	-	-	-	-
Selenium	µg/L	Y	50		-	-	-	-	-	-	-	-	-
Silver	µg/L	N	NE	1.3	-	-	-	-	-	-	-	-	-
Silver	µg/L	Y	NE		-	-	-	-	-	-	-	-	-
Sodium	µg/L	N	NE		96,000			98,100			109,000		
Sodium	µg/L	Y	NE		95,500			103,000			107,000		
Thallium	µg/L	N	2	17	-	-	-	-	-	-	-	-	-
Thallium	µg/L	Y	2		-	-	-	-	-	-	-	-	-
Vanadium	µg/L	N	NE	44	-	-	-	7.8	B	J	-	-	-
Vanadium	µg/L	Y	NE		-	-	-	-	-	-	-	-	-
Zinc	µg/L	N	NE	390	21.6			18.5	B	J	12.3	B	J
Zinc	µg/L	Y	NE		-	-	-	3	B	J	2.8	B J	B
Acenaphthene	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Acenaphthylene	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Anthracene	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Benzo(a)anthracene	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Benzo(a)pyrene	µg/L	N	0.2		-	-	-	-	-	-	-	-	-
Benzo(b)fluoranthene	µg/L	N	NE		-	-	-	-	-	-	-	-	-

Table 4-4

Monitoring Well BED-MW27 Groundwater Results
West Area Red Water Ponds Area
Former Plum Brook Ordnance Works, Sandusky, Ohio

LOCATION_CODE					PB-BED-MW27			PB-BED-MW27			PB-BED-MW27		
SAMPLE_NO					BD3032			CB3012			CD3009		
SAMPLE_DATE					9-Oct-01			9-Apr-02			18-Oct-02		
FK_DEPTH								85 - 88 Ft					
SAMPLE_PURPOSE					REG			REG			REG		
Parameter	Units	Filtered	MCL	SW ARAR	Result	Qual	ValQual	Result	Qual	ValQual	Result	Qual	ValQual
Benzo(ghi)perylene	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Benzo(k)fluoranthene	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Bis(2-chloroethoxy)methane	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Bis(2-chloroethyl)ether	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Bis(2-chloroisopropyl)ether	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Bis(2-ethylhexyl)phthalate	µg/L	N	6	8.4	2.9	J	J	-	-	-	-	-	-
Bromophenyl phenyl ether, 4-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Butyl benzyl phthalate	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Carbazole	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Chloro-3-methylphenol, 4-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Chloroaniline, 4-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Chloronaphthalene, 2-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Chlorophenol, 2-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Chlorophenyl phenyl ether, 4-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Chrysene	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Dibenz(a,h)anthracene	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Dibenzofuran	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Dichlorobenzene, 1,2-	µg/L	N	600		-	-	-	-	-	-	-	-	-
Dichlorobenzene, 1,3-	µg/L	N	600		-	-	-	-	-	-	-	-	-
Dichlorobenzene, 1,4-	µg/L	N	75		-	-	-	-	-	-	-	-	-
Dichlorobenzidine, 3,3'-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Dichlorophenol, 2,4-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Diethyl phthalate	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Dimethyl phthalate	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Dimethylphenol, 2,4-	µg/L	N	NE	15	3.1	J	J	5.1	J	J	4.2	J	J
Di-n-butyl phthalate	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Dinitro-2-methylphenol, 4,6-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Dinitrophenol, 2,4-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Dinitrotoluene, 2,4-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Dinitrotoluene, 2,6-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Di-n-octyl phthalate	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Fluoranthene	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Fluorene	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Hexachlorobenzene	µg/L	N	1		-	-	-	-	-	-	-	-	-
Hexachlorobutadiene	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Hexachlorocyclopentadiene	µg/L	N	50		-	-	-	-	-	-	-	-	-
Hexachloroethane	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Indeno(1,2,3-cd)pyrene	µg/L	N	NE		-	-	-	-	-	-	-	-	-

Table 4-4

Monitoring Well BED-MW27 Groundwater Results
West Area Red Water Ponds Area
Former Plum Brook Ordnance Works, Sandusky, Ohio

LOCATION_CODE					PB-BED-MW27			PB-BED-MW27			PB-BED-MW27		
SAMPLE_NO					BD3032			CB3012			CD3009		
SAMPLE_DATE					9-Oct-01			9-Apr-02			18-Oct-02		
FK_DEPTH								85 - 88 Ft					
SAMPLE_PURPOSE					REG			REG			REG		
Parameter	Units	Filtered	MCL	SW ARAR	Result	Qual	ValQual	Result	Qual	ValQual	Result	Qual	ValQual
Isophorone	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Methylnaphthalene, 2-	µg/L	N	NE	NE	24			18			19		
Methylphenol, 2-	µg/L	N	NE	67	-	-	-	0.89	J	J	-	-	-
Methylphenol, 4-	µg/L	N	NE	53	-	-	-	1.1	J	J	-	-	-
Naphthalene	µg/L	N	NE	21	17			14			12		
Nitroaniline, 2-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Nitroaniline, 3-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Nitroaniline, 4-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Nitrobenzene	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Nitrophenol, 2-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Nitrophenol, 4-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
n-Nitroso-di-n-propylamine	µg/L	N	NE		-	-	-	-	-	-	-	-	-
n-Nitrosodiphenylamine	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Pentachlorophenol	µg/L	N	1		-	-	-	-	-	-	-	-	-
Phenanthrene	µg/L	N	NE	2.3	1.4	J	J	0.75	J	J	-	-	-
Phenol	µg/L	N	NE	400	1.3	J	J	2	J	J	1.2	J	J
Pyrene	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Trichlorobenzene, 1,2,4-	µg/L	N	70		-	-	-	-	-	-	-	-	-
Trichlorophenol, 2,4,5-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Trichlorophenol, 2,4,6-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Acetone	µg/L	N	NE	NE	210	J B	J	100	J	J	-	-	-
Benzene	µg/L	N	5	**5** [2]	**130**	J	J	**70**		J	**60**	J	J
Bromodichloromethane	µg/L	N	80		-	-	-	-	-	-	-	-	-
Bromoform	µg/L	N	80		-	-	-	-	-	-	-	-	-
Bromomethane	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Butanone, 2-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Carbon disulfide	µg/L	N	NE		-	-	-	-	-	-	11	J	J
Carbon tetrachloride	µg/L	N	5		-	-	-	-	-	-	-	-	-
Chlorobenzene	µg/L	N	100		-	-	-	-	-	-	-	-	-
Chloroethane	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Chloroform	µg/L	N	80		-	-	-	-	-	-	-	-	-
Chloromethane	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Dibromochloromethane	µg/L	N	80		-	-	-	-	-	-	-	-	-
Dichloroethane, 1,1-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Dichloroethane, 1,2-	µg/L	N	5		-	-	-	-	-	-	-	-	-
Dichloroethene, 1,1-	µg/L	N	7		-	-	-	-	-	-	-	-	-
Dichloroethene, 1,2-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Dichloropropane, 1,2-	µg/L	N	5		-	-	-	-	-	-	-	-	-

Table 4-4

Monitoring Well BED-MW27 Groundwater Results
West Area Red Water Ponds Area
Former Plum Brook Ordnance Works, Sandusky, Ohio

LOCATION_CODE					PB-BED-MW27			PB-BED-MW27			PB-BED-MW27		
SAMPLE_NO					BD3032			CB3012			CD3009		
SAMPLE_DATE					9-Oct-01			9-Apr-02			18-Oct-02		
FK_DEPTH								85 - 88 Ft					
SAMPLE_PURPOSE					REG			REG			REG		
Parameter	Units	Filtered	MCL	SW ARAR	Result	Qual	ValQual	Result	Qual	ValQual	Result	Qual	ValQual
Dichloropropene, cis-1,3-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Dichloropropene, trans-1,3-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Ethylbenzene	µg/L	N	700	**5 [2]**	**100**	J	J	**83**		J	**76**	J	J
Hexanone, 2-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Methyl-2-pentanone, 4-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Methylene chloride	µg/L	N	5	1900	98	J B	J	18	J B	J	-	-	-
Styrene	µg/L	N	100		-	-	-	-	-	-	-	-	-
Tetrachloroethane, 1,1,2,2-	µg/L	N	NE		-	-	-	-	-	-	-	-	-
Tetrachloroethene	µg/L	N	5		-	-	-	-	-	-	-	-	-
Toluene	µg/L	N	1,000	**5 [2]**	**120**	J	J	**73**		J	**75**	J	J
Trichloroethane, 1,1,1-	µg/L	N	200		-	-	-	-	-	-	-	-	-
Trichloroethane, 1,1,2-	µg/L	N	5		-	-	-	-	-	-	-	-	-
Trichloroethene	µg/L	N	5		-	-	-	-	-	-	-	-	-
Vinyl chloride	µg/L	N	2		-	-	-	-	-	-	-	-	-
Xylenes, total	µg/L	N	10,000	**5 [2]**	**560**			**460**			**370**		

ARAR = Applicable or relevant and appropriate requirements.
NE = No criteria found in regulation.

Bold and shaded cells indicate constituent concentrations in excess of the SW ARAR. The SW ARAR is the most stringent criteria promulgated for each designated use of the waterbody

[1] Potential SW ARAR listed is free cyanide. Analytical results are listed as total cyanide.

[2] Potential SW ARAR listed is the thirty-day average effluent limit for VOCs using best available demonstrated control technology, as required in the Ohio Anti-degradation rules [OAC 3745-1-05(A)(3)(f)]

Table 5-1

Alternative GW-2 Cost Estimate
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

Site: PBOW
Alternative GW-2

Alternative GW-2
Monitoring and Institutional Controls

Date: 02/01/07

Scope:
1 Groundwater Monitoring Plan and Procurement
2 Mobilization
3 Installation of Bedrock Monitoring Wells
4 Groundwater Use Controls
5 Total Capitol Cost
6 Annual Long Term O&M: Years 1 - 150 (Annualized)

1.0 Groundwater Monitoring Plan and Procurement

Includes:
1 Prepare Long-Term Groundwater Monitoring Plan.
2 Procure equipment, materials, and subcontracts.

Service/Materials	Unit	Unit Cost		Subtotal
Long-Term Groundwater Monitoring Plan	1	$40,000.00	/ea	$40,000.00
Contractor Office Labor:				
Mrg, Contract Admin (E09)	40	$77.75	/hr	$3,110.00
Procurement Coordinator (N07)	20	$35.80	/hr	$716.00
			Subtotal	**$43,826.00**

Table 5-1

Alternative GW-2 Cost Estimate
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

2.0 Mobilization

Includes:
1 Mobilize personnel, equipment, and subcontractors.
2 Conduct preconstruction conference.

Assumptions:
1 Allow two days to mobilize personnel, equipment, and subcontractors.
2 Mobilization/ demobilization charges for each piece of equipment is $300 round trip, unless noted otherwise.
3 Travel costs are included for a Site Manager, H&S coordinator, and QC engineer. Travel costs are reflected for each subsequent task.
4 Contractor Field Labor rotate home every 3 weeks.
5 Hours work per day = 10 hours
6 Schedule (10-hr workday) = 2 days
7 Schedule (5-day workweek) = 0.4 weeks

Service/Materials	Unit	Unit Cost		Subtotal
Contractor Office Labor:				
Sr. Geologist (E10)	10	$93.94	/hr	$939.40
Engineer/Scientist IV (E10)	10	$92.56	/hr	$925.60
Geologist (E08)	20	$68.82	/hr	$1,376.40
Engineer/Scientist III (E08)	20	$68.82	/hr	$1,376.40
Contractor Field Labor:				
Site Manager (E06)	20	$57.06	/hr	$1,141.20
H&S Coordinator (E09)	20	$86.13	/hr	$1,722.60
QC/QA (E08)	20	$68.82	/hr	$1,376.40
Subcontractor Field Labor:				
Equipment Operator	2	$327.00	/day	$654.00
Equipment Operator	2	$327.00	/day	$654.00
Equipment Operator	2	$327.00	/day	$654.00
Equipment Operator	2	$327.00	/day	$654.00
Laborer	2	$288.00	/day	$576.00
Laborer	2	$288.00	/day	$576.00
Laborer	2	$288.00	/day	$576.00
Laborer	2	$288.00	/day	$576.00
Laborer	2	$288.00	/day	$576.00
Site Support Facilities				
Installed Site Trailer, 50' x 10'	1	$13,335.00	/ls	$13,335.00
Installed Site Trailer, 50' x 10'	1	$13,335.00	/ls	$13,335.00
Utility and Power Hook-lp	1	$3,000.00	/ls	$3,000.00
Equipment Rental:				
Excavator	1	$300.00	/mobe-demobe	$300.00
Backhoe (85 hp)	1	$300.00	/mobe-demobe	$300.00
Dozer (140 hp)	1	$300.00	/mobe-demobe	$300.00
Trencher	1	$300.00	/mobe-demobe	$300.00
Dump truck (14 cy)	1	$300.00	/mobe-demobe	$300.00
Pressure washer (2000 psi)	1	$100.00	/mobe-demobe	$100.00
Travel:				
Perdiem	6	$39.00	/day	$234.00
Lodging	6	$91.00	/night	$546.00
Air Fare	3	$800.00	/trip	$2,400.00
Rental Car	6	$46.00	/day	$276.00
Rental Car FOGM	6	$12.00	/day	$72.00
			Subtotal	**$49,152.00**

Table 5-1

Alternative GW-2 Cost Estimate
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

3.0 Installation of Bedrock Monitoring Wells

Includes:

1 Installation of Additional Bedrock Monitoring Wells using Hollow-Stem Auger/Air Rotary
2 Development of Monitoring Wells
3 Well Constructed of 2-inch PVC with 15-feet of 0.010 Slot Continuous Wrap PVC Screen

Assumptions:

1	Number of New Bedrock Monitoring Wells:		29	
2	Construct and Develop One Well =		3	days
3	Well Installation Field Days =		87	days
4	Hours work per day =	10	hours	
5	Schedule (10-hr workday) =	87	days	
6	Schedule (5-day workweek) =	17	weeks	
7	Schedule (months) =	4.1	month	

Service/Materials	Unit	Unit Cost		Cost
Contractor Office Labor:				
Engineer/Scientist III (E08)	20	$68.82	/hr	$1,376.35
Procurement Coordinator (N07)	16	$35.80	/hr	$572.80
Secretary III (N06)	16	$34.80	/hr	$556.80
Contractor Field Labor:				
Geologist (E08)	870	$ 68.82	/hr	$59,871.31
Engineering Technician III (N08)	870	$ 46.80	/hr	$40,717.57
Drilling Subcontractor:				
Mobilization	1	$2,500.00	/ea	$2,500.00
Demobilization	1	$2,500.00	/ea	$2,500.00
Posthole first 5 feet 5'	29	$25.00	/ea	$725.00
Decon pad construction	5	$750.00	/ea	$3,750.00
Drill soil with 12" HSA to bedrock 15'	435	$50.00	/ft	$21,750.00
Cut 5' bedrock with 10" tricone roller bit 5'	145	$41.00	/ft	$5,945.00
Install 6" steel casing 35'	1015	$45.00	/ft	$45,675.00
Cut bedrock with 6" OD tricone roller bit 35'	1015	$44.00	/ft	$44,660.00
2-inch ID, Sch 40, PVC casing 47.5'	1378	$9.00	/ft	$12,397.50
2-inch ID, Sch 40, PVC screen '15	435	$12.00	/ft	$5,220.00
2-inch Bedrock Well Construction	29	$1,200.00	/ft	$34,800.00
Well Development	29	$1,200.00	/ea	$34,800.00
Surface Completion	29	$425.00	/ea	$12,325.00
Decontamination	29	$85.00	/ea	$2,465.00
Site cleanup	29	$125.00	/ea	$3,625.00
IDW disposal	29	$250.00	/ea	$7,250.00
Surveying	29	$268.72	/ea	$7,792.88
Travel:				
Per Diem	178	$39.00	/day	$6,942.00
Lodging	178	$91.00	/day	$16,198.00
Air Fare	24	$800.00	/trip	$19,200.00
Rental Car	178	$46.00	/day	$8,188.00
Rental Car FOGM	178	$12.00	/day	$2,136.00
			Subtotal	**$403,939.21**

4.0 Groundwater Use Controls

Service/Materials	Unit	Unit Cost		Cost	
Land Use Control Implementation Plan	1	$50,000.00	/ea	$50,000.00	
				Subtotal	**$50,000.00**

Table 5-1

Alternative GW-2 Cost Estimate
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

5.0 Annual Long Term O&M: Years 1 - 150 (Annualized)

Includes:
1 Groundwater Monitoring

Includes:
1 Annual monitoring of 33 wells in the bedrock zone for COCs.
2 Data verification, evaluation, and preparation of annual report

3	No. of wells sampled =	33	wells/event
4	Number of technicians in field crew =	2	personnel
5	Sampling time (per well) =	3	hrs/well
6	Sampling time per seep =	1	hrs/seep
7	Number of well sampling events =	1	events/year
8	Well sampling time =	10	days
9	Hours work per day =	10	hours

Data Management and QA/QC Assumptions:

Data Entry Technician (E04)	1	hr/sample
Chemist III (E06)	0.75	hr/sample
Database Manager (E08)	1.5	hr/sample
Senior Consultant I (E12)	0.175	hr/sample

Service/Materials	Unit	Unit Cost		Cost
Office Labor:				
Project Manager II (E11)	20	$106.75	/hr	$2,135.00
Senior Consultant I (E12)	10	$118.41	/hr	$1,184.10
Engineer/Scientist III (E08)	40	$68.82	/hr	$2,752.80
Engineer/Scientist II (E06)	100	$57.06	/hr	$5,706.00
Data Entry Technician (E04)	33	$45.00	/hr	$1,485.00
Chemist III (E06)	25	$54.20	/hr	$1,355.00
Database Manager (E08)	50	$64.40	/hr	$3,220.00
Senior Consultant I (E12)	6	$118.41	/hr	$710.46
Secretary III (N06)	20	$34.80	/hr	$696.00
Draftsperson (N08)	40	$53.36	/hr	$2,134.40
Word Processor (N06)	20	$41.82	/hr	$836.40
Field Labor:				
Engineering Technician III (N08)	100	$46.80	/hr	$4,680.00
Engineering Technician III (N08)	100	$46.80	/hr	$4,680.00
Materials:				
Sampling Equipment	1	$500.00	/event	$500.00
Document Reproduction	1	$400.00	/ea	$400.00
RDW Treatment and Disposal	1	$1,250.00	/event	$1,250.00
Analytical:				
Analytical:	1	$5,124.00	/ls	$5,124.00
Travel:				
Per Diem	20	$39.00	/day	$780.00
Lodging	20	$91.00	/day	$1,820.00
Air Fare	2	$800.00	/trip	$1,600.00
Rental Car	20	$46.00	/day	$920.00
Rental Car FOGM	20	$12.00	/day	$240.00
			Subtotal	**$44,209.16**

6.0 Total Capitol Cost

Item	Unit	Unit Cost		Cost	
1 Groundwater Monitoring Plan and Procurement	1	$43,826.00	/ls	$43,826.00	
2 Mobilization	1	$49,152.00	/ls	$49,152.00	
3 Installation of Bedrock Monitoring Wells	1	$403,939.21	/ls	$403,939.21	
4 Groundwater Use Controls	1	$50,000.00	/ls	$50,000.00	
			Total		**546,917.21**

7.0 Total O&M Cost

1 Years 1 - 150	150	$44,209.16	/yr	$6,631,374.00	
			Total		**$6,631,374.00**

Note: This is an 'order of magnitude' engineering cost estimate that is expected to be within + 50% to - 30% of actual project cost.

Table 5-2

Alternative GW-3 Cost Estimate
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

Site: PBOW
Alternative GW-3

Alternative GW-3
In-situ Enhanced Bioremediation (ISEB) and Pump and Treat for Mitigation / Protection of the Bedrock Groundwater

Date: 02/01/07

Scope:
1 Groundwater Modeling, Remedial Design, Work Plans, and Procurement
2 Mobilization
3 Site Preparation, Clearing, and Layout
4 Installation of Overburden Monitoring Wells
5 Installation of Bedrock Monitoring Wells
6 Extraction and Reinjection Well Installation
7 Installation of the Groundwater Treatment Systems
8 ISEB - Emulsified Vegetable Oil Injection
9 Site Restoration, Testing and Demobilization
10 Groundwater Use Controls
11 Total Capitol Cost
12 Annual Pump and Treat Operation and Maintenance (O&M)
13 Annual Long Term O&M: Years 1 - 5 (Annualized)
14 Annual Long Term O&M: Years 6 - 150 (Annualized)

1.0 Groundwater Modeling, Remedial Design, Work Plans, and Procurement

Includes:
1 Perform groundwater modeling verifying placement of wells screen interval.
2 Mobilize drilling subcontractor and geologist to perform one 72-hour pump test at PRRWP and one at WARWP, two total.
3 Prepare RD/RA work plan, H&S work plan, and CQCP.
4 Procure equipment, materials, and subcontracts.

Assumptions:
1 The vertical well depth at PRRWP is 70 feet and the vertical well depth at WARWP is 54 feet.
2 The 72-hour pump test at PRRWP and WARWP shall include pumping from one well within the bedrock and sampling for characterization of the groundwater under pumping conditions. Assume the PRRWP and WARWP wells are installed as part of the scope for installation of the new Bedrock Monitoring Wells (Section 5.0).
3 Assume a Hydrogeologist on-site for a week at 10 hours per day to perform the 72-hour pump test.

Service/Materials	Unit	Unit Cost		Subtotal	
Contractor Office Labor:					
Senior Consultant I (E12)	30	$118.41	/hr	$3,552.30	
Sr. Geologist (E10)	60	$93.94	/hr	$5,636.40	
RD/RA Work Plan	1	$60,000.00	/ea	$60,000.00	
Health & Safety Plan	1	$5,000.00	/ea	$5,000.00	
CQCP	1	$9,000.00	/ea	$9,000.00	
Mrg, Contract Admin (E09)	60	$77.75	/hr	$4,665.00	
Procurement Coordinator (N07)	120	$35.80	/hr	$4,296.00	
GW Modeling	1	$25,000.00	/ls	$25,000.00	
Contractor Field Labor:					
Hydrogeologist (E08)	50	$68.82	/hr	$3,441.00	
Travel:					
Perdiem	5	$39.00	/day	$195.00	
Lodging	5	$91.00	/night	$455.00	
Air Fare	1	$500.00	/trip	$500.00	
Rental Car	5	$46.00	/day	$230.00	
Rental Car FOGM	5	$12.00	/day	$60.00	
				Subtotal	**$122,000.00**

Table 5-2

Alternative GW-3 Cost Estimate
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

2.0 Mobilization

Includes:
1 Mobilize personnel, equipment, and subcontractors.
2 Conduct preconstruction conference.

Assumptions:
1 Setup Shaw Field office. The annual utilities and office supplies are covered within the Pump and Treat O&M (Section 11.0).
2 Allow five days to mobilize personnel, equipment, and subcontractors.
3 Mobilization/ demobilization charges for each piece of equipment is $300 round trip, unless noted otherwise.
4 Travel costs are included for a Site Manager, H&S coordinator, and QC engineer. Travel costs are reflected for each subsequent task.
5 Contractor Field Labor rotate home every 3 weeks.
6 Hours work per day = 10 hours
7 Schedule (10-hr workday) = 5 days
8 Schedule (5-day workweek) = 1 weeks

Service/Materials	Unit	Unit Cost		Subtotal	
Contractor Office Labor:					
Sr. Geologist (E10)	10	$93.94	/hr	$939.40	
Engineer/Scientist IV (E10)	10	$92.56	/hr	$925.60	
Geologist (E08)	20	$68.82	/hr	$1,376.40	
Engineer/Scientist III (E08)	20	$68.82	/hr	$1,376.40	
Contractor Field Labor:					
Site Manager (E06)	50	$57.06	/hr	$2,853.00	
H&S Coordinator (E09)	50	$86.13	/hr	$4,306.50	
QC/QA (E08)	50	$68.82	/hr	$3,441.00	
Subcontractor Field Labor:					
Equipment Operator	5	$327.00	/day	$1,635.00	
Equipment Operator	5	$327.00	/day	$1,635.00	
Equipment Operator	5	$327.00	/day	$1,635.00	
Equipment Operator	5	$327.00	/day	$1,635.00	
Laborer	5	$288.00	/day	$1,440.00	
Laborer	5	$288.00	/day	$1,440.00	
Laborer	5	$288.00	/day	$1,440.00	
Laborer	5	$288.00	/day	$1,440.00	
Laborer	5	$288.00	/day	$1,440.00	
Site Support Facilities					
Installed Site Trailer, 50' x 10'	1	$13,335.00	/ls	$13,335.00	
Installed Site Trailer, 50' x 10'	1	$13,335.00	/ls	$13,335.00	
Utility and Power Hook-lp	1	$3,000.00	/ls	$3,000.00	
Equipment Rental:					
Excavator	1	$300.00	/mobe-demobe	$300.00	
Backhoe (85 hp)	1	$300.00	/mobe-demobe	$300.00	
Dozer (140 hp)	1	$300.00	/mobe-demobe	$300.00	
Trencher	1	$300.00	/mobe-demobe	$300.00	
Dump truck (14 cy)	1	$300.00	/mobe-demobe	$300.00	
Pressure washer (2000 psi)	1	$100.00	/mobe-demobe	$100.00	
Travel:					
Perdiem	15	$39.00	/day	$585.00	
Lodging	15	$91.00	/night	$1,365.00	
Air Fare	3	$800.00	/trip	$2,400.00	
Rental Car	15	$46.00	/day	$690.00	
Rental Car FOGM	15	$12.00	/day	$180.00	
				Subtotal	**$65,400.00**

Table 5-2

Alternative GW-3 Cost Estimate
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

3.0 Site Preparation, Clearing, and Layout

Includes:

1 Survey locations of monitoring wells, extraction wells, reinjection wells, PRRWP and WARWP groundwater treatment systems (WTP), and location of route for piping to and from the PRRWP WTP and WARWP WTP.
2 Install erosion controls, perform clearing and grubbing, and rehabilitate existing access roads at PRRWP and WARWP.

Assumptions:

1 Existing survey monuments adequate for locating new wells and pipe route.
Clearing and Grubbing
2 All clearing debris to be disposed on site.
3 Assume that 30% of pipe route length requires silt fencing and all well location perimeters require silt fencing.
4 Length of piping for extraction and reinjection wells to the WTPs = 8,000 linear feet [Note: See Section 6 for footage.]
5 Area of clearing along pipe route (20 feet width) = 3.7 acres
6 PRRWP shall have 3 extraction wells and 3 reinjection wells while WARWP shall have 5 extraction wells and 5 reinjection wells installed. In addition, 10 overburden monitoring wells and 29 bedrock monitoring wells shall be installed at specified locations at TNT A, TNT B, TNT C, PRRWP, and WARWP.
7 Total number of wells installed = 55 wells
8 Area of clearing for well , at 60' x 60' per site = 4.6 acres
9 Assume that each WTP (at PRRWP and WARWP) are centrally located within the said area and occupy two acres each.
10 Area of clearing for PRRWP and WARWP WTPs = 4.0 acres
11 TNT A, TNT B, TNT C, PRRWP, and WARP have an ISEB injection barrier at each site. So, this area requires clearing for injection point installation.
12 Assume an area of 25-foot wide times the length of the barrier at each site.
13 Area of clearing for ISEB injection barriers =

	Length (ft)	Width (ft)	Area (acres)
TNT A	344	25	0.2
TNT B	331	25	0.2
TNT C	245	25	0.1
PRRWP	663	25	0.4
WARWP	825	25	0.5
		Total	1.4

14 All areas shall require some tree removal and / or brush. Shall be performed Subcontractor.
Site Access Roads
15 PRRWP has an existing access road off of Pentolite Road, ~900 feet, and WARWP has an existing access road off of Patrol Road, ~1,100 feet. Both roads are currently mud/dirt. Thus, assume rehabilitation to a standard access road condition.
16 Length of existing access road at PRRWP, 6"depth x 12 ft. = 990 linear feet [Includes 10% for realignment.]
17 Length of existing access road at WARWP, 6"depth x 12 ft. = 1,210 linear feet [Includes 10% for realignment.]
Duration
18 Hours work per day = 10 hours
19 Schedule (10-hr workday) = 10 days [Note: Accounts for Shaw oversight, erosion control
20 Schedule (5-day workweek) = 2 weeks installation, and site access road rehabilitation.]
21 Schedule (months) = 0.5 month

Service/Materials	Unit	Unit Cost		Subtotal
Contractor Office Labor:				
Sr. Geologist (E10)	8	$93.94	/hr	$751.52
Engineer/Scientist IV (E10)	8	$92.56	/hr	$740.48
Geologist (E08)	20	$68.82	/hr	$1,376.40
Engineer/Scientist III (E08)	20	$68.82	/hr	$1,376.40
Contractor Field Labor:				
Site Manager (E06)	100	$57.06	/hr	$5,706.00
H&S Coordinator (E09)	100	$83.18	/hr	$8,318.00
QC/QA (E08)	100	$68.82	/hr	$6,882.00
Subcontractor Field Labor:				
Equipment Operator	10	$327.00	/day	$3,270.00
Equipment Operator	10	$327.00	/day	$3,270.00
Equipment Operator	10	$327.00	/day	$3,270.00
Equipment Operator	10	$327.00	/day	$3,270.00
Laborer	10	$288.00	/day	$2,880.00
Laborer	10	$288.00	/day	$2,880.00
Laborer	10	$288.00	/day	$2,880.00
Laborer	10	$288.00	/day	$2,880.00
Laborer	10	$288.00	/day	$2,880.00
Subcontractor:				
Survey crew (2-man)	10	$1,100.00	/day	$11,000.00
Med. brush, avg. grub, some trees, clearing	12.30	$810.00	/acre	$9,963.00
Chipping medium brush	12.30	$1,940.00	/acre	$23,862.00
Med. brush, med. trees-clear/grub/haul	1.40	$8,100.00	/acre	$11,340.00
Equipment Rental:				
Excavator	0.5	$4,600.00	/month	$2,300.00
Backhoe (85 hp)	0.5	$1,650.00	/month	$825.00
Dozer (140 hp)	0.5	$4,350.00	/month	$2,175.00
Dump truck (14 cy)	0.5	$3,590.00	/month	$1,795.00
Trencher (diesel, 4 ft. deep, 12" width)	0.5	$6,550.00	/month	$3,275.00
Pressure washer (2000 psi)	0.5	$480.00	/month	$240.00
FOGM	0.5	$3,000.00	/month	$1,500.00
Chemical toilets (x2)	0.5	$300.00	/month	$150.00

Table 5-2

Alternative GW-3 Cost Estimate
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

3.0 Site Preparation, Clearing, and Layout, Continued…

Service/Materials	Unit	Unit Cost		Subtotal	
Materials:					
Silt fencing	12,300	$0.75	/linear foot	$9,225.00	
Straw bales	400	$4.00	/ea	$1,600.00	
Geotextile for road underlayment	26,400	$0.42	/sf	$11,088.00	
Dense graded aggregate (delivered)	890.00	$17.00	/ton	$15,130.00	
Travel:					
Perdiem	36	$39.00	/day	$1,404.00	
Lodging	36	$91.00	/night	$3,276.00	
Air Fare	3	$800.00	/trip	$2,400.00	
Rental Car	36	$46.00	/day	$1,656.00	
Rental Car FOGM	36	$12.00	/day	$432.00	
				Subtotal	**$167,300.00**

4.0 Installation of Overburden Monitoring Wells

Includes:

1 Installation of Overburden Monitoring Wells using Hollow-Stem Auger Drilling
2 Installation of 10 wells to a total depth of 25 ft.
3 Development of Monitoring Wells
4 Well Constructed of 2-inch PVC with 10-feet of 0.010 Slot Continuous Wrap PVC Screen

Assumptions:

1	Number of New Overburden Monitoring Wells =	10	
2	Drill, construct, and develop one well =	1.5	days
3	Cost drilling per foot =	$18.00	ft/well
4	Total number of wells =	10	ea
5	Well Installation Field Days =	15	days
6	Soil and bedrock (for this task) can be drilled using HSA.		
7	Hours work per day =	10	hours
8	Schedule (10-hr workday) =	15	days
9	Schedule (5-day workweek) =	3	weeks
10	Schedule (months) =	0.7	month

Service/Materials	Unit	Unit Cost		Cost	
Contractor Office Labor:					
Engineer/Scientist III (E08)	16	$68.82	/hr	$1,101.08	
Procurement Coordinator (N07)	8	$35.80	/hr	$286.40	
Secretary III (N06)	8	$34.80	/hr	$278.40	
Contractor Field Labor:					
Geologist (E08)	150	$ 68.82	/hr	$10,322.64	
Engineering Technician III (N08)	150	$ 46.80	/hr	$7,020.27	
Drilling Subcontractor:					
Mobilization	1	$2,500.00	/ea	$2,500.00	
Demobilization	1	$2,500.00	/ea	$2,500.00	
Posthole first 5 feet	10	$25.00	/ea	$250.00	
Decon pad construction	5	$750.00	/ea	$3,750.00	
Average drilling cost in soil, per foot	250	$18.00	/ft	$4,500.00	
2-inch ID, Sch 40, PVC casing	175	$9.00	/ft	$1,575.00	
2-inch ID, Sch 40, PVC screen	100	$12.00	/ft	$1,200.00	
2-inch Overburden Well Construction	10	$1,200.00	/ea	$12,000.00	
Well Development	10	$1,200.00	/ea	$12,000.00	
Surface Completion	10	$425.00	/ea	$4,250.00	
Decontamination	10	$85.00	/ea	$850.00	
Site cleanup	10	$125.00	/ea	$1,250.00	
IDW disposal	10	$250.00	/ea	$2,500.00	
Surveying	10	$268.72	/ea	$2,687.20	
				$51,812.20	
Travel:					
Perdiem	34	$39.00	/day	$1,326.00	
Lodging	34	$91.00	/night	$3,094.00	
Air Fare	4	$800.00	/trip	$3,200.00	
Rental Car	34	$46.00	/day	$1,564.00	
Rental Car FOGM	34	$12.00	/day	$408.00	
				Subtotal	**$80,412.99**

Table 5-2

Alternative GW-3 Cost Estimate
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

5.0 Installation of Bedrock Monitoring Wells

Includes:

1 Installation of 29 Additional Bedrock Monitoring Wells using Hollow-Stem Auger/Air Rotary to a total depth of 60 ft.
2 Development of Monitoring Wells
3 Well Constructed of 2-inch PVC with 15-feet of 0.010 Slot Continuous Wrap PVC Screen

Assumptions:

1	Number of New Bedrock Monitoring Wells:		29	
2	Construct and Develop One Well =		3	days
3	Well Installation Field Days =		87	days
4	Hours work per day =	10	hours	
5	Schedule (10-hr workday) =	87	days	
6	Schedule (5-day workweek) =	17	weeks	
7	Schedule (months) =	4.1	month	

Service/Materials	Unit	Unit Cost		Cost
Contractor Office Labor:				
Engineer/Scientist III (E08)	20	$68.82	/hr	$1,376.35
Procurement Coordinator (N07)	16	$35.80	/hr	$572.80
Secretary III (N06)	16	$34.80	/hr	$556.80
Contractor Field Labor:				
Geologist (E08)	870	$ 68.82	/hr	$59,871.31
Engineering Technician III (N08)	870	$ 46.80	/hr	$40,717.57
Drilling Subcontractor:				
Mobilization	1	$2,500.00	/ea	$2,500.00
Demobilization	1	$2,500.00	/ea	$2,500.00
Posthole first 5 feet 5'	29	$25.00	/ea	$725.00
Decon pad construction	5	$750.00	/ea	$3,750.00
Drill soil with 12" HSA to bedrock 15'	435	$50.00	/ft	$21,750.00
Cut 5' bedrock with 10" tricone roller bit 5'	145	$41.00	/ft	$5,945.00
Install 6" steel casing 35'	1015	$45.00	/ft	$45,675.00
Cut bedrock with 6" OD tricone roller bit 35'	1015	$44.00	/ft	$44,660.00
2-inch ID, Sch 40, PVC casing 47.5'	1378	$9.00	/ft	$12,397.50
2-inch ID, Sch 40, PVC screen '15	435	$12.00	/ft	$5,220.00
2-inch Bedrock Well Construction	29	$1,200.00	/ft	$34,800.00
Well Development	29	$1,200.00	/ea	$34,800.00
Surface Completion	29	$425.00	/ea	$12,325.00
Decontamination	29	$85.00	/ea	$2,465.00
Site cleanup	29	$125.00	/ea	$3,625.00
IDW disposal	29	$250.00	/ea	$7,250.00
Surveying	29	$268.72	/ea	$7,792.88
Total Well Cost				**$351,275.21**
Travel:				
Per Diem	178	$39.00	/day	$6,942.00
Lodging	178	$91.00	/day	$16,198.00
Air Fare	24	$800.00	/trip	$19,200.00
Rental Car	178	$46.00	/day	$8,188.00
Rental Car FOGM	178	$12.00	/day	$2,136.00
				Subtotal **$507,034.04**

Table 5-2

Alternative GW-3 Cost Estimate
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

6.0 Extraction and Reinjection Well Installation

Includes:

1 Installation of extraction and reinjection wells along with pumps, power, controls and surface completions.
2 Eight extraction wells, 3 at PRRWP and 5 at WARWP will be installed:

3 at PRRWP -	70	avgas depth (ft)	210	total depth (ft)
5 at WARWP -	54	avgas depth (ft)	270	total depth (ft)

3 Eight reinjection wells, 3 at PRRWP and 5 at WARWP:

3 at PRRWP -	70	avg depth (ft)	210	total depth (ft)
5 at WARWP -	54	avg depth (ft)	270	total depth (ft)

4 Average depth to bedrock estimated to be 50 ft at both PRRWP and WARWP.
5 Development of wells.
6 Install piping, valving, interim lift station, along with power and controls related with the PRRWP WTP and WARWP WTP.
7 Baseline sampling of the newly installed wells.

Assumptions:

1 Medium voltage distribution line is available in the proximity to each well cluster.
2 No other existing utilities require relocation.
3 Piping to the groundwater treatment systems shall be HDPE, SDR 21, single wall.
4 Assume each WTP is centrally located to the extraction and reinjection wells at said location, i.e., PRRWP and WARWP.
5 Assume that on average, 500 feet of pipe for each extraction well and each reinjection well.
6 Assume 250 linear of piping, fittings and valves can be installed per day.
7 Installation of wells using air rotary drilling methods.

8 Number of extraction wells =	8	each	
9 Construct and develop one well =	3	days	[Note: Does not incl. surface completion.]
10 Overburden drilling=	456	feet	
11 Bedrock drilling=	380	feet	
12 Total depth =	836	feet	
13 Well installation field days =	24	days	
14 Number of Reinjection Wells =	8	each	
15 Construct and develop one well =	3	days	[Note: Does not incl. surface completion.]
16 Overburden drilling=	320	feet	
17 Bedrock drilling=	160	feet	
18 Total depth =	480	feet	
19 Well installation field days =	24	days	
20 Total field days =	48.0	days	
21 Number of wells to be sampled =	16	each	
22 Total field days for sampling wells (3 dy) =	6.0	days	
23 Length of manifold piping from extraction wells =	3,000	linear feet	
24 Length of piping WTP to reinjection wells =	5,000	linear feet	
25 Assume 250 feet of pipe shall be installed per day. Duration =	32.0	days	

26 Assume Shaw Field Labor for installation of piping and utilization of a Drilling Subcontractor for well installation.

26 Hours work per day =	10	hours	
27 Schedule (10-hr workday) =	54	days	[Note: Based on well installation to have Shaw oversight.]
28 Schedule (5-day workweek) =	11	weeks	
29 Schedule (months) =	2.5	months	

Service/Materials	Unit	Unit Cost		Subtotal
Contractor Office Labor:				
Sr. Geologist (E10)	44	$93.94	/hr	$4,133.36
Engineer/Scientist IV (E10)	44	$92.56	/hr	$4,072.64
Geologist (E08)	108	$68.82	/hr	$7,432.56
Engineer/Scientist III (E08)	108	$68.82	/hr	$7,432.56
Chemist III (E06)	40	$54.20	/hr	$2,168.00
Data Entry Technician (E04)	40	$45.00	/hr	$1,800.00
Contractor Field Labor:				
Site Manager (E06)	540	$57.06	/hr	$30,812.40
H&S Coordinator (E09)	540	$83.18	/hr	$44,917.20
QC/QA (E08)	540	$68.82	/hr	$37,162.80
Subcontractor Field Labor:				
Equipment Operator	32	$327.00	/day	$10,464.00
Equipment Operator	32	$327.00	/day	$10,464.00
Equipment Operator	32	$327.00	/day	$10,464.00
Equipment Operator	32	$327.00	/day	$10,464.00
Laborer	32	$288.00	/day	$9,216.00
Laborer	32	$288.00	/day	$9,216.00
Laborer	32	$288.00	/day	$9,216.00
Laborer	32	$288.00	/day	$9,216.00
Laborer	32	$288.00	/day	$9,216.00
Baseline Sampling:				
Sampling, analytical, and reporting	16	$2,000.00	/well	$32,000.00

Table 5-2

Alternative GW-3 Cost Estimate
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

6.0 Extraction and Reinjection Well Installation

Service/Materials	Unit	Unit Cost		Subtotal	
Equipment Rental:					
Excavator	1.5	$4,600.00	/month	$6,900.00	
Backhoe (85 hp)	1.5	$1,650.00	/month	$2,475.00	
Dozer (140 hp)	1.5	$4,350.00	/month	$6,525.00	
Trencher (diesel, 4 ft. deep, 12" width)	1.5	$6,550.00	/month	$9,825.00	
Dump truck (14 cy)	1.5	$3,590.00	/month	$5,385.00	
Pressure washer (2000 psi)	1.5	$480.00	/month	$720.00	
FOGM	1.5	$3,000.00	/month	$4,500.00	
Chemical toilets (x2)	1.5	$300.00	/month	$450.00	
Materials:					
4" gw pump (<7 gpm, <800 ft head, 1.5 hp, cntrls)	8	$3,750.00	/ea	$30,000.00	
Reinjection wellhead completion & vault	8	$3,500.00	/ea	$28,000.00	
Control panel	7	$2,500.00	/ea	$17,500.00	
3" dia. HDPE, SDR 21 pipe (welder & machine only)	3,000	$7.19	/linear foot	$21,570.00	
4" dia. HDPE, SDR 21 pipe (welder & machine only)	5,000	$8.44	/linear foot	$42,200.00	
Buried utility marking tape (foil backing)	8,000	$0.15	/linear foot	$1,200.00	
Valving and fittings (10% of pipe total)	1	$6,377.00	/lump sum	$6,377.00	
Package lift station (18 gpm)	1	$4,000.00	/lump sum	$4,000.00	
Drilling Subcontractor:					
Mobilization/demobilization (10-day rotation)	5	$5,000.00	/ea	$25,000.00	
Minirae 2000 (10.6)	12	$225.00	/week	$2,700.00	
4-inch PVC, schedule 40, well casing	1,076	$18.00	/vf	$19,368.00	
4-inch PVC, schedule 40, well screen	240	$25.00	/vf	$6,000.00	
8" roller cone soil drilling, casing installation	776	$80.00	/vf	$62,080.00	
6" roller cone bedrock drilling	540	$44.00	/feet	$23,760.00	
Install well and materials	16	$675.00	/feet	$10,800.00	
Furnish and Install flush well and pad	16	$500.00	/ea	$8,000.00	
Well development	8	$250.00	/ea	$2,000.00	
Decontamination	16	$150.00	/ea	$2,400.00	
Cleanup	16	$85.00	/ea	$1,360.00	
IDW disposal	16	$500.00	/ea	$8,000.00	
Travel:					
Perdiem	162	$39.00	/day	$6,318.00	
Lodging	162	$91.00	/night	$14,742.00	
Air Fare	6	$800.00	/trip	$4,800.00	
Rental Car	162	$46.00	/day	$7,452.00	
Rental Car FOGM	162	$12.00	/day	$1,944.00	
				Subtotal	**$654,200.00**

7.0 Installation of the Groundwater Treatment Systems

Includes:
1 Installation of the PRRWP WTP and WARWP WTP.

Assumptions:
1 Non-equipment costs estimated by factoring based on total equipment costs.
2 Flow rate of PRRWP WTP = 10.5 gpm
3 Flow rate of WARWP WTP= 6 gpm

Service/Materials	Unit	Unit Cost		Cost	
Plant and Equipment:					
Anoxic FBR Denitrification System	1	$250,000.00	/ea	$250,000.00	Total installed cost
Aerobic Bioreactor	1	$660,000.00	/ea	$660,000.00	Total installed cost
Subtotal - Biological Treatment Systems				**$910,000.00**	Total installed cost
Air Stripper	1	$15,000.00	/ea	$15,000.00	
Polymer Feed System	2	$4,000.00	/ea	$8,000.00	
Coagulation/Flocculation Tanks w/ Agitators	2	$8,000.00	/ea	$16,000.00	
Parallel Plate Clarifier	2	$17,000.00	/ea	$34,000.00	
Duplex Bag Filter w/ Pump	2	$11,000.00	/ea	$22,000.00	
Dual Bed Carbon Adsorber	1	$12,000.00	/ea	$12,000.00	
Sludge Storage Tank	2	$8,000.00	/ea	$16,000.00	
Filter Press w/ Pump	2	$25,000.00	/ea	$50,000.00	
Subtotal - Non-Biological Treatment Systems				**$173,000.00**	
Subtotal Equipment Cost				**$1,083,000.00**	
Miscellaneous					
Site Improvements	1	$108,300.00	/ea	$108,300.00	
Buildings	1	$194,940.00		$194,940.00	
Equipment Installation	1	$81,310.00	/ea	$81,310.00	
Instrumentation and Controls (Installed)	1	$43,250.00	/ea	$43,250.00	
Piping (Installed)	1	$114,180.00	/ea	$114,180.00	
Electrical (Installed)	1	$19,030.00	/ea	$19,030.00	
Utilities (Installed)	1	$541,500.00	/ea	$541,500.00	
Engineering and Supervision	1	$57,090.00	/ea	$57,090.00	
Construction Expense	1	$70,930.00	/ea	$70,930.00	
Subtotal Other Costs				**$1,230,530.00**	
				Subtotal	**$2,313,500.00**

Table 5-2

Alternative GW-3 Cost Estimate
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

8.0 ISEB - Emulsified Vegetable Oil Injection

Includes:
1 DPT Injection of emulsified vegetable oil in plumes designated in Table 3-6.
2 DPT injection implemented in a series of parallel biobarriers per Table 5-2.

Assumptions:
1 DPT rig, field truck, water truck and substrate metering system purchased outright for long-term project.
2 All field personnel hired direct for duration of project, therefore expenses for travel, lodging and meals not incurred.
3 Office engineer travels to the site 3 days (including travel) per month for duration of project.

Total Plume Areas

1	Total number of injection points =	4609	points
2	Substrate demand =	1,161,600	pounds
3	Substrate density =	7.64	pounds/gal
4	Substrate demand per injection point =	252	pounds
5	Ratio substrate to water =	0.2	
6	Water required =	760	kgal
7	Injection points completed per day =	4	points/DPT crew*day
8	Estimated field duration =	1153	crew days
9	Number of DPT crews =	1	crews
10	Estimated field duration =	1153	work days
11	Work days per month =	22	work days/month
12	Estimated field duration =	52	months
13	Field workers per DPT crew =	2	workers/crew
14	Hours per Work Day =	8	hours/day
15	Number of supervisory crew =	2	workers

Service/Materials	Unit	Unit Cost		Cost	
Contractor Office Labor:					
Project Manager II (E11)	624	$106.75	/hr	$66,612.00	
Engineer Scientist IV (E10)	1,664	$ 92.56	/hr	$154,020.00	
Geologist (E08)	416	$68.82	/hr	$28,629.00	
Procurement Coordinator (N07)	416	$35.80	/hr	$14,892.80	
Contractor Field Labor:					
Site Manager (E06)	9,224	$ 57.06	/hr	$526,321.44	
Engineering Technician (N08)	9,224	$46.80	/hr	$431,683.20	
Equipment & Materials:					
EOS (incl. shipping)	1,161,600	$1.90	/lb	$2,207,040.00	
Dilution Water	760	$2.87	/kgal	$2,182.00	
Metering System	1	$25,000.00	/ea	$25,000.00	Purchased
Water truck	1	$30,000.00	/ea	$30,000.00	Purchased
Injection Supplies	52	$5,000.00	/month	$260,000.00	
Field Truck	1	$25,000.00	/ea	$25,000.00	Purchased
Rental Car FOGM	2,306	$12.00	/day	$27,672.00	
DPT Drilling Crew:					
DPT Rig	1	$140,000.00	/ea	$140,000.00	Purchased
Equipment Operator	2,306	$327.00	/day	$754,062.00	
Travel:					
Per Diem	156	$39.00	/day	$6,084.00	
Lodging	104	$91.00	/day	$9,464.00	
Air Fare	52	$800.00	/trip	$41,600.00	
Rental Car	156	$46.00	/day	$7,176.00	
				Subtotal	**$4,757,400.00**

Table 5-2

Alternative GW-3 Cost Estimate
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

9.0 Site Restoration, Testing and Demobilization

Includes:

1 Conduct hydrostatic pressure testing on pipe line and "shakedown/startup" testing of pumps and controls.
2 Site restoration including finish grading and seeding.
3 Demobilization

Assumptions:

1 Groundwater from wells will be used to hydrostatic test pipe lines, then it will be discharged to PRRWP WTP and WARWP WTP.
2 Dozer will finish grade areas as work is completed in line items above.
3 Testing and shakedown completed by contractor labor for one week duration.
4 Reference clearing areas in Section 3.0.
5 Demobilization of equipment was accounted for in Section 2.0.

6	Hours work per day =	10	hours
7	Schedule (10-hr workday) =	15	days
8	Schedule (5-day workweek) =	3	weeks
9	Schedule	0.7	months

Service/Materials	Unit	Unit Cost		Cost	
Office Labor:					
Sr. Geologist (E10)	12	$93.94	/hr	$1,127.28	
Engineer/Scientist IV (E10)	12	$92.56	/hr	$1,110.72	
Geologist (E08)	30	$68.82	/hr	$2,064.60	
Engineer/Scientist III (E08)	30	$68.82	/hr	$2,064.60	
Construction completion report	1	$12,500.00	/lump sum	$12,500.00	
LTM plan	1	$15,000.00	/lump sum	$15,000.00	
Contractor Field Labor:					
Site Manager (E06)	150	$57.06	/hr	$8,559.00	
H&S Coordinator (E09)	150	$83.18	/hr	$12,477.00	
QC/QA (E08)	150	$68.82	/hr	$10,323.00	
Engineer/Scientist III (E08) - Mechanical	50	$68.82	/hr	$3,441.00	
Engineer/Scientist III (E08) - Electrical	50	$68.82	/hr	$3,441.00	
Equipment Rental:					
Backhoe (85 hp)	1	$1,650.00	/month	$1,650.00	
Dozer (140 hp)	1	$4,350.00	/month	$4,350.00	
Pump for testing	1	$480.00	/month	$480.00	
Pressure washer (2000 psi)	1	$480.00	/month	$480.00	
FOGM	1	$3,000.00	/month	$3,000.00	
Subcontractor Field Labor:					
Equipment Operator	15	$327.00	/day	$4,905.00	
Equipment Operator	15	$327.00	/day	$4,905.00	
Laborer	15	$288.00	/day	$4,320.00	
Laborer	15	$288.00	/day	$4,320.00	
Subcontractor:					
Mob/Demob	1	$2,500.00	/ea	$2,500.00	
Seed, mulch, water	13.70	$4,700.00	/acre	$64,390.00	
Travel:					
Per diem	61	$39.00	/day	$2,379.00	
Lodging	61	$91.00	/day	$5,551.00	
Air Fare	5	$800.00	/trip	$4,000.00	
Rental Car	56	$46.00	/day	$2,576.00	
Rental Car FOGM	56	$12.00	/day	$672.00	
				Subtotal	**$182,600.00**

10.0 Groundwater Use Controls

Service/Materials	Unit	Unit Cost		Cost	
Land Use Control Implementation Plan	1	$50,000.00	/ea	$50,000.00	
				Subtotal	**$50,000.00**

Table 5-2

Alternative GW-3 Cost Estimate
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

11.0 Annual Pump and Treat Operation and Maintenance (O&M), Years 1-150

Includes:
1 Groundwater Treatment System O&M
2 Installed Wells, Piping, and Site Facilities

Assumptions:
1 Field labor is local; therefore no cost for travel is included.
2 Annual reporting cost sufficient to cover five-year reviews.

Note:
Cost for capital improvements to replace substantial portions of the groundwater treatment systems are not included in this evaluation.

Service/Materials	Unit	Unit Cost			Cost	
I. Groundwater Treatment System O&M - PRRWP WTP and WARWP WTP						
Labor:						
Operator labor	2	$26,000.00	/ls		$52,000.00	
Management	2	$1,500.00	/ls		$3,000.00	
Materials:						
Filter replacement	2	$200.00	/ls		$400.00	
Carbon for Polishing, at 2ppm	1	$3,800.00	/ls		$3,800.00	
Chemical/Flocculants, at 20 ppm	1	$2,800.00	/ls		$2,800.00	
Utilities:						
Electric Power for Treatment System 4 pumps + 1 blower (3 heaps each)	2	$8,900.00	/ls		$17,800.00	
Disposal:						
Filter Cake Solids, lb/day	204	$2.00	/lb/day		$408.00	
Sampling:						
Water Sample Analysis	2	$16,800.00	/ls		$33,600.00	
Anoxic and Aerobic Equipment:						
Anoxic FBR Denitrification System	1	$327.00	/ea		$327.00	
Aerobic Bioreactor	1	$19,457.00	/ea		$19,457.00	
Miscellaneous:						
Reporting	2	$5,000.00	/ls		$10,000.00	
Maintenance	2	$4,000.00	/ls		$8,000.00	
				Subtotal	**$151,592.00**	
II. Installed Wells, Piping, and Site Facilities						
Monitoring, Extraction, and Reinjection Well Repairs	1	$5,000.00	/ls		$5,000.00	
Miscellaneous Repairs to Pipeline	1	$1,000.00	/ls		$1,000.00	
Field Office Utilities	1	$7,332.00	/ls		$7,332.00	
				Subtotal	**$13,332.00**	
					Subtotal	**$164,900.00**

Table 5-2

Alternative GW-3 Cost Estimate
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

12.0 Annual Long Term O&M: Years 1 - 5 (Annualized)

Includes:
1 Groundwater Monitoring

Includes:
1 Annual monitoring of 19 wells in the overburden/weathered shale and 33 wells in the bedrock zone for COCs.
2 Data verification, evaluation, and preparation of annual report

3	No. of wells sampled =	52	wells/event
4	Number of technicians in field crew =	2	personnel
5	Sampling time (per well) =	3	hrs/well
6	Sampling time per seep =	1	hrs/seep
7	Number of well sampling events =	1	events/year
8	Well sampling time =	16	days
9	Hours work per day =	10	hours

Data Management and QA/QC Assumptions:

Data Entry Technician (E04)	1	hr/sample
Chemist III (E06)	0.75	hr/sample
Database Manager (E08)	1.5	hr/sample
Senior Consultant I (E12)	0.175	hr/sample

Service/Materials	Unit	Unit Cost		Cost
Office Labor:				
Project Manager II (E11)	20	$106.75	/hr	$2,135.00
Senior Consultant I (E12)	10	$118.41	/hr	$1,184.10
Engineer/Scientist III (E08)	40	$68.82	/hr	$2,752.80
Engineer/Scientist II (E06)	100	$57.06	/hr	$5,706.00
Data Entry Technician (E04)	52	$45.00	/hr	$2,340.00
Chemist III (E06)	39	$54.20	/hr	$2,113.80
Database Manager (E08)	78	$64.40	/hr	$5,023.20
Senior Consultant I (E12)	9	$118.41	/hr	$1,065.69
Secretary III (N06)	20	$34.80	/hr	$696.00
Draftsperson (N08)	40	$53.36	/hr	$2,134.40
Word Processor (N06)	20	$41.82	/hr	$836.40
Field Labor:				
Engineering Technician III (N08)	160	$46.80	/hr	$7,488.00
Engineering Technician III (N08)	160	$46.80	/hr	$7,488.00
Materials:				
Sampling Equipment	1	$500.00	/event	$500.00
Document Reproduction	1	$400.00	/ea	$400.00
RDW Treatment and Disposal	1	$1,250.00	/event	$1,250.00
Analytical:				
Analytical:	1	$11,147.00	/ls	$11,147.00
Travel:				
Per Diem	32	$39.00	/day	$1,248.00
Lodging	32	$91.00	/day	$2,912.00
Air Fare	2	$800.00	/trip	$1,600.00
Rental Car	32	$46.00	/day	$1,472.00
Rental Car FOGM	32	$12.00	/day	$384.00
				Subtotal

$61,900.00

Table 5-2

Alternative GW-3 Cost Estimate
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

13.0 Annual Long Term O&M: Years 6 - 150 (Annualized)

Includes:
1 Groundwater Monitoring

Includes:
1 Annual monitoring of 33 wells in the bedrock zone for COCs.
2 Data verification, evaluation, and preparation of annual report

3	No. of wells sampled =	33	wells/event
4	Number of technicians in field crew =	2	personnel
5	Sampling time (per well) =	3	hrs/well
6	Sampling time per seep =	1	hrs/seep
7	Number of well sampling events =	1	events/year
8	Well sampling time =	10	days
9	Hours work per day =	10	hours

Data Management and QA/QC Assumptions:

Data Entry Technician (E04)	1	hr/sample
Chemist III (E06)	0.75	hr/sample
Database Manager (E08)	1.5	hr/sample
Senior Consultant I (E12)	0.175	hr/sample

Service/Materials	Unit	Unit Cost		Cost
Office Labor:				
Project Manager II (E11)	20	$106.75	/hr	$2,135.00
Senior Consultant I (E12)	10	$118.41	/hr	$1,184.10
Engineer/Scientist III (E08)	40	$68.82	/hr	$2,752.80
Engineer/Scientist II (E06)	100	$57.06	/hr	$5,706.00
Data Entry Technician (E04)	33	$45.00	/hr	$1,485.00
Chemist III (E06)	25	$54.20	/hr	$1,355.00
Database Manager (E08)	50	$64.40	/hr	$3,220.00
Senior Consultant I (E12)	6	$118.41	/hr	$710.46
Secretary III (N06)	20	$34.80	/hr	$696.00
Draftsperson (N08)	40	$53.36	/hr	$2,134.40
Word Processor (N06)	20	$41.82	/hr	$836.40
Field Labor:				
Engineering Technician III (N08)	100	$46.80	/hr	$4,680.00
Engineering Technician III (N08)	100	$46.80	/hr	$4,680.00
Materials:				
Sampling Equipment	1	$500.00	/event	$500.00
Document Reproduction	1	$400.00	/ea	$400.00
RDW Treatment and Disposal	1	$1,250.00	/event	$1,250.00
Analytical:				
Analytical:	1	$5,124.00	/ls	$5,124.00
Travel:				
Per Diem	20	$39.00	/day	$780.00
Lodging	20	$91.00	/day	$1,820.00
Air Fare	2	$800.00	/trip	$1,600.00
Rental Car	20	$46.00	/day	$920.00
Rental Car FOGM	20	$12.00	/day	$240.00
				Subtotal **$44,200.00**

14.0 Total Capitol Cost

	Item	Unit	Unit Cost		Cost
1	Groundwater Modeling, Remedial Design, Work Plans, and Procurement	1	$122,000.00	/ls	$122,000.00
2	Mobilization	1	$65,400.00	/ls	$65,400.00
3	Site Preparation, Clearing, and Layout	1	$167,300.00	/ls	$167,300.00
4	Installation of Overburden Monitoring Wells	1	$ 80,412.99	/ls	$ 80,412.99
5	Installation of Bedrock Monitoring Wells	1	$507,034.04	/ls	$507,034.04
6	Extraction and Reinjection Well Installation	1	$654,200.00	/ls	$654,200.00
7	Installation of the Groundwater Treatment Systems	1	$2,313,500.00	/ls	$2,313,500.00
8	ISEB - Emulsified Vegetable Oil Injection	1	$4,757,400.00	/ls	$4,757,400.00
9	Site Restoration, Testing and Demobilization	1	$182,600.00	/ls	$182,600.00
10	Groundwater Use Controls	1	$50,000.00	/ls	$50,000.00
					Total **$8,899,847.03**

15.0 Total O&M Cost

	Item	Unit	Unit Cost		Cost
1	Years 1 - 5	5	$226,800.00	/yr	$1,134,000.00
2	Years 6 - 150	145	$209,100.00	/yr	$30,319,500.00
					Total **$31,453,500.00**

Note: This is an 'order of magnitude' engineering cost estimate that is expected to be within + 50% to - 30% of actual project cost.

Table 5-3

Alternative GW-4 Cost Estimate
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

Site: PBOW
Alternative GW-4

Alternative GW-4
In-situ Enhanced Bioremediation (ISEB) and Pump and Treat for Mitigation / Protection of the Overburden / Shale and Bedrock Groundwater

Date: 02/01/07

Scope:
1 Groundwater Modeling, Remedial Design, Work Plans, and Procurement
2 Mobilization
3 Site Preparation, Clearing, and Layout
4 Installation of Overburden Monitoring Wells
5 Installation of Bedrock Monitoring Wells
6 Extraction and Reinjection Well Installation
7 Installation of the Groundwater Treatment Systems
8 ISEB - Emulsified Vegetable Oil Injection
9 Site Restoration, Testing and Demobilization
10 Groundwater Use Controls
11 Total Capitol Cost
12 Annual Pump and Treat Operation and Maintenance (O&M)
13 Annual Long Term O&M: Years 1 - 5 (Annualized)
14 Annual Long Term O&M: Years 6 - 150 (Annualized)

1.0 Groundwater Modeling, Remedial Design, Work Plans, and Procurement

Includes:
1 Perform groundwater modeling verifying placement of wells screen interval.
2 Mobilize drilling subcontractor and geologist to perform one 72-hour pump test at PRRWP and one at WARWP, two total.
3 Prepare RD/RA work plan, H&S work plan, and CQCP.
4 Procure equipment, materials, and subcontracts.

Assumptions:
1 The vertical well depth at PRRWP is 70 feet and the vertical well depth at WARWP is 54 feet.
2 The 72-hour pump test at PRRWP and WARWP shall include pumping from one well within the bedrock and sampling for characterization of the groundwater under pumping conditions. Assume the PRRWP and WARWP wells are installed as part of the scope for installation of the new Bedrock Monitoring Wells (Section 5.0).
3 Assume a Hydrogeologist on-site for a week at 10 hours per day to perform the 72-hour pump test.

Service/Materials	Unit	Unit Cost		Subtotal	
Contractor Office Labor:					
Senior Consultant I (E12)	30	$118.41	/hr	$3,552.30	
Sr. Geologist (E10)	60	$93.94	/hr	$5,636.40	
RD/RA Work Plan	1	$60,000.00	/ea	$60,000.00	
Health & Safety Plan	1	$5,000.00	/ea	$5,000.00	
CQCP	1	$9,000.00	/ea	$9,000.00	
Mrg, Contract Admin (E09)	60	$77.75	/hr	$4,665.00	
Procurement Coordinator (N07)	120	$35.80	/hr	$4,296.00	
GW Modeling	1	$25,000.00	/ls	$25,000.00	
Contractor Field Labor:					
Hydrogeologist (E08)	50	$68.82	/hr	$3,441.00	
Travel:					
Perdiem	5	$39.00	/day	$195.00	
Lodging	5	$91.00	/night	$455.00	
Air Fare	1	$500.00	/trip	$500.00	
Rental Car	5	$46.00	/day	$230.00	
Rental Car FOGM	5	$12.00	/day	$60.00	
				Subtotal	**$122,000.00**

Table 5-3

Alternative GW-4 Cost Estimate
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

2.0 Mobilization

Includes:
1 Mobilize personnel, equipment, and subcontractors.
2 Conduct preconstruction conference.

Assumptions:
1 Setup Shaw Field office. The annual utilities and office supplies are covered within the Pump and Treat O&M (Section 11.0).
2 Allow five days to mobilize personnel, equipment, and subcontractors.
3 Mobilization/ demobilization charges for each piece of equipment is $300 round trip, unless noted otherwise.
4 Travel costs are included for a Site Manager, H&S coordinator, and QC engineer. Travel costs are reflected for each subsequent task.
5 Contractor Field Labor rotate home every 3 weeks.
6 Hours work per day = 10 hours
7 Schedule (10-hr workday) = 5 days
8 Schedule (5-day workweek) = 1 weeks

Service/Materials	Unit	Unit Cost		Subtotal	
Contractor Office Labor:					
Sr. Geologist (E10)	10	$93.94	/hr	$939.40	
Engineer/Scientist IV (E10)	10	$92.56	/hr	$925.60	
Geologist (E08)	20	$68.82	/hr	$1,376.40	
Engineer/Scientist III (E08)	20	$68.82	/hr	$1,376.40	
Contractor Field Labor:					
Site Manager (E06)	50	$57.06	/hr	$2,853.00	
H&S Coordinator (E09)	50	$86.13	/hr	$4,306.50	
QC/QA (E08)	50	$68.82	/hr	$3,441.00	
Subcontractor Field Labor:					
Equipment Operator	5	$327.00	/day	$1,635.00	
Equipment Operator	5	$327.00	/day	$1,635.00	
Equipment Operator	5	$327.00	/day	$1,635.00	
Equipment Operator	5	$327.00	/day	$1,635.00	
Laborer	5	$288.00	/day	$1,440.00	
Laborer	5	$288.00	/day	$1,440.00	
Laborer	5	$288.00	/day	$1,440.00	
Laborer	5	$288.00	/day	$1,440.00	
Laborer	5	$288.00	/day	$1,440.00	
Site Support Facilities					
Installed Site Trailer, 50' x 10'	1	$13,335.00	/ls	$13,335.00	
Installed Site Trailer, 50' x 10'	1	$13,335.00	/ls	$13,335.00	
Utility and Power Hook-Ip	1	$3,000.00	/ls	$3,000.00	
Equipment Rental:					
Excavator	1	$300.00	/mobe-demobe	$300.00	
Backhoe (85 hp)	1	$300.00	/mobe-demobe	$300.00	
Dozer (140 hp)	1	$300.00	/mobe-demobe	$300.00	
Trencher	1	$300.00	/mobe-demobe	$300.00	
Dump truck (14 cy)	1	$300.00	/mobe-demobe	$300.00	
Pressure washer (2000 psi)	1	$100.00	/mobe-demobe	$100.00	
Travel:					
Perdiem	15	$39.00	/day	$585.00	
Lodging	15	$91.00	/night	$1,365.00	
Air Fare	3	$800.00	/trip	$2,400.00	
Rental Car	15	$46.00	/day	$690.00	
Rental Car FOGM	15	$12.00	/day	$180.00	
				Subtotal	**$65,400.00**

Table 5-3

Alternative GW-4 Cost Estimate
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

3.0 Site Preparation, Clearing, and Layout

Includes:

1 Survey locations of monitoring wells, extraction wells, reinjection wells, PRRWP and WARWP groundwater treatment systems (WTP), and location of route for piping to and from the PRRWP WTP and WARWP WTP.
2 Install erosion controls, perform clearing and grubbing, and rehabilitate existing access roads at PRRWP and WARWP.

Assumptions:

1 Existing survey monuments adequate for locating new wells and pipe route.
Clearing and Grubbing
2 All clearing debris to be disposed on site.
3 Assume that 30% of pipe route length requires silt fencing and all well location perimeters require silt fencing.
4 Length of piping for extraction and reinjection wells to the WTPs = 8,000 linear feet [Note: See Section 6 for footage.]
5 Area of clearing along pipe route (20 feet width) = 3.7 acres
6 PRRWP shall have 3 extraction wells and 3 reinjection wells while WARWP shall have 5 extraction wells and 5 reinjection wells installed. In addition, 25 overburden monitoring wells and 29 bedrock monitoring wells shall be installed at specified locations at TNT A, TNT B, TNT C, PRRWP, and WARWP.
7 Total number of wells installed = 70 wells
8 Area of clearing for well , at 60' x 60' per site = 5.8 acres
9 Assume that each WTP (at PRRWP and WARWP) are centrally located within the said area and occupy two acres each.
10 Area of clearing for PRRWP and WARWP WTPs = 4.0 acres
11 TNT A, TNT B, TNT C, PRRWP, and WARP have an ISEB injection barrier at each site. So, this area requires clearing for injection point installation.
12 Assume an area of 25-foot wide times the length of the barrier at each site.
13 Area of clearing for ISEB injection barriers =

	Length (ft)	Width (ft)	Area (acres)
TNT A	344	25	0.2
TNT B	331	25	0.2
TNT C	245	25	0.1
PRRWP	663	25	0.4
WARWP	825	25	0.5
		Total	1.4

14 All areas shall require some tree removal and / or brush. Shall be performed Subcontractor.
Site Access Roads
15 PRRWP has an existing access road off of Pentolite Road, ~900 feet, and WARWP has an existing access road off of Patrol Road, ~1,100 feet. Both roads are currently mud/dirt. Thus, assume rehabilitation to a standard access road condition.
16 Length of existing access road at PRRWP, 6"depth x 12 ft. = 990 linear feet [Includes 10% for realignment.]
17 Length of existing access road at WARWP, 6"depth x 12 ft. = 1,210 linear feet [Includes 10% for realignment.]
Duration
18 Hours work per day = 10 hours
19 Schedule (10-hr workday) = 10 days [Note: Accounts for Shaw oversight, erosion control
20 Schedule (5-day workweek) = 2 weeks installation, and site access road rehabilitation.]
21 Schedule (months) = 0.5 month

Service/Materials	Unit	Unit Cost		Subtotal
Contractor Office Labor:				
Sr. Geologist (E10)	8	$93.94	/hr	$751.52
Engineer/Scientist IV (E10)	8	$92.56	/hr	$740.48
Geologist (E08)	20	$68.82	/hr	$1,376.40
Engineer/Scientist III (E08)	20	$68.82	/hr	$1,376.40
Contractor Field Labor:				
Site Manager (E06)	100	$57.06	/hr	$5,706.00
H&S Coordinator (E09)	100	$83.18	/hr	$8,318.00
QC/QA (E08)	100	$68.82	/hr	$6,882.00
Subcontractor Field Labor:				
Equipment Operator	10	$327.00	/day	$3,270.00
Equipment Operator	10	$327.00	/day	$3,270.00
Equipment Operator	10	$327.00	/day	$3,270.00
Equipment Operator	10	$327.00	/day	$3,270.00
Laborer	10	$288.00	/day	$2,880.00
Laborer	10	$288.00	/day	$2,880.00
Laborer	10	$288.00	/day	$2,880.00
Laborer	10	$288.00	/day	$2,880.00
Laborer	10	$288.00	/day	$2,880.00
Subcontractor:				
Survey crew (2-man)	10	$1,100.00	/day	$11,000.00
Med. brush, avg. grub, some trees, clearing	13.50	$810.00	/acre	$10,935.00
Chipping medium brush	13.50	$1,940.00	/acre	$26,190.00
Med. brush, med. trees-clear/grub/haul	1.40	$8,100.00	/acre	$11,340.00
Equipment Rental:				
Excavator	0.5	$4,600.00	/month	$2,300.00
Backhoe (85 hp)	0.5	$1,650.00	/month	$825.00
Dozer (140 hp)	0.5	$4,350.00	/month	$2,175.00
Dump truck (14 cy)	0.5	$3,590.00	/month	$1,795.00
Trencher (diesel, 4 ft. deep, 12" width)	0.5	$6,550.00	/month	$3,275.00
Pressure washer (2000 psi)	0.5	$480.00	/month	$240.00
FOGM	0.5	$3,000.00	/month	$1,500.00
Chemical toilets (x2)	0.5	$300.00	/month	$150.00

Table 5-3

Alternative GW-4 Cost Estimate
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

3.0 Site Preparation, Clearing, and Layout, Continued…

Service/Materials	Unit	Unit Cost		Subtotal	
Materials:					
Silt fencing	15,000	$0.75	/linear foot	$11,250.00	
Straw bales	400	$4.00	/ea	$1,600.00	
Geotextile for road underlayment	26,400	$0.42	/sf	$11,088.00	
Dense graded aggregate (delivered)	890.00	$17.00	/ton	$15,130.00	
Travel:					
Perdiem	36	$39.00	/day	$1,404.00	
Lodging	36	$91.00	/night	$3,276.00	
Air Fare	3	$800.00	/trip	$2,400.00	
Rental Car	36	$46.00	/day	$1,656.00	
Rental Car FOGM	36	$12.00	/day	$432.00	
				Subtotal	**$172,600.00**

4.0 Installation of Overburden Monitoring Wells

Includes:

1 Installation of Overburden Monitoring Wells using Hollow-Stem Auger Drilling
2 Installation of 25 wells to a total depth of 25 ft.
3 Development of Monitoring Wells
4 Well Constructed of 2-inch PVC with 10-feet of 0.010 Slot Continuous Wrap PVC Screen

Assumptions:

1	Number of New Overburden Monitoring Wells =	25	
2	Drill, construct, and develop one well =	1.5	days
3	Cost drilling per foot =	$18.00	ft/well
4	Total number of wells =	25	ea
5	Well Installation Field Days =	38	days
6	Soil and bedrock (for this task) can be drilled using HSA.		
7	Hours work per day =	10	hours
8	Schedule (10-hr workday) =	38	days
9	Schedule (5-day workweek) =	8	weeks
10	Schedule (months) =	1.8	month

Service/Materials	Unit	Unit Cost		Cost
Contractor Office Labor:				
Engineer/Scientist III (E08)	16	$68.82	/hr	$1,101.08
Procurement Coordinator (N07)	8	$35.80	/hr	$286.40
Secretary III (N06)	8	$34.80	/hr	$278.40
Contractor Field Labor:				
Geologist (E08)	380	$ 68.82	/hr	$26,150.69
Engineering Technician III (N08)	380	$ 46.80	/hr	$17,784.68
Drilling Subcontractor:				
Mobilization	1	$2,500.00	/ea	$2,500.00
Demobilization	1	$2,500.00	/ea	$2,500.00
Posthole first 5 feet	25	$25.00	/ea	$625.00
Decon pad construction	5	$750.00	/ea	$3,750.00
Average drilling cost in soil, per foot	625	$18.00	/ft	$11,250.00
2-inch ID, Sch 40, PVC casing	438	$9.00	/ft	$3,937.50
2-inch ID, Sch 40, PVC screen	250	$12.00	/ft	$3,000.00
2-inch Overburden Well Construction	25	$1,200.00	/ea	$30,000.00
Well Development	25	$1,200.00	/ea	$30,000.00
Surface Completion	25	$425.00	/ea	$10,625.00
Decontamination	25	$85.00	/ea	$2,125.00
Site cleanup	25	$125.00	/ea	$3,125.00
IDW disposal	25	$250.00	/ea	$6,250.00
Surveying	25	$268.72	/ea	$6,718.00
Total Cost	**25 Wells**			**$162,006.75**
Travel:				
Perdiem	80	$39.00	/day	$3,120.00
Lodging	80	$91.00	/night	$7,280.00
Air Fare	4	$800.00	/trip	$3,200.00
Rental Car	80	$46.00	/day	$3,680.00
Rental Car FOGM	80	$12.00	/day	$960.00
				Subtotal	**$180,246.75**

Table 5-3

Alternative GW-4 Cost Estimate
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

5.0 Installation of Bedrock Monitoring Wells

Includes:

1 Installation of 29 Additional Bedrock Monitoring Wells using Hollow-Stem Auger/Air Rotary to a total depth of 60 ft.
2 Development of Monitoring Wells
3 Well Constructed of 2-inch PVC with 15-feet of 0.010 Slot Continuous Wrap PVC Screen

Assumptions:

1	Number of New Bedrock Monitoring Wells:		29	
2	Construct and Develop One Well =		3	days
3	Well Installation Field Days =		87	days
4	Hours work per day =	10	hours	
5	Schedule (10-hr workday) =	87	days	
6	Schedule (5-day workweek) =	17	weeks	
7	Schedule (months) =	4.1	month	

Service/Materials		Unit		Unit Cost		Cost	
Contractor Office Labor:							
Engineer/Scientist III (E08)		20		$68.82	/hr	$1,376.35	
Procurement Coordinator (N07)		16		$35.80	/hr	$572.80	
Secretary III (N06)		16		$34.80	/hr	$556.80	
Contractor Field Labor:							
Geologist (E08)		870	$	68.82	/hr	$59,871.31	
Engineering Technician III (N08)		870	$	46.80	/hr	$40,717.57	
Drilling Subcontractor:							
Mobilization		1		$2,500.00	/ea	$2,500.00	
Demobilization		1		$2,500.00	/ea	$2,500.00	
Posthole first 5 feet	5'	29		$25.00	/ea	$725.00	
Decon pad construction		5		$750.00	/ea	$3,750.00	
Drill soil with 12" HSA to bedrock	15'	435		$50.00	/ft	$21,750.00	
Cut 5' bedrock with 10" tricone roller bit	5'	145		$41.00	/ft	$5,945.00	
Install 6" steel casing	35'	1015		$45.00	/ft	$45,675.00	
Cut bedrock with 6" OD tricone roller bit	35'	1015		$44.00	/ft	$44,660.00	
2-inch ID, Sch 40, PVC casing	47.5'	1378		$9.00	/ft	$12,397.50	
2-inch ID, Sch 40, PVC screen	'15	435		$12.00	/ft	$5,220.00	
2-inch Bedrock Well Construction		29		$1,200.00	/ft	$34,800.00	
Well Development		29		$1,200.00	/ea	$34,800.00	
Surface Completion		29		$425.00	/ea	$12,325.00	
Decontamination		29		$85.00	/ea	$2,465.00	
Site cleanup		29		$125.00	/ea	$3,625.00	
IDW disposal		29		$250.00	/ea	$7,250.00	
Surveying		29		$268.72	/ea	$7,792.88	
Total Well Cost						**$351,275.21**	
Travel:							
Per Diem		178		$39.00	/day	$6,942.00	
Lodging		178		$91.00	/day	$16,198.00	
Air Fare		24		$800.00	/trip	$19,200.00	
Rental Car		178		$46.00	/day	$8,188.00	
Rental Car FOGM		178		$12.00	/day	$2,136.00	
						Subtotal	**$507,034.04**

Table 5-3

Alternative GW-4 Cost Estimate
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

6.0 Extraction and Reinjection Well Installation

Includes:

1 Installation of extraction and reinjection wells along with pumps, power, controls and surface completions.
2 Eight extraction wells, 3 at PRRWP and 5 at WARWP will be installed:

3 at PRRWP -	70	avgas depth (ft)	210	total depth (ft)
5 at WARWP -	54	avgas depth (ft)	270	total depth (ft)

3 Eight reinjection wells, 3 at PRRWP and 5 at WARWP:

3 at PRRWP -	70	avg depth (ft)	210	total depth (ft)
5 at WARWP -	54	avg depth (ft)	270	total depth (ft)

4 Average depth to bedrock estimated to be 50 ft at both PRRWP and WARWP.
5 Development of wells.
6 Install piping, valving, interim lift station, along with power and controls related with the PRRWP WTP and WARWP WTP.
7 Baseline sampling of the newly installed wells.

Assumptions:

1 Medium voltage distribution line is available in the proximity to each well cluster.
2 No other existing utilities require relocation.
3 Piping to the groundwater treatment systems shall be HDPE, SDR 21, single wall.
4 Assume each WTP is centrally located to the extraction and reinjection wells at said location, i.e., PRRWP and WARWP.
5 Assume that on average, 500 feet of pipe for each extraction well and each reinjection well.
6 Assume 250 linear of piping, fittings and valves can be installed per day.
7 Installation of wells using air rotary drilling methods.

8 Number of extraction wells =	8	each	
9 Construct and develop one well =	3	days	[Note: Does not incl. surface completion.]
10 Overburden drilling=	456	feet	
11 Bedrock drilling=	380	feet	
12 Total depth =	836	feet	
13 Well installation field days =	24	days	
14 Number of Reinjection Wells =	8	each	
15 Construct and develop one well =	3	days	[Note: Does not incl. surface completion.]
16 Overburden drilling=	320	feet	
17 Bedrock drilling=	160	feet	
18 Total depth =	480	feet	
19 Well installation field days =	24	days	
20 Total field days =	48.0	days	
21 Number of wells to be sampled =	16	each	
22 Total field days for sampling wells (3 dy) =	6.0	days	
23 Length of manifold piping from extraction wells =	3,000	linear feet	
24 Length of piping WTP to reinjection wells =	5,000	linear feet	
25 Assume 250 feet of pipe shall be installed per day. Duration =	32.0	days	

26 Assume Shaw Field Labor for installation of piping and utilization of a Drilling Subcontractor for well installation.

26 Hours work per day =	10	hours	
27 Schedule (10-hr workday) =	54	days	[Note: Based on well installation to have Shaw oversight.]
28 Schedule (5-day workweek) =	11	weeks	
29 Schedule (months) =	2.5	months	

Service/Materials	Unit	Unit Cost		Subtotal
Contractor Office Labor:				
Sr. Geologist (E10)	44	$93.94	/hr	$4,133.36
Engineer/Scientist IV (E10)	44	$92.56	/hr	$4,072.64
Geologist (E08)	108	$68.82	/hr	$7,432.56
Engineer/Scientist III (E08)	108	$68.82	/hr	$7,432.56
Chemist III (E06)	40	$54.20	/hr	$2,168.00
Data Entry Technician (E04)	40	$45.00	/hr	$1,800.00
Contractor Field Labor:				
Site Manager (E06)	540	$57.06	/hr	$30,812.40
H&S Coordinator (E09)	540	$83.18	/hr	$44,917.20
QC/QA (E08)	540	$68.82	/hr	$37,162.80
Subcontractor Field Labor:				
Equipment Operator	32	$327.00	/day	$10,464.00
Equipment Operator	32	$327.00	/day	$10,464.00
Equipment Operator	32	$327.00	/day	$10,464.00
Equipment Operator	32	$327.00	/day	$10,464.00
Laborer	32	$288.00	/day	$9,216.00
Laborer	32	$288.00	/day	$9,216.00
Laborer	32	$288.00	/day	$9,216.00
Laborer	32	$288.00	/day	$9,216.00
Laborer	32	$288.00	/day	$9,216.00
Baseline Sampling:				
Sampling, analytical, and reporting	16	$2,000.00	/well	$32,000.00

Table 5-3

Alternative GW-4 Cost Estimate
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

6.0 Extraction and Reinjection Well Installation

Service/Materials	Unit	Unit Cost		Subtotal	
Equipment Rental:					
Excavator	1.5	$4,600.00	/month	$6,900.00	
Backhoe (85 hp)	1.5	$1,650.00	/month	$2,475.00	
Dozer (140 hp)	1.5	$4,350.00	/month	$6,525.00	
Trencher (diesel, 4 ft. deep, 12" width)	1.5	$6,550.00	/month	$9,825.00	
Dump truck (14 cy)	1.5	$3,590.00	/month	$5,385.00	
Pressure washer (2000 psi)	1.5	$480.00	/month	$720.00	
FOGM	1.5	$3,000.00	/month	$4,500.00	
Chemical toilets (x2)	1.5	$300.00	/month	$450.00	
Materials:					
4" gw pump (<7 gpm, <800 ft head, 1.5 hp, cntrls)	8	$3,750.00	/ea	$30,000.00	
Reinjection wellhead completion & vault	8	$3,500.00	/ea	$28,000.00	
Control panel	7	$2,500.00	/ea	$17,500.00	
3" dia. HDPE, SDR 21 pipe (welder & machine only)	3,000	$7.19	/linear foot	$21,570.00	
4" dia. HDPE, SDR 21 pipe (welder & machine only)	5,000	$8.44	/linear foot	$42,200.00	
Buried utility marking tape (foil backing)	8,000	$0.15	/linear foot	$1,200.00	
Valving and fittings (10% of pipe total)	1	$6,377.00	/lump sum	$6,377.00	
Package lift station (18 gpm)	1	$4,000.00	/lump sum	$4,000.00	
Drilling Subcontractor:					
Mobilization/demobilization (10-day rotation)	5	$5,000.00	/ea	$25,000.00	
Minirae 2000 (10.6)	12	$225.00	/week	$2,700.00	
4-inch PVC, schedule 40, well casing	1,076	$18.00	/vf	$19,368.00	
4-inch PVC, schedule 40, well screen	240	$25.00	/vf	$6,000.00	
8" roller cone soil drilling, casing installation	776	$80.00	/vf	$62,080.00	
6" roller cone bedrock drilling	540	$44.00	/feet	$23,760.00	
Install well and materials	16	$675.00	/feet	$10,800.00	
Furnish and Install flush well and pad	16	$500.00	/ea	$8,000.00	
Well development	8	$250.00	/ea	$2,000.00	
Decontamination	16	$150.00	/ea	$2,400.00	
Cleanup	16	$85.00	/ea	$1,360.00	
IDW disposal	16	$500.00	/ea	$8,000.00	
Travel:					
Perdiem	162	$39.00	/day	$6,318.00	
Lodging	162	$91.00	/night	$14,742.00	
Air Fare	6	$800.00	/trip	$4,800.00	
Rental Car	162	$46.00	/day	$7,452.00	
Rental Car FOGM	162	$12.00	/day	$1,944.00	
				Subtotal	**$654,200.00**

7.0 Installation of the Groundwater Treatment Systems

Includes:
1 Installation of the PRRWP WTP and WARWP WTP.

Assumptions:
1 Non-equipment costs estimated by factoring based on total equipment costs.
2 Flow rate of PRRWP WTP = 10.5 gpm
3 Flow rate of WARWP WTP= 6 gpm

Service/Materials	Unit	Unit Cost		Cost	
Plant and Equipment:					
Anoxic FBR Denitrification System	1	$250,000.00	/ea	$250,000.00	Total installed cost
Aerobic Bioreactor	1	$660,000.00	/ea	$660,000.00	Total installed cost
Subtotal - Biological Treatment Systems				**$910,000.00**	Total installed cost
Air Stripper	1	$15,000.00	/ea	$15,000.00	
Polymer Feed System	2	$4,000.00	/ea	$8,000.00	
Coagulation/Flocculation Tanks w/ Agitators	2	$8,000.00	/ea	$16,000.00	
Parallel Plate Clarifier	2	$17,000.00	/ea	$34,000.00	
Duplex Bag Filter w/ Pump	2	$11,000.00	/ea	$22,000.00	
Dual Bed Carbon Adsorber	1	$12,000.00	/ea	$12,000.00	
Sludge Storage Tank	2	$8,000.00	/ea	$16,000.00	
Filter Press w/ Pump	2	$25,000.00	/ea	$50,000.00	
Subtotal - Non-Biological Treatment Systems				**$173,000.00**	
Subtotal Equipment Cost				**$1,083,000.00**	
Miscellaneous					
Site Improvements	1	$108,300.00	/ea	$108,300.00	
Buildings	1	$194,940.00		$194,940.00	
Equipment Installation	1	$81,310.00	/ea	$81,310.00	
Instrumentation and Controls (Installed)	1	$43,250.00	/ea	$43,250.00	
Piping (Installed)	1	$114,180.00	/ea	$114,180.00	
Electrical (Installed)	1	$19,030.00	/ea	$19,030.00	
Utilities (Installed)	1	$541,500.00	/ea	$541,500.00	
Engineering and Supervision	1	$57,090.00	/ea	$57,090.00	
Construction Expense	1	$70,930.00	/ea	$70,930.00	
Subtotal Other Costs				**$1,230,530.00**	
				Subtotal	**$2,313,500.00**

Table 5-3

Alternative GW-4 Cost Estimate
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

8.0 ISEB - Emulsified Vegetable Oil Injection

Includes:
1. DPT Injection of emulsified vegetable oil in plumes designated in Table 3-6.
2. DPT injection implemented in a series of parallel biobarriers per Table 5-2.

Assumptions:
1. DPT rig, field truck, water truck and substrate metering system purchased outright for long-term project.
2. All field personnel hired direct for duration of project, therefore expenses for travel, lodging and meals not incurred.
3. Office engineer travels to the site 3 days (including travel) per month for duration of project.

Total Plume Areas

1. Total number of injection points =	8,173	points
2. Substrate demand =	2,076,850	pounds
3. Substrate density =	7.64	pounds/gal
4. Substrate demand per injection point =	254	pounds
5. Ratio substrate to water =	0.2	
6. Water required =	1,359	kgal
7. Injection points completed per day =	4	points/DPT crew*day
8. Estimated field duration =	2,044	crew days
9. Number of DPT crews =	1	crews
10. Estimated field duration =	2,044	work days
11. Work days per month =	22	work days/month
12. Estimated field duration =	93	months
13. Field workers per DPT crew =	2	workers/crew
14. Hours per Work Day =	8	hours/day
16. Number of supervisory crew =	2	workers

Service/Materials	Unit	Unit Cost		Cost	
Contractor Office Labor:					
Project Manager II (E11)	1,116	$106.75	/hr	$119,133.00	
Engineer Scientist IV (E10)	2,976	$ 92.56	/hr	$275,459.00	
Geologist (E08)	744	$68.82	/hr	$51,202.00	
Procurement Coordinator (N07)	744	$35.80	/hr	$26,635.20	
Contractor Field Labor:					
Site Manager (E06)	16,352	$ 57.06	/hr	$933,045.12	
Engineering Technician (N08)	16,352	$46.80	/hr	$765,273.60	
Equipment & Materials:					
EOS (incl. shipping)	2,076,850	$1.90	/lb	$3,946,015.00	
Dilution Water	1,359	$2.87	/kgal	$3,901.00	
Metering System	1	$25,000.00	/ea	$25,000.00	Purchased
Water truck	1	$30,000.00	/ea	$30,000.00	Purchased
Injection Supplies	93	$5,000.00	/month	$465,000.00	
Field Truck	1	$25,000.00	/ea	$25,000.00	Purchased
Rental Car FOGM	4,088	$12.00	/day	$49,056.00	
DPT Drilling Crew:					
DPT Rig	1	$140,000.00	/ea	$140,000.00	Purchased
Equipment Operator	4,088	$327.00	/day	$1,336,776.00	
Travel:					
Per Diem	279	$39.00	/day	$10,881.00	
Lodging	186	$67.20	/day	$12,499.20	
Air Fare	93	$800.00	/trip	$74,400.00	
Rental Car	279	$46.00	/day	$12,834.00	
				Subtotal	**$8,302,100.00**

Table 5-3

Alternative GW-4 Cost Estimate
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

9.0 Site Restoration, Testing and Demobilization

Includes:

1 Conduct hydrostatic pressure testing on pipe line and "shakedown/startup" testing of pumps and controls.
2 Site restoration including finish grading and seeding.
3 Demobilization

Assumptions:

1 Groundwater from wells will be used to hydrostatic test pipe lines, then it will be discharged to PRRWP WTP and WARWP WTP.
2 Dozer will finish grade areas as work is completed in line items above.
3 Testing and shakedown completed by contractor labor for one week duration.
4 Reference clearing areas in Section 3.0.
5 Demobilization of equipment was accounted for in Section 2.0.
6 Hours work per day = 10 hours
7 Schedule (10-hr workday) = 15 days
8 Schedule (5-day workweek) = 3 weeks
9 Schedule 0.7 months

Service/Materials	Unit	Unit Cost		Cost
Office Labor:				
Sr. Geologist (E10)	12	$93.94	/hr	$1,127.28
Engineer/Scientist IV (E10)	12	$92.56	/hr	$1,110.72
Geologist (E08)	30	$68.82	/hr	$2,064.60
Engineer/Scientist III (E08)	30	$68.82	/hr	$2,064.60
Construction completion report	1	$12,500.00	/lump sum	$12,500.00
LTM plan	1	$15,000.00	/lump sum	$15,000.00
Contractor Field Labor:				
Site Manager (E06)	150	$57.06	/hr	$8,559.00
H&S Coordinator (E09)	150	$83.18	/hr	$12,477.00
QC/QA (E08)	150	$68.82	/hr	$10,323.00
Engineer/Scientist III (E08) - Mechanical	50	$68.82	/hr	$3,441.00
Engineer/Scientist III (E08) - Electrical	50	$68.82	/hr	$3,441.00
Equipment Rental:				
Backhoe (85 hp)	1	$1,650.00	/month	$1,650.00
Dozer (140 hp)	1	$4,350.00	/month	$4,350.00
Pump for testing	1	$480.00	/month	$480.00
Pressure washer (2000 psi)	1	$480.00	/month	$480.00
FOGM	1	$3,000.00	/month	$3,000.00
Subcontractor Field Labor:				
Equipment Operator	15	$327.00	/day	$4,905.00
Equipment Operator	15	$327.00	/day	$4,905.00
Laborer	15	$288.00	/day	$4,320.00
Laborer	15	$288.00	/day	$4,320.00
Subcontractor:				
Mob/Demob	1	$2,500.00	/ea	$2,500.00
Seed, mulch, water	14.90	$4,700.00	/acre	$70,030.00
Travel:				
Per diem	61	$39.00	/day	$2,379.00
Lodging	61	$91.00	/day	$5,551.00
Air Fare	5	$800.00	/trip	$4,000.00
Rental Car	56	$46.00	/day	$2,576.00
Rental Car FOGM	56	$12.00	/day	$672.00
			Subtotal	**$188,200.00**

10.0 Groundwater Use Controls

Service/Materials	Unit	Unit Cost		Cost
Land Use Control Implementation Plan	1	$50,000.00	/ea	$50,000.00
			Subtotal	**$50,000.00**

Table 5-3

Alternative GW-4 Cost Estimate
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

11.0 Annual Pump and Treat Operation and Maintenance (O&M), Years 1-150

Includes:
1 Groundwater Treatment System O&M
2 Installed Wells, Piping, and Site Facilities

Assumptions:
1 Field labor is local; therefore no cost for travel is included.
2 Annual reporting cost sufficient to cover five-year reviews.

Note:
Cost for capital improvements to replace substantial portions of the groundwater treatment systems are not included in this evaluation.

Service/Materials	Unit	Unit Cost			Cost	
I. Groundwater Treatment System O&M - PRRWP WTP and WARWP WTP						
Labor:						
Operator labor	2	$26,000.00	/ls		$52,000.00	
Management	2	$1,500.00	/ls		$3,000.00	
Materials:						
Filter replacement	2	$200.00	/ls		$400.00	
Carbon for Polishing, at 2ppm	1	$3,800.00	/ls		$3,800.00	
Chemical/Flocculants, at 20 ppm	1	$2,800.00	/ls		$2,800.00	
Utilities:						
Electric Power for Treatment System 4 pumps + 1 blower (3 heaps each)	2	$8,900.00	/ls		$17,800.00	
Disposal:						
Filter Cake Solids, lb/day	204	$2.00	/lb/day		$408.00	
Sampling:						
Water Sample Analysis	2	$16,800.00	/ls		$33,600.00	
Anoxic and Aerobic Equipment:						
Anoxic FBR Denitrification System	1	$327.00	/ea		$327.00	
Aerobic Bioreactor	1	$19,457.00	/ea		$19,457.00	
Miscellaneous:						
Reporting	2	$5,000.00	/ls		$10,000.00	
Maintenance	2	$4,000.00	/ls		$8,000.00	
				Subtotal	**$151,592.00**	
II. Installed Wells, Piping, and Site Facilities						
Monitoring, Extraction, and Reinjection Well Repairs	1	$5,000.00	/ls		$5,000.00	
Miscellaneous Repairs to Pipeline	1	$1,000.00	/ls		$1,000.00	
Field Office Utilities	1	$7,332.00	/ls		$7,332.00	
				Subtotal	**$13,332.00**	
					Subtotal	**$164,900.00**

Table 5-3

Alternative GW-4 Cost Estimate
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

12.0 Annual Long Term O&M: Years 1 - 5 (Annualized)

Includes:
1 Groundwater Monitoring

Includes:
1 Annual monitoring of 35 wells in the overburden/weathered shale and 33 wells in the bedrock zone for COCs.
2 Data verification, evaluation, and preparation of annual report

3	No. of wells sampled =	68	wells/event
4	Number of technicians in field crew =	2	personnel
5	Sampling time (per well) =	3	hrs/well
6	Sampling time per seep =	1	hrs/seep
7	Number of well sampling events =	1	events/year
8	Well sampling time =	20	days
9	Hours work per day =	10	hours

Data Management and QA/QC Assumptions:

Data Entry Technician (E04)	1	hr/sample
Chemist III (E06)	0.75	hr/sample
Database Manager (E08)	1.5	hr/sample
Senior Consultant I (E12)	0.175	hr/sample

Service/Materials	Unit	Unit Cost		Cost
Office Labor:				
Project Manager II (E11)	20	$106.75	/hr	$2,135.00
Senior Consultant I (E12)	10	$118.41	/hr	$1,184.10
Engineer/Scientist III (E08)	40	$68.82	/hr	$2,752.80
Engineer/Scientist II (E06)	100	$57.06	/hr	$5,706.00
Data Entry Technician (E04)	68	$45.00	/hr	$3,060.00
Chemist III (E06)	51	$54.20	/hr	$2,764.20
Database Manager (E08)	102	$64.40	/hr	$6,568.80
Senior Consultant I (E12)	12	$118.41	/hr	$1,420.92
Secretary III (N06)	20	$34.80	/hr	$696.00
Draftsperson (N08)	40	$53.36	/hr	$2,134.40
Word Processor (N06)	20	$41.82	/hr	$836.40
Field Labor:				
Engineering Technician III (N08)	200	$46.80	/hr	$9,360.00
Engineering Technician III (N08)	200	$46.80	/hr	$9,360.00
Materials:				
Sampling Equipment	1	$500.00	/event	$500.00
Document Reproduction	1	$400.00	/ea	$400.00
RDW Treatment and Disposal	1	$1,250.00	/event	$1,250.00
Analytical:				
Analytical:	1	$16,219.00	/ls	$16,219.00
Travel:				
Per Diem	40	$39.00	/day	$1,560.00
Lodging	40	$91.00	/day	$3,640.00
Air Fare	2	$800.00	/trip	$1,600.00
Rental Car	40	$46.00	/day	$1,840.00
Rental Car FOGM	40	$12.00	/day	$480.00
			Subtotal	**$75,500.00**

Table 5-3

Alternative GW-4 Cost Estimate
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

13.0 Annual Long Term O&M: Years 6 - 150 (Annualized)

Includes:
1 Groundwater Monitoring

Includes:
1 Annual monitoring of 33 wells in the bedrock zone for COCs.
2 Data verification, evaluation, and preparation of annual report

3	No. of wells sampled =	33	wells/event
4	Number of technicians in field crew =	2	personnel
5	Sampling time (per well) =	3	hrs/well
6	Sampling time per seep =	1	hrs/seep
7	Number of well sampling events =	1	events/year
8	Well sampling time =	10	days
9	Hours work per day =	10	hours

Data Management and QA/QC Assumptions:

Data Entry Technician (E04)	1	hr/sample
Chemist III (E06)	0.75	hr/sample
Database Manager (E08)	1.5	hr/sample
Senior Consultant I (E12)	0.175	hr/sample

Service/Materials	Unit	Unit Cost		Cost
Office Labor:				
Project Manager II (E11)	20	$106.75	/hr	$2,135.00
Senior Consultant I (E12)	10	$118.41	/hr	$1,184.10
Engineer/Scientist III (E08)	40	$68.82	/hr	$2,752.80
Engineer/Scientist II (E06)	100	$57.06	/hr	$5,706.00
Data Entry Technician (E04)	33	$45.00	/hr	$1,485.00
Chemist III (E06)	25	$54.20	/hr	$1,355.00
Database Manager (E08)	50	$64.40	/hr	$3,220.00
Senior Consultant I (E12)	6	$118.41	/hr	$710.46
Secretary III (N06)	20	$34.80	/hr	$696.00
Draftsperson (N08)	40	$53.36	/hr	$2,134.40
Word Processor (N06)	20	$41.82	/hr	$836.40
Field Labor:				
Engineering Technician III (N08)	100	$46.80	/hr	$4,680.00
Engineering Technician III (N08)	100	$46.80	/hr	$4,680.00
Materials:				
Sampling Equipment	1	$500.00	/event	$500.00
Document Reproduction	1	$400.00	/ea	$400.00
RDW Treatment and Disposal	1	$1,250.00	/event	$1,250.00
Analytical:				
Analytical:	1	$5,124.00	/ls	$5,124.00
Travel:				
Per Diem	20	$39.00	/day	$780.00
Lodging	20	$91.00	/day	$1,820.00
Air Fare	2	$800.00	/trip	$1,600.00
Rental Car	20	$46.00	/day	$920.00
Rental Car FOGM	20	$12.00	/day	$240.00
				Subtotal **$44,200.00**

14.0 Total Capitol Cost

	Item	Unit	Unit Cost		Cost
1	Groundwater Modeling, Remedial Design, Work Plans, and Procurement	1	$122,000.00	/ls	$122,000.00
2	Mobilization	1	$65,400.00	/ls	$65,400.00
3	Site Preparation, Clearing, and Layout	1	$172,600.00	/ls	$172,600.00
4	Installation of Overburden Monitoring Wells	1	$180,246.75	/ls	$180,246.75
5	Installation of Bedrock Monitoring Wells	1	$507,034.04	/ls	$507,034.04
6	Extraction and Reinjection Well Installation	1	$654,200.00	/ls	$654,200.00
7	Installation of the Groundwater Treatment Systems	1	$2,313,500.00	/ls	$2,313,500.00
8	ISEB - Emulsified Vegetable Oil Injection	1	$8,302,100.00	/ls	$8,302,100.00
9	Site Restoration, Testing and Demobilization	1	$188,200.00	/ls	$188,200.00
10	Groundwater Use Controls	1	$50,000.00	/ls	$50,000.00
					Total **$12,555,280.79**

15.0 Total O&M Cost

	Item	Unit	Unit Cost		Cost
1	Years 1 - 5	5	$240,400.00	/yr	$1,202,000.00
2	Years 6 - 150	145	$209,100.00	/yr	$30,319,500.00
					Total **$31,521,500.00**

Note: This is an 'order of magnitude' engineering cost estimate that is expected to be within + 50% to - 30% of actual project cost.

Table 5-4

Present Value of O&M Costs
Remedial Alternatives for Groundwater
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

	Discount Rate = 0.031						
	Years of O&M =	150		150		150	
Year	Discount DF	Alternative GW-2 xt	Alternative GW-2 PV	Alternative GW-3 x_t	Alternative GW-3 PV	Alternative GW-4 x_t	Alternative GW-4 PV
1	0.969932105	$44,200.00	$42,871.00	$226,800.00	$219,980.60	$240,400.00	$233,171.68
2	0.940768288	$44,200.00	$41,581.96	$226,800.00	$213,366.25	$240,400.00	$226,160.70
3	0.912481365	$44,200.00	$40,331.68	$226,800.00	$206,950.77	$240,400.00	$219,360.52
4	0.885044971	$44,200.00	$39,118.99	$226,800.00	$200,728.20	$240,400.00	$212,764.81
5	0.858433532	$44,200.00	$37,942.76	$226,800.00	$194,692.73	$240,400.00	$206,367.42
6	0.832622242	$44,200.00	$36,801.90	$209,100.00	$174,101.31	$209,100.00	$174,101.31
7	0.807587044	$44,200.00	$35,695.35	$209,100.00	$168,866.45	$209,100.00	$168,866.45
8	0.783304601	$44,200.00	$34,622.06	$209,100.00	$163,788.99	$209,100.00	$163,788.99
9	0.759752281	$44,200.00	$33,581.05	$209,100.00	$158,864.20	$209,100.00	$158,864.20
10	0.736908129	$44,200.00	$32,571.34	$209,100.00	$154,087.49	$209,100.00	$154,087.49
11	0.714750852	$44,200.00	$31,591.99	$209,100.00	$149,454.40	$209,100.00	$149,454.40
12	0.693259799	$44,200.00	$30,642.08	$209,100.00	$144,960.62	$209,100.00	$144,960.62
13	0.672414936	$44,200.00	$29,720.74	$209,100.00	$140,601.96	$209,100.00	$140,601.96
14	0.652196834	$44,200.00	$28,827.10	$209,100.00	$136,374.36	$209,100.00	$136,374.36
15	0.632586648	$44,200.00	$27,960.33	$209,100.00	$132,273.87	$209,100.00	$132,273.87
16	0.613566099	$44,200.00	$27,119.62	$209,100.00	$128,296.67	$209,100.00	$128,296.67
17	0.595117457	$44,200.00	$26,304.19	$209,100.00	$124,439.06	$209,100.00	$124,439.06
18	0.577223528	$44,200.00	$25,513.28	$209,100.00	$120,697.44	$209,100.00	$120,697.44
19	0.559867631	$44,200.00	$24,746.15	$209,100.00	$117,068.32	$209,100.00	$117,068.32
20	0.54303359	$44,200.00	$24,002.08	$209,100.00	$113,548.32	$209,100.00	$113,548.32
21	0.526705713	$44,200.00	$23,280.39	$209,100.00	$110,134.16	$209,100.00	$110,134.16
22	0.510868781	$44,200.00	$22,580.40	$209,100.00	$106,822.66	$209,100.00	$106,822.66
23	0.495508032	$44,200.00	$21,901.46	$209,100.00	$103,610.73	$209,100.00	$103,610.73
24	0.480609148	$44,200.00	$21,242.92	$209,100.00	$100,495.37	$209,100.00	$100,495.37
25	0.466158243	$44,200.00	$20,604.19	$209,100.00	$97,473.69	$209,100.00	$97,473.69
26	0.452141845	$44,200.00	$19,984.67	$209,100.00	$94,542.86	$209,100.00	$94,542.86
27	0.438546892	$44,200.00	$19,383.77	$209,100.00	$91,700.16	$209,100.00	$91,700.16
28	0.42536071	$44,200.00	$18,800.94	$209,100.00	$88,942.92	$209,100.00	$88,942.92
29	0.412571009	$44,200.00	$18,235.64	$209,100.00	$86,268.60	$209,100.00	$86,268.60
30	0.400165867	$44,200.00	$17,687.33	$209,100.00	$83,674.68	$209,100.00	$83,674.68
31	0.388133721	$44,200.00	$17,155.51	$209,100.00	$81,158.76	$209,100.00	$81,158.76
32	0.376463357	$44,200.00	$16,639.68	$209,100.00	$78,718.49	$209,100.00	$78,718.49
33	0.365143896	$44,200.00	$16,139.36	$209,100.00	$76,351.59	$209,100.00	$76,351.59
34	0.354164788	$44,200.00	$15,654.08	$209,100.00	$74,055.86	$209,100.00	$74,055.86
35	0.343515798	$44,200.00	$15,183.40	$209,100.00	$71,829.15	$209,100.00	$71,829.15
36	0.333187001	$44,200.00	$14,726.87	$209,100.00	$69,669.40	$209,100.00	$69,669.40
37	0.323168769	$44,200.00	$14,284.06	$209,100.00	$67,574.59	$209,100.00	$67,574.59
38	0.313451765	$44,200.00	$13,854.57	$209,100.00	$65,542.76	$209,100.00	$65,542.76
39	0.30402693	$44,200.00	$13,437.99	$209,100.00	$63,572.03	$209,100.00	$63,572.03
40	0.29488548	$44,200.00	$13,033.94	$209,100.00	$61,660.55	$209,100.00	$61,660.55
41	0.286018894	$44,200.00	$12,642.04	$209,100.00	$59,806.55	$209,100.00	$59,806.55
42	0.277418908	$44,200.00	$12,261.92	$209,100.00	$58,008.29	$209,100.00	$58,008.29
43	0.269077505	$44,200.00	$11,893.23	$209,100.00	$56,264.11	$209,100.00	$56,264.11
44	0.260986911	$44,200.00	$11,535.62	$209,100.00	$54,572.36	$209,100.00	$54,572.36
45	0.253139584	$44,200.00	$11,188.77	$209,100.00	$52,931.49	$209,100.00	$52,931.49
46	0.24552821	$44,200.00	$10,852.35	$209,100.00	$51,339.95	$209,100.00	$51,339.95

Table 5-4

Present Value of O&M Costs
Remedial Alternatives for Groundwater
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

	Discount Rate = 0.031						
	Years of O&M =	150		150		150	
Year	Discount DF	Alternative GW-2 xt	Alternative GW-2 PV	Alternative GW-3 x_t	Alternative GW-3 PV	Alternative GW-4 x_t	Alternative GW-4 PV
47	0.238145693	$44,200.00	$10,526.04	$209,100.00	$49,796.26	$209,100.00	$49,796.26
48	0.230985153	$44,200.00	$10,209.54	$209,100.00	$48,299.00	$209,100.00	$48,299.00
49	0.224039916	$44,200.00	$9,902.56	$209,100.00	$46,846.75	$209,100.00	$46,846.75
50	0.217303507	$44,200.00	$9,604.82	$209,100.00	$45,438.16	$209,100.00	$45,438.16
51	0.210769648	$44,200.00	$9,316.02	$209,100.00	$44,071.93	$209,100.00	$44,071.93
52	0.204432248	$44,200.00	$9,035.91	$209,100.00	$42,746.78	$209,100.00	$42,746.78
53	0.198285401	$44,200.00	$8,764.21	$209,100.00	$41,461.48	$209,100.00	$41,461.48
54	0.192323376	$44,200.00	$8,500.69	$209,100.00	$40,214.82	$209,100.00	$40,214.82
55	0.186540617	$44,200.00	$8,245.10	$209,100.00	$39,005.64	$209,100.00	$39,005.64
56	0.180931733	$44,200.00	$7,997.18	$209,100.00	$37,832.83	$209,100.00	$37,832.83
57	0.175491497	$44,200.00	$7,756.72	$209,100.00	$36,695.27	$209,100.00	$36,695.27
58	0.170214837	$44,200.00	$7,523.50	$209,100.00	$35,591.92	$209,100.00	$35,591.92
59	0.165096835	$44,200.00	$7,297.28	$209,100.00	$34,521.75	$209,100.00	$34,521.75
60	0.160132721	$44,200.00	$7,077.87	$209,100.00	$33,483.75	$209,100.00	$33,483.75
61	0.155317867	$44,200.00	$6,865.05	$209,100.00	$32,476.97	$209,100.00	$32,476.97
62	0.150647786	$44,200.00	$6,658.63	$209,100.00	$31,500.45	$209,100.00	$31,500.45
63	0.146118124	$44,200.00	$6,458.42	$209,100.00	$30,553.30	$209,100.00	$30,553.30
64	0.141724659	$44,200.00	$6,264.23	$209,100.00	$29,634.63	$209,100.00	$29,634.63
65	0.137463297	$44,200.00	$6,075.88	$209,100.00	$28,743.58	$209,100.00	$28,743.58
66	0.133330065	$44,200.00	$5,893.19	$209,100.00	$27,879.32	$209,100.00	$27,879.32
67	0.129321111	$44,200.00	$5,715.99	$209,100.00	$27,041.04	$209,100.00	$27,041.04
68	0.125432697	$44,200.00	$5,544.13	$209,100.00	$26,227.98	$209,100.00	$26,227.98
69	0.1216612	$44,200.00	$5,377.43	$209,100.00	$25,439.36	$209,100.00	$25,439.36
70	0.118003104	$44,200.00	$5,215.74	$209,100.00	$24,674.45	$209,100.00	$24,674.45
71	0.114454999	$44,200.00	$5,058.91	$209,100.00	$23,932.54	$209,100.00	$23,932.54
72	0.111013578	$44,200.00	$4,906.80	$209,100.00	$23,212.94	$209,100.00	$23,212.94
73	0.107675633	$44,200.00	$4,759.26	$209,100.00	$22,514.97	$209,100.00	$22,514.97
74	0.104438054	$44,200.00	$4,616.16	$209,100.00	$21,838.00	$209,100.00	$21,838.00
75	0.101297821	$44,200.00	$4,477.36	$209,100.00	$21,181.37	$209,100.00	$21,181.37
76	0.098252009	$44,200.00	$4,342.74	$209,100.00	$20,544.50	$209,100.00	$20,544.50
77	0.095297778	$44,200.00	$4,212.16	$209,100.00	$19,926.77	$209,100.00	$19,926.77
78	0.092432374	$44,200.00	$4,085.51	$209,100.00	$19,327.61	$209,100.00	$19,327.61
79	0.089653127	$44,200.00	$3,962.67	$209,100.00	$18,746.47	$209,100.00	$18,746.47
80	0.086957446	$44,200.00	$3,843.52	$209,100.00	$18,182.80	$209,100.00	$18,182.80
81	0.084342819	$44,200.00	$3,727.95	$209,100.00	$17,636.08	$209,100.00	$17,636.08
82	0.081806808	$44,200.00	$3,615.86	$209,100.00	$17,105.80	$209,100.00	$17,105.80
83	0.079347049	$44,200.00	$3,507.14	$209,100.00	$16,591.47	$209,100.00	$16,591.47
84	0.076961251	$44,200.00	$3,401.69	$209,100.00	$16,092.60	$209,100.00	$16,092.60
85	0.074647188	$44,200.00	$3,299.41	$209,100.00	$15,608.73	$209,100.00	$15,608.73
86	0.072402704	$44,200.00	$3,200.20	$209,100.00	$15,139.41	$209,100.00	$15,139.41
87	0.070225707	$44,200.00	$3,103.98	$209,100.00	$14,684.20	$209,100.00	$14,684.20
88	0.068114168	$44,200.00	$3,010.65	$209,100.00	$14,242.67	$209,100.00	$14,242.67
89	0.066066118	$44,200.00	$2,920.12	$209,100.00	$13,814.43	$209,100.00	$13,814.43
90	0.064079649	$44,200.00	$2,832.32	$209,100.00	$13,399.05	$209,100.00	$13,399.05
91	0.062152909	$44,200.00	$2,747.16	$209,100.00	$12,996.17	$209,100.00	$12,996.17
92	0.060284102	$44,200.00	$2,664.56	$209,100.00	$12,605.41	$209,100.00	$12,605.41
93	0.058471486	$44,200.00	$2,584.44	$209,100.00	$12,226.39	$209,100.00	$12,226.39

Table 5-4

Present Value of O&M Costs
Remedial Alternatives for Groundwater
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

	Discount Rate = 0.031						
	Years of O&M =	150		150		150	
Year	Discount DF	Alternative GW-2 xt	Alternative GW-2 PV	Alternative GW-3 x_t	Alternative GW-3 PV	Alternative GW-4 x_t	Alternative GW-4 PV
94	0.056713371	$44,200.00	$2,506.73	$209,100.00	$11,858.77	$209,100.00	$11,858.77
95	0.055008119	$44,200.00	$2,431.36	$209,100.00	$11,502.20	$209,100.00	$11,502.20
96	0.053354141	$44,200.00	$2,358.25	$209,100.00	$11,156.35	$209,100.00	$11,156.35
97	0.051749894	$44,200.00	$2,287.35	$209,100.00	$10,820.90	$209,100.00	$10,820.90
98	0.050193884	$44,200.00	$2,218.57	$209,100.00	$10,495.54	$209,100.00	$10,495.54
99	0.04868466	$44,200.00	$2,151.86	$209,100.00	$10,179.96	$209,100.00	$10,179.96
100	0.047220814	$44,200.00	$2,087.16	$209,100.00	$9,873.87	$209,100.00	$9,873.87
101	0.045800984	$44,200.00	$2,024.40	$209,100.00	$9,576.99	$209,100.00	$9,576.99
102	0.044423845	$44,200.00	$1,963.53	$209,100.00	$9,289.03	$209,100.00	$9,289.03
103	0.043088113	$44,200.00	$1,904.49	$209,100.00	$9,009.72	$209,100.00	$9,009.72
104	0.041792544	$44,200.00	$1,847.23	$209,100.00	$8,738.82	$209,100.00	$8,738.82
105	0.04053593	$44,200.00	$1,791.69	$209,100.00	$8,476.06	$209,100.00	$8,476.06
106	0.0393171	$44,200.00	$1,737.82	$209,100.00	$8,221.21	$209,100.00	$8,221.21
107	0.038134918	$44,200.00	$1,685.56	$209,100.00	$7,974.01	$209,100.00	$7,974.01
108	0.036988281	$44,200.00	$1,634.88	$209,100.00	$7,734.25	$209,100.00	$7,734.25
109	0.035876121	$44,200.00	$1,585.72	$209,100.00	$7,501.70	$209,100.00	$7,501.70
110	0.034797402	$44,200.00	$1,538.05	$209,100.00	$7,276.14	$209,100.00	$7,276.14
111	0.033751117	$44,200.00	$1,491.80	$209,100.00	$7,057.36	$209,100.00	$7,057.36
112	0.032736292	$44,200.00	$1,446.94	$209,100.00	$6,845.16	$209,100.00	$6,845.16
113	0.031751981	$44,200.00	$1,403.44	$209,100.00	$6,639.34	$209,100.00	$6,639.34
114	0.030797266	$44,200.00	$1,361.24	$209,100.00	$6,439.71	$209,100.00	$6,439.71
115	0.029871257	$44,200.00	$1,320.31	$209,100.00	$6,246.08	$209,100.00	$6,246.08
116	0.028973091	$44,200.00	$1,280.61	$209,100.00	$6,058.27	$209,100.00	$6,058.27
117	0.028101931	$44,200.00	$1,242.11	$209,100.00	$5,876.11	$209,100.00	$5,876.11
118	0.027256965	$44,200.00	$1,204.76	$209,100.00	$5,699.43	$209,100.00	$5,699.43
119	0.026437405	$44,200.00	$1,168.53	$209,100.00	$5,528.06	$209,100.00	$5,528.06
120	0.025642488	$44,200.00	$1,133.40	$209,100.00	$5,361.84	$209,100.00	$5,361.84
121	0.024871473	$44,200.00	$1,099.32	$209,100.00	$5,200.62	$209,100.00	$5,200.62
122	0.02412364	$44,200.00	$1,066.26	$209,100.00	$5,044.25	$209,100.00	$5,044.25
123	0.023398293	$44,200.00	$1,034.20	$209,100.00	$4,892.58	$209,100.00	$4,892.58
124	0.022694755	$44,200.00	$1,003.11	$209,100.00	$4,745.47	$209,100.00	$4,745.47
125	0.022012372	$44,200.00	$972.95	$209,100.00	$4,602.79	$209,100.00	$4,602.79
126	0.021350506	$44,200.00	$943.69	$209,100.00	$4,464.39	$209,100.00	$4,464.39
127	0.020708541	$44,200.00	$915.32	$209,100.00	$4,330.16	$209,100.00	$4,330.16
128	0.020085879	$44,200.00	$887.80	$209,100.00	$4,199.96	$209,100.00	$4,199.96
129	0.019481939	$44,200.00	$861.10	$209,100.00	$4,073.67	$209,100.00	$4,073.67
130	0.018896158	$44,200.00	$835.21	$209,100.00	$3,951.19	$209,100.00	$3,951.19
131	0.01832799	$44,200.00	$810.10	$209,100.00	$3,832.38	$209,100.00	$3,832.38
132	0.017776906	$44,200.00	$785.74	$209,100.00	$3,717.15	$209,100.00	$3,717.15
133	0.017242392	$44,200.00	$762.11	$209,100.00	$3,605.38	$209,100.00	$3,605.38
134	0.01672395	$44,200.00	$739.20	$209,100.00	$3,496.98	$209,100.00	$3,496.98
135	0.016221096	$44,200.00	$716.97	$209,100.00	$3,391.83	$209,100.00	$3,391.83
136	0.015733362	$44,200.00	$695.41	$209,100.00	$3,289.85	$209,100.00	$3,289.85
137	0.015260292	$44,200.00	$674.50	$209,100.00	$3,190.93	$209,100.00	$3,190.93
138	0.014801448	$44,200.00	$654.22	$209,100.00	$3,094.98	$209,100.00	$3,094.98
139	0.014356399	$44,200.00	$634.55	$209,100.00	$3,001.92	$209,100.00	$3,001.92
140	0.013924732	$44,200.00	$615.47	$209,100.00	$2,911.66	$209,100.00	$2,911.66

Table 5-4

Present Value of O&M Costs
Remedial Alternatives for Groundwater
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

	Discount Rate = 0.031						
	Years of O&M =	150		150		150	
Year	Discount DF	Alternative GW-2 xt	Alternative GW-2 PV	Alternative GW-3 x_t	Alternative GW-3 PV	Alternative GW-4 x_t	Alternative GW-4 PV
141	0.013506045	$44,200.00	$596.97	$209,100.00	$2,824.11	$209,100.00	$2,824.11
142	0.013099947	$44,200.00	$579.02	$209,100.00	$2,739.20	$209,100.00	$2,739.20
143	0.012706059	$44,200.00	$561.61	$209,100.00	$2,656.84	$209,100.00	$2,656.84
144	0.012324014	$44,200.00	$544.72	$209,100.00	$2,576.95	$209,100.00	$2,576.95
145	0.011953457	$44,200.00	$528.34	$209,100.00	$2,499.47	$209,100.00	$2,499.47
146	0.011594042	$44,200.00	$512.46	$209,100.00	$2,424.31	$209,100.00	$2,424.31
147	0.011245434	$44,200.00	$497.05	$209,100.00	$2,351.42	$209,100.00	$2,351.42
148	0.010907307	$44,200.00	$482.10	$209,100.00	$2,280.72	$209,100.00	$2,280.72
149	0.010579347	$44,200.00	$467.61	$209,100.00	$2,212.14	$209,100.00	$2,212.14
150	0.010261249	$44,200.00	$453.55	$209,100.00	$2,145.63	$209,100.00	$2,145.63
Total		$6,674,200.00	$1,455,375.90	$31,680,300.00	$6,983,577.40	$31,761,900.00	$7,059,283.98

Notes:

1. Discount factor (DF) = $[1 / (1 + i)^t]$, where i = discount rate and t = year of payment
2. Present value (PV) = DF * x_t, where x_t = payment in year t

Table 5-5

Remedial Cost Summary for Groundwater Alternatives
TNT Manufacturing and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

	Alternative GW-1	Alternative GW-2	Alternative GW-3	Alternative GW-4
Cost Element	**No Further Action**	**MNA/LUC**	**Targeted ISEB/P&T**	**ISEB/P&T**
Capital Cost	$0	$547,000	$8,900,000	$12,555,000
Present Value O&M	$0	$1,455,000	$6,984,000	$7,059,000
Total Present Value	**$0**	**$2,002,000**	**$15,884,000**	**$19,614,000**
Minimum Present Value	**$0**	**$1,401,000**	**$11,119,000**	**$13,730,000**
Maximum Present Value	**$0**	**$3,003,000**	**$23,826,000**	**$29,421,000**

Notes:

Alternative GW-1: No action

Alternative GW-2: Monitoring and Institutional Controls

Alternative GW-3: ISEB and Pump & Treat for Mitigation / Protection of the Delaware Limestone Bedrock Groundwater

Alternative GW-4: ISEB and Pump & Treat for Mitigation / Protection of the Overburden / Weathered Shale and Limestone Bedrock Groundwater

Range of present value (PV) cost presented in the table represents a -30% (minimum PV) to +50% (maximum PV) contingency on the calculated present value.

ISEB - In Situ Enhanced Bioremediation.

O&M - Operation and Maintenance costs.

A discount rate of 3.1% was used to calculate the present value of O&M costs (does not include inflation).

Reference: OSWER 9355.0-75, July 2000.

Table 5-6

Remedial Alternative GW-3
Preliminary Design Basis for ISEB Treatment
Overburden/Shale Water-Bearing Zone
Former Plum Brook Ordnance Works
Sandusky, Ohio

Site	Plume Area (ft^2)	Number of Barriers	Barrier Width (ft)	Barrier Length (ft)	Distance Between Barriers (ft)	Average Thickness Of Injection Zone (ft)	Number of DP Injection Points per Barrier	Total Number of DP Injection Points	Mass of Oil Emulsion Injected (lbs)
TNTA	88,100	4	297	10	83	20	30	120	26,440
TNTB	16,400	2	128	10	88	1	13	26	280
TNTC	52,900	5	230	10	54	10	23	115	12,800
WARWP	320,000	10	566	10	62	13	57	570	90,080
PRRWP	370,000	61	608	10	10	25	61	3721	1,032,000
Total	847,400							4609	1,161,600

Notes:

1. Plume area is the combined area of all plumes within the designated sites.
2. Barrier width is in the direction perpendicular to groundwater flow. Barrier length is in the direction parallel to groundwater flow.
3. Distance between barriers is in the direction parallel to groundwater flow.
4. DP = direct push.

ft - Feet.
ft^2 - Square feet.
lbs - Pounds.

Table 5-7

Remedial Alternative GW-4
Preliminary Design Basis for ISEB Treatment
Overburden/Shale Water-Bearing Zone
Former Plum Brook Ordnance Works
Sandusky, Ohio

Site	Plume Area (ft)	Number of Barriers	Barrier Width (ft)	Barrier Length (ft)	Distance Between Barriers (ft)	Average Thickness Of Injection Zone (ft)	Number of DP Injection Points per Barrier	Total Number of DP Injection Points	Mass of Oil Emulsion Injected (lbs)
TNTA	118,300	4	344	10	106	16	34	136	24,500
TNTB	109,400	5	331	10	80	1	33	165	1,840
TNTC	60,200	5	245	10	53	15	25	125	20,450
WARWP	440,000	13	663	10	53	13	66	858	124,710
PRRWP	680,000	83	825	10	10	25	83	6889	1,905,350
Total	1,407,900							8173	2,076,850

Notes:

1. Plume area is the combined area of all plumes within the designated sites.
2. Barrier width is in the direction perpendicular to groundwater flow. Barrier length is in the direction parallel to groundwater flow.
3. Distance between barriers is in the direction parallel to groundwater flow.
4. DP = direct push.

ft - Feet.
lbs - Pounds.

Table 6-1

Comparative Analysis of Remedial Alternatives for Groundwater
TNT and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

Criteria	**Alternative GW-1:** No Further Action	**Alternative GW-2:** Groundwater Monitoring and Institutional Controls	**Alternative GW-3:** In Situ Enhanced Bioremediation/Pump and Treat for Mitigation/Protection of the Bedrock, Groundwater Monitoring, and Institutional Controls	**Alternative GW-4:** In Situ Enhanced Bioremediation/Pump and Treat for Mitigation/Protection of the Overburden/Shale and Bedrock, Groundwater Monitoring, and Institutional Controls
Protection of Human Health and the Environment				
Human Health Protection	Not protective. Contamination would be left in place and no restrictions would be placed on its future use. Adverse human health effects could be incurred by a future on-site resident who may install a well and use the groundwater as household drinking water. Chemicals of concern (COC) in groundwater may migrate off site in the limestone aquifer and potentially pose a human health threat to a resident who may use this off-site groundwater as drinking water.	Protective. Legally enforceable groundwater use restrictions would be implemented to prevent the use of groundwater on site. Long-term groundwater monitoring would be performed to ensure that potential off-site groundwater users would not be exposed to contaminated groundwater from the site. Additional remedial action for groundwater could be taken if COCs in groundwater threaten potential off-site drinking water.	Protective. Legally enforceable groundwater use restrictions would be implemented to prevent the use of groundwater on site while the concentrations of COCs exceed the RGOs. Groundwater monitoring would be performed to ensure that potential off-site groundwater users would not be exposed to contaminated limestone bedrock groundwater from the site. Additional remedial action for groundwater could be taken if COCs in groundwater threaten potential off-site drinking water. Targeted use of in situ enhanced bioremediation (ISEB) would be implemented to reduce the concentrations of COCs and prevent migration of COCs to limestone bedrock groundwater. Pump and treat within the bedrock aquifer in the WARWP and PRRWP Areas would reduce concentrations of COCs in these plumes and prevent off-site migration of contaminated groundwater in these areas.	Protective. Legally enforceable groundwater use restrictions would be implemented to prevent the use of groundwater on site while the concentrations of COCs exceed the RGOs. Groundwater monitoring would be performed to ensure that potential off-site groundwater users would not be exposed to contaminated limestone bedrock groundwater from the site. Additional remedial action for groundwater could be taken if COCs in groundwater threaten potential off-site drinking water. Use of ISEB would be implemented to reduce the concentrations of COCs to drinking water quality in the overburden/shale groundwater and prevent migration of COCs to limestone bedrock groundwater. Pump and treat within the bedrock aquifer in the WARWP and PRRWP Areas would reduce concentrations of COCs in these plumes and prevent off-site migration of contaminated groundwater in these areas.
Environmental Protection	Protective. Impacted groundwater does not discharge to surface water. Thus, contaminated groundwater does not present a threat to ecological receptors or other environmental media.	Protective. Impacted groundwater does not discharge to surface water. Thus, contaminated groundwater does not present a threat to ecological receptors or other environmental media.	Protective. Impacted groundwater does not discharge to surface water. Thus, contaminated groundwater does not present a threat to ecological receptors or other environmental media.	Protective. Impacted groundwater does not discharge to surface water. Thus, contaminated groundwater does not present a threat to ecological receptors or other environmental media.
Compliance with ARARs				
Chemical-Specific ARARs	Not compliant. Would not comply with the Ohio drinking water standards for nitrate in limestone groundwater. If the overburden/shale groundwater is regarded as a potential drinking water source, then would not comply with the Ohio drinking water standards for nitrate or toluene in overburden/shale groundwater. No chemical-specific ARARs are available for nitroaromatic compounds.	Would not immediately comply with the Ohio drinking water standards for nitrate in limestone groundwater. If the overburden/shale groundwater is regarded as a potential drinking water source, then would not comply with the Ohio drinking water standards for nitrate or possibly for toluene in overburden/shale groundwater. No chemical-specific ARARs are available for nitroaromatic compounds.	Compliant. Would reduce the concentration of nitrate in limestone bedrock to below the Ohio drinking water standard. If the overburden/shale groundwater is regarded as a potential drinking water source, then would comply with the Ohio drinking water standards for nitrate and possibly for toluene in overburden/shale groundwater. No chemical-specific ARARs available for nitroaromatic compounds.	Compliant. Would reduce the concentration of nitrate in limestone bedrock to below the Ohio drinking water standard. If the overburden/shale groundwater is regarded as a potential drinking water source, then would comply with the Ohio drinking water standards for nitrate and possibly for toluene in overburden/shale groundwater. No chemical-specific ARARs available for nitroaromatic compounds.
Location-Specific ARARs	No location-specific ARARs.	No location-specific ARARs.	Will protect sensitive cultural resources if encountered.	Will protect sensitive cultural resources if encountered.
Action-Specific ARARs	No action-specific ARARs.	Will comply with hazardous waste management regulations, if such waste is generated during groundwater monitoring.	Will comply with underground injection control, hazardous waste management, and air quality requirements, if applicable.	Will comply with underground injection control, hazardous waste management, and air quality requirements, if applicable.
Other Criteria and Guidance	Not predicted to attain drinking water RGOs for COCs in the overburden/shale or limestone bedrock groundwater for over 150 years.	Not predicted to attain drinking water RGOs for COCs in the overburden/shale or limestone bedrock groundwater for over 150 years. Off-site contamination has not been observed. Monitoring would verify if RGOs are met in the limestone bedrock aquifer at the PBOW.	Not predicted to attain drinking water RGOs for COCs in the limestone bedrock groundwater for over 150 years, even with active P&T. Off-site contamination has not been observed. Monitoring would verify if RGOs are met in the limestone bedrock aquifer at the PBOW. Monitoring would also verify the effectiveness of targeted ISEB in minimizing the potential impact of the overburden/shale groundwater on the limestone bedrock groundwater..	Not predicted to attain drinking water RGOs for COCs in the limestone bedrock groundwater for over 150 years, even with active P&T. Off-site contamination has not been observed. Monitoring would verify if RGOs are met in the limestone bedrock aquifer at the PBOW. Monitoring would also verify the effectiveness of targeted ISEB in restoring the overburden/shale groundwater to drinking water quality, as well as minimizing its potential impact on the limestone bedrock groundwater..

Table 6-1

Comparative Analysis of Remedial Alternatives for Groundwater
TNT and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

Criteria	**Alternative GW-1:** No Further Action	**Alternative GW-2:** Groundwater Monitoring and Institutional Controls	**Alternative GW-3:** In Situ Enhanced Bioremediation/Pump and Treat for Mitigation/Protection of the Bedrock, Groundwater Monitoring, and Institutional Controls	**Alternative GW-4:** In Situ Enhanced Bioremediation/Pump and Treat for Mitigation/Protection of the Overburden/Shale and Bedrock, Groundwater Monitoring, and Institutional Controls
Long-Term Effectiveness and Permanence				
Magnitude of Residual Risk	Does not reduce the magnitude of residual risk.	Residual risk from concentrations of COC above RGOs is managed by (1) implementation of on-site groundwater use restrictions and (2) groundwater monitoring to guard against off-site exposure to contaminated groundwater. Groundwater modeling predicts that concentrations of COCs in limestone bedrock groundwater will remain above RGOs for more than 150 years. The presence of naturally-occurring petroleum hydrocarbons and reducing conditions within the limestone bedrock groundwater may promote the natural biodegradation of nitrate and nitroaromatic compounds.	Would reduce the magnitude of residual risk by reducing the concentrations of COCs in overburden/weathered shale (some areas) and limestone bedrock groundwater through treatment. Residual risk from concentrations of COC above RGOs is managed by (1) implementation of on-site groundwater use restrictions and (2) groundwater monitoring to guard against off-site exposure to contaminated groundwater. Groundwater modeling predicts that concentrations of COCs in limestone bedrock groundwater will remain above RGOs for more than 150 years. The presence of naturally-occurring petroleum hydrocarbons and reducing conditions within the limestone bedrock groundwater may promote the natural biodegradation of nitrate and nitroaromatic compounds.	Would reduce the magnitude of residual risk by reducing the concentrations of COCs in overburden/weathered shale (all areas) and limestone bedrock groundwater through treatment. Residual risk from concentrations of COC above RGOs is managed by (1) implementation of on-site groundwater use restrictions and (2) groundwater monitoring to guard against off-site exposure to contaminated groundwater. Groundwater modeling predicts that concentrations of COCs in limestone bedrock groundwater will remain above RGOs for more than 150 years. The presence of naturally-occurring petroleum hydrocarbons and reducing conditions within the limestone bedrock groundwater may promote the natural biodegradation of nitrate and nitroaromatic compounds.
Adequacy and Reliability of Controls	Not adequate or reliable. Groundwater modeling indicates that contaminants may migrate offsite.	Adequate and reliable. Action would be taken to ensure groundwater use restrictions are continually enforced. Monitoring would observe any potential future off-site contamination, so that a future action could be taken, should it become necessary.	Adequate and reliable. Action would be taken to ensure groundwater use restrictions are enforced as long as the RGOs are not met. Monitoring would observe any potential future off-site contamination, so that a future action could be taken, should it become necessary.	Adequate and reliable. Action would be taken to ensure groundwater use restrictions are enforced as long as the RGOs are not met. Monitoring would observe any potential future off-site contamination, so that a future action could be taken, should it become necessary.
Reduction of Toxicity, Mobility or Volume through Treatment				
Treatment Process Used	None.	None.	ISEB and P&T. Injection of a carbon substrate into the overburden/shale groundwater for ISEB. Biological treatment would be used in the WARWP Area treatment system. A carbon adsorption system would be used in the PRRWP Area treatment system.	ISEB and P&T. Injection of a carbon substrate into the overburden/shale groundwater for ISEB. Biological treatment would be used in the WARWP Area treatment system. A carbon adsorption system would be used in the PRRWP Area treatment system.
Amount Destroyed or Treated	None.	None.	23.7 million gallons of overburden/shale groundwater to be treated over an area of 968,000 ft^2 and 106 million gallons of limestone bedrock current groundwater pore space to be treated over an area of 1,380,000 ft^2.	38.4 million gallons of overburden/shale groundwater to be treated over an area of 1,411,700 ft^2 and 106 million gallons of limestone bedrock current groundwater pore space to be treated over an area of 1,380,000 ft^2.
Irreversible Treatment	None.	None.	COCs will be biologically degraded or irreversibly transformed into less toxic and immobile reaction products.	COCs will be biologically degraded or irreversibly transformed into less toxic and immobile reaction products.
Type and Quantity of Residuals Remaining after Treatment	None.	None.	Both P&T systems would generate a non-hazardous filter cake that would require off-site disposal.	Both P&T systems would generate a non-hazardous filter cake that would require off-site disposal.
Short-Term Effectiveness				
Community Protection	No short term threat to community because no remedial action would be taken.	Groundwater monitoring would protect the community by providing advance warning of groundwater contamination that might threaten nearby water supplies.	Implementation poses no threat to the community.	Implementation poses no threat to the community.
Worker Protection	No risk to workers.	No risk to workers.	Site workers would be protected through implementation of remedial action health & safety plan and groundwater use restrictions.	Site workers would be protected through implementation of remedial action health & safety plan and groundwater use restrictions.

Table 6-1

Comparative Analysis of Remedial Alternatives for Groundwater
TNT and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

Criteria	**Alternative GW-1:** No Further Action	**Alternative GW-2:** Groundwater Monitoring and Institutional Controls	**Alternative GW-3:** In Situ Enhanced Bioremediation/Pump and Treat for Mitigation/Protection of the Bedrock, Groundwater Monitoring, and Institutional Controls	**Alternative GW-4:** In Situ Enhanced Bioremediation/Pump and Treat for Mitigation/Protection of the Overburden/Shale and Bedrock, Groundwater Monitoring, and Institutional Controls
Environmental Impacts	No short-term environmental impact.	No short-term environmental impact.	No short-term environmental impact.	No short-term environmental impact.
Time Until Action is Complete	Not applicable.	Not applicable.	Approximately 4.3 years for ISEB and 2 years for design and construction of the P&T systems, after additional groundwater characterization and technology pilot studies are completed. The P&T system would operate for at least 150 years, unless the remedial duration estimated by the model is overly conservative or natural attenuation processes reduce COCs concentrations.	Approximately 7.8 years for ISEB and 2 years for design and construction of the P&T systems, after additional groundwater characterization and technology pilot studies are completed. The P&T system would operate for at least 150 years, unless the remedial duration estimated by the model is overly conservative or natural attenuation processes reduce COCs concentrations.
Implementability				
Ability to Construct and Operate	No construction or operation.	No construction or operation.	Technology is readily implementable. Additional data should be collected prior to full-scale implementation of the ISEB and P&T technologies to ensure that they will be effectively implemented. The groundwater plumes at target areas should have well-defined boundaries. The distribution of COCs and potential competing electron acceptors should be well understood so that the demand for carbon substrate can be predicted and the configuration of injection points can be designed effectively for ISEB areas. Of particular concern is the concentration of sulfate and nitrate throughout the ISEB target area at the PRRWP plume. The available data indicate that sulfate would exert a high demand on carbon substrate within this plume leading to potentially costly ISEB implementation.	Technology is readily implementable. Additional data should be collected prior to full-scale implementation of the ISEB and P&T technologies to ensure that they will be effectively implemented. The groundwater plumes at target areas should have well-defined boundaries. The distribution of COCs and potential competing electron acceptors should be well understood so that the demand for carbon substrate can be predicted and the configuration of injection points can be designed effectively for ISEB areas. Of particular concern is the concentration of sulfate and nitrate throughout the ISEB target area at the PRRWP plume. The available data indicate that sulfate would exert a high demand on carbon substrate within this plume leading to potentially costly ISEB implementation.
Ease of Doing More Action if Needed	Does not preclude additional action.	Does not preclude additional action.	GWP&T may continue beyond projected time frame until RGOs are met. ISEB may continue beyond projected time frame until short-term objectives related to protection of the limestone bedrock groundwater are met. Additional injection/extraction wells may be installed and treatment capacity augmented if needed. Alternative does not preclude additional action.	GWP&T may continue beyond projected time frame until RGOs are met. ISEB may continue beyond projected time frame until short-term objectives related to restoration of the overburden/shale groundwater are met. Additional injection/extraction wells may be installed and treatment capacity augmented if needed. Alternative does not preclude additional action.
Ability to Monitor Effectiveness	No monitoring required.	Effectiveness gauged through groundwater monitoring.	Effectiveness gauged through groundwater monitoring.	Effectiveness gauged through groundwater monitoring.
Ability to Obtain Approvals and Coordinate with Other Agencies	None required.	None required.	Underground injection control (UIC) permit required	UIC permit required.
Availability of Equipment, Specialists, and Materials	None required.	None required.	Equipment, specialists and materials available. Scale of project may be difficult for USACE to fund entire scope. Remedial action may need to be implemented in a phased approach.	Equipment, specialists and materials available. Scale of project may be difficult for USACE to fund entire scope. Remedial action may need to be implemented in a phased approach.
Availability of Technologies	None required.	None required.	Available and well developed	Available and well developed
Cost				
Capital Cost Estimate	$0	$460,000	$8,699,000	$12,344,000
Present Value O&M Cost Estimate	$0	$1,455,000	$6,984,000	$7,059,000
Present Worth Cost Estimate	$0	$1,915,000	$15,683,000	$19,403,000
Present Worth Estimated Range (-30%/+50%)	$0	$1,341,000 to $2,873,000	$10,978,000 to $23,525,000	$13,582,000 to $29,105,000

Table 6-1

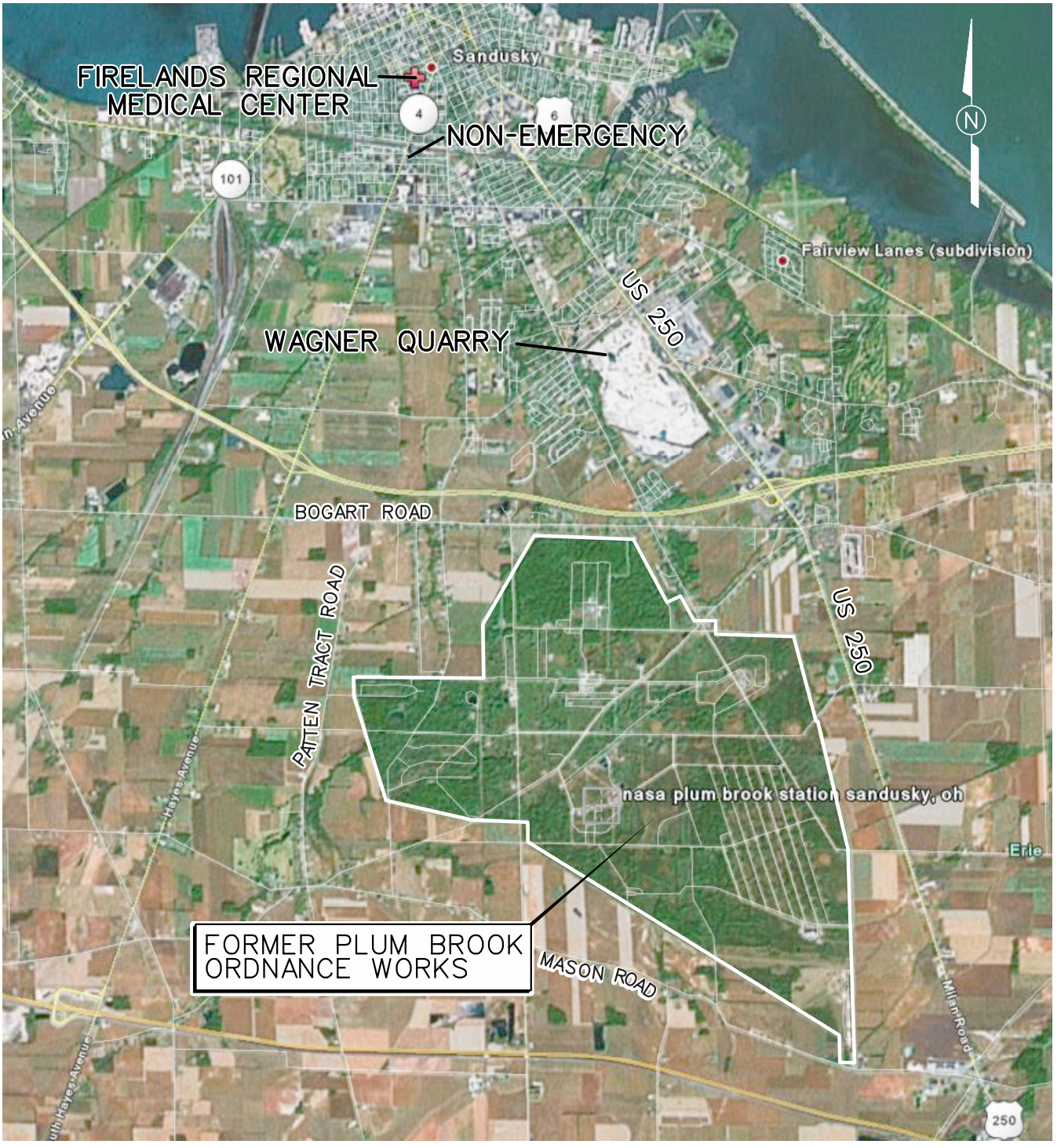
Comparative Analysis of Remedial Alternatives for Groundwater
TNT and Red Water Pond Areas Groundwater Feasibility Study
Former Plum Brook Ordnance Works, Sandusky, Ohio

Criteria	**Alternative GW-1:** No Further Action	**Alternative GW-2:** Groundwater Monitoring and Institutional Controls	**Alternative GW-3:** In Situ Enhanced Bioremediation/Pump and Treat for Mitigation/Protection of the Bedrock, Groundwater Monitoring, and Institutional Controls	**Alternative GW-4:** In Situ Enhanced Bioremediation/Pump and Treat for Mitigation/Protection of the Overburden/Shale and Bedrock, Groundwater Monitoring, and Institutional Controls
State Acceptance				
State Acceptance	Likely not acceptable	To be determined.	To be determined.	To be determined.
Community Acceptance				
Community Acceptance	Likely not acceptable	To be determined.	To be determined.	To be determined.

COC - Contaminant of concern.
RGO - Remedial goal option.
ISEB - In situ enhanced bioremediation.
WARWP - West Area Red Water Ponds.
PRRWP - Pentolite Road Red Water Pond.
ARAR - Applicable or relevant and appropriate requirement.
P&T - Pump and treat.
PBOW - Plum Brook Ordnance Works.
GW - Groundwater.
UIC - Underground injection control.

FIGURES

FIGURES



NOT TO SCALE

FIGURE 1-1
PBOW VICINITY MAP

GROUNDWATER FEASIBILITY STUDY
TNT AND RED WATER POND AREAS
FORMER PLUM BROOK ORDNANCE WORKS
NASA PLUM BROOK STATION
SANDUSKY, OHIO

Shaw® Shaw Environmental, Inc.

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DRAWN BY: D. BOMAR	DRAWN BY:	ENGR. CHCK. BY: C. ANGLIN	PROJ. MGR.: S. DOWNEY
			DWG. NO.: 119268_001.DGN
			PROJ. NO.: 119268

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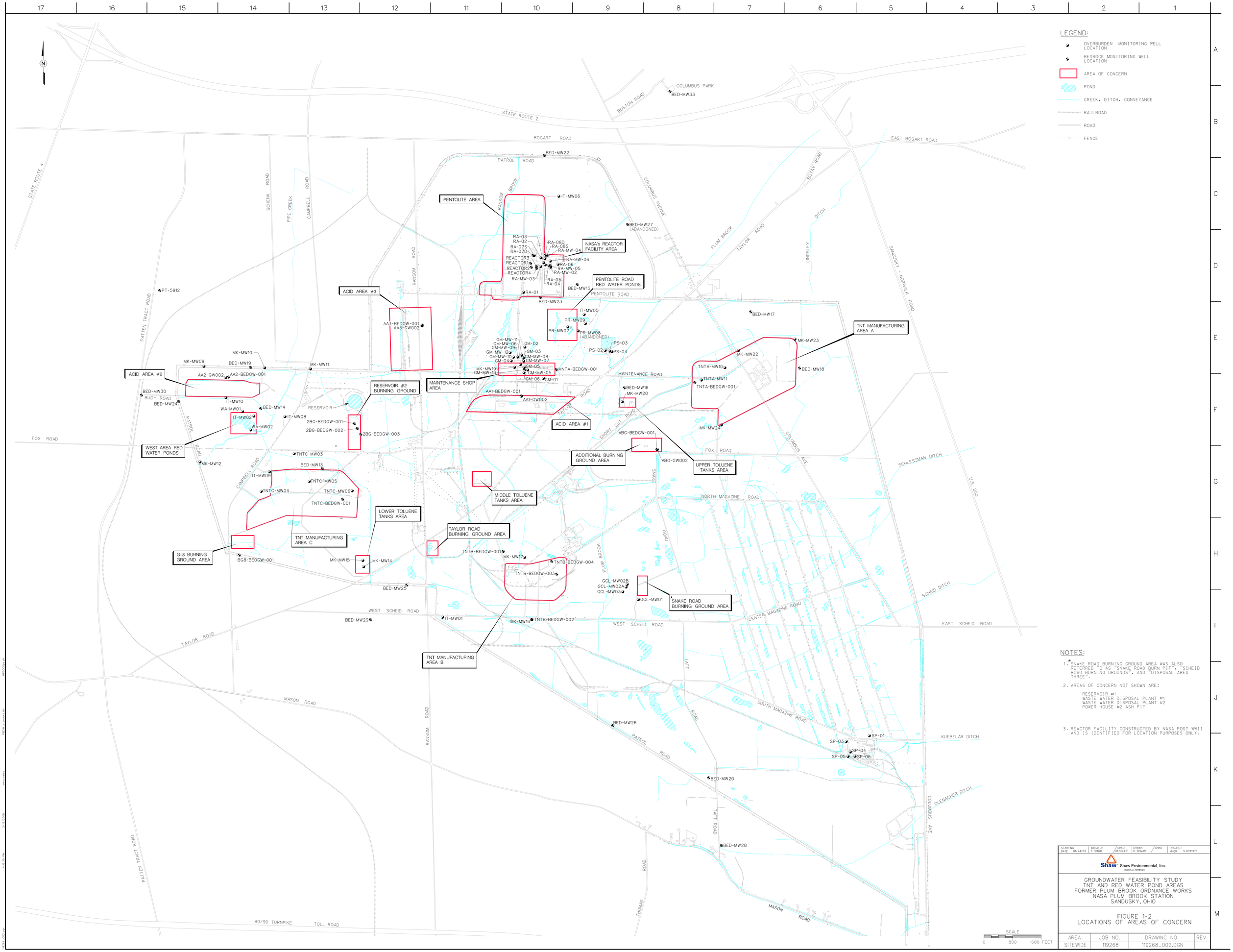


NOTES:

1. *SNAKE ROAD BURNING GROUND AREA WAS ALSO REFERRED TO AS "SNAKE ROAD BURN PIT", "SCHEID ROAD BURNING GROUNDS", AND "DISPOSAL AREA THREE".

2. AREAS OF CONCERN NOT SHOWN ARE:

   RESERVOIR #1
   WASTE WATER DISPOSAL PLANT #1
   WASTE WATER DISPOSAL PLANT #2
   POWER HOUSE #2 ASH PIT

3. REACTOR FACILITY CONSTRUCTED BY NASA POST WWII AND IS IDENTIFIED FOR LOCATION PURPOSES ONLY.

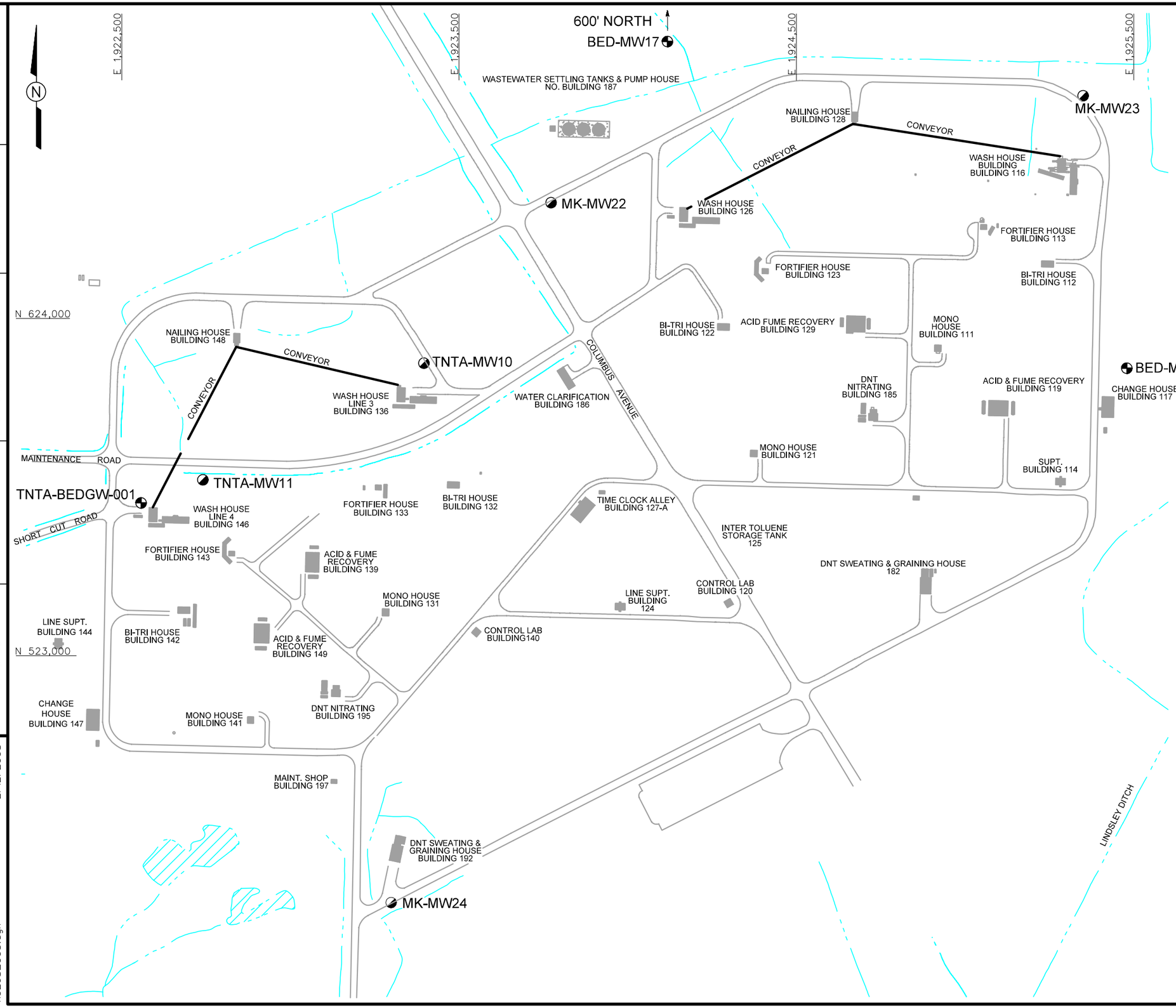
STARTING DATE	INITIATOR / CHKD.	DRAWN / CHKD	PROJECT MNGR
01/24/07	T. SIARD / KESSLER	D. BOMAR /	S.DOWNEY

Shaw Environmental, Inc.
KNOXVILLE, TENNESSEE

GROUNDWATER FEASIBILITY STUDY
TNT AND RED WATER POND AREAS
FORMER PLUM BROOK ORDNANCE WORKS
NASA PLUM BROOK STATION
SANDUSKY, OHIO

FIGURE 1-2
LOCATIONS OF AREAS OF CONCERN

AREA	JOB NO.	DRAWING NO.	REV
SITEWIDE	119268	119268_002.DGN	



LEGEND

- HISTORICAL BUILDINGS
- SURFACE DRAINAGE
- SURFACE WATER
- OVERBURDEN/SHALE MONITORING WELL LOCATION
- BEDROCK MONITORING WELL LOCATION

NOTE:

1. ALL HISTORICAL BUILDINGS AND SOME OF THE ROADWAYS NO LONGER EXIST.

SCALE

0 300 600 FEET

FIGURE 1-3
TNT AREA A
GENERAL SITE FEATURES

GROUNDWATER FEASIBILITY STUDY
TNT AND RED WATER POND AREAS
FORMER PLUM BROOK ORDNANCE WORKS
NASA PLUM BROOK STATION
SANDUSKY, OHIO

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PROJ. NO.: 119268
INITIATOR: C. ANGLIN
PROJ. MGR.: S. DOWNEY
DRAFT. CHCK. BY:
ENGR. CHCK. BY: C. ANGLIN
DATE LAST REV.:
DRAWN BY:
STARTING DATE: 11/06/06
DRAWN BY: D. BOMAR
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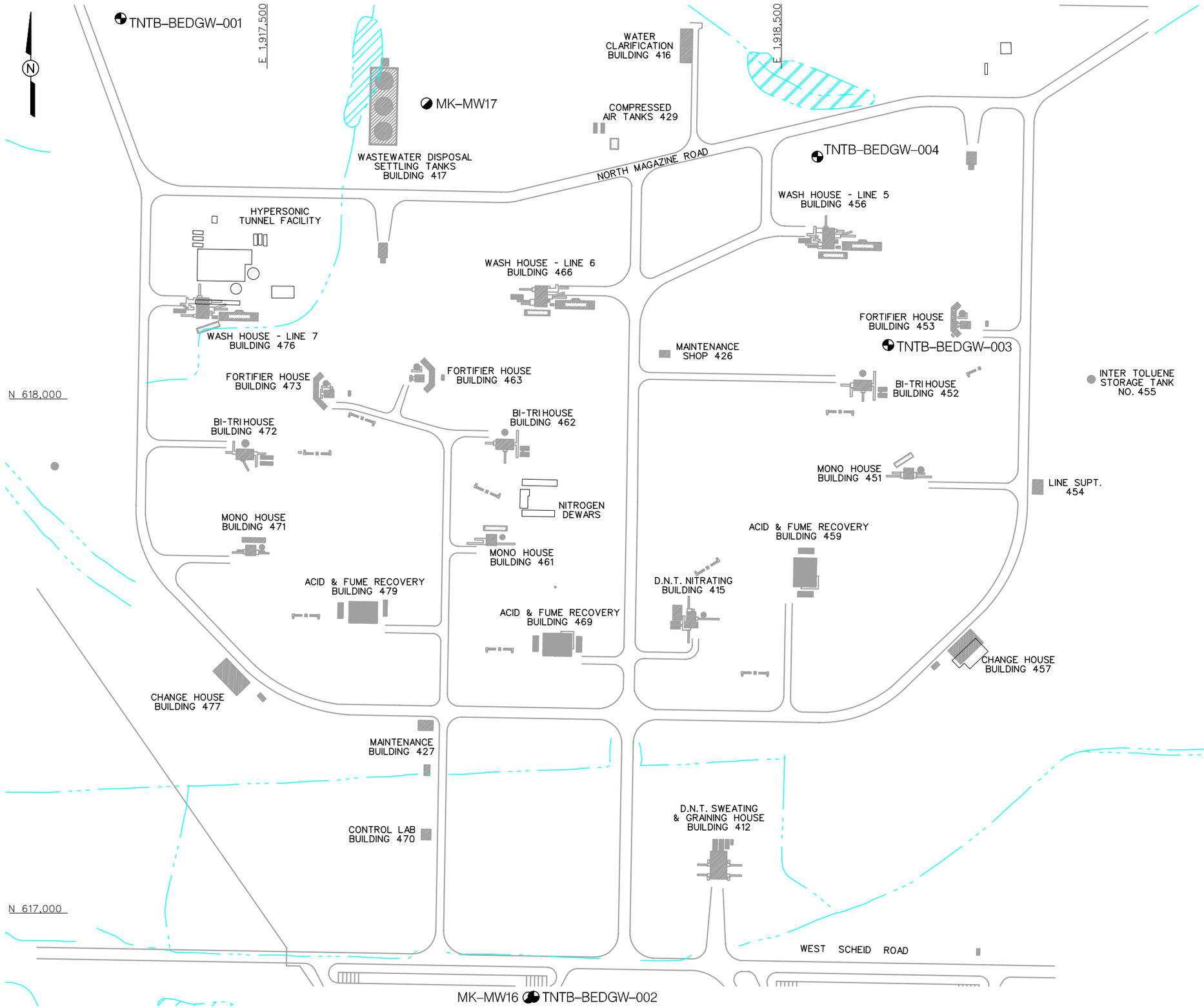

LEGEND

- HISTORICAL BUILDINGS
- SURFACE DRAINAGE
- SURFACE WATER
- OVERBURDEN/SHALE MONITORING WELL LOCATION
- BEDROCK MONITORING WELL LOCATION

NOTE:

1. ALL HISTORICAL BUILDINGS AND SOME OF THE ROADWAYS NO LONGER EXIST.

SCALE

0 200 400 FEET

FIGURE 1-4
TNT AREA B
GENERAL SITE FEATURES

GROUNDWATER FEASIBILITY STUDY
TNT AND RED WATER POND AREAS
FORMER PLUM BROOK ORDNANCE WORKS
NASA PLUM BROOK STATION
SANDUSKY, OHIO

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INITIATOR: C. ANGLIN | PROJ. MGR.: S. DOWNEY
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DATE LAST REV.: | DRAWN BY:
STARTING DATE: 11/06/06 | DRAWN BY: D. BOMAR
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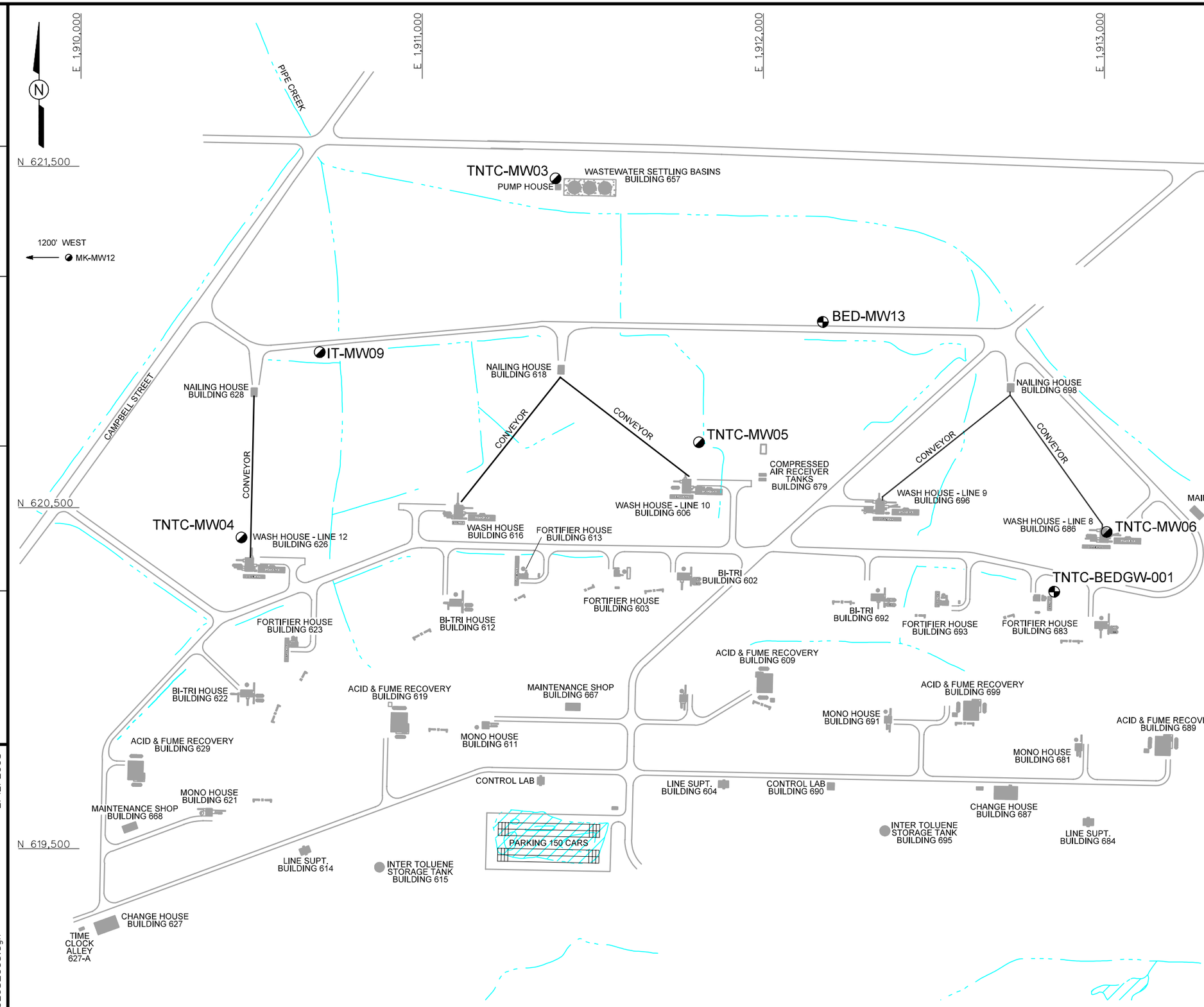

LEGEND

- HISTORICAL BUILDINGS
- SURFACE DRAINAGE
- SURFACE WATER
- OVERBURDEN/SHALE MONITORING WELL LOCATION
- BEDROCK MONITORING WELL LOCATION

NOTE:

1. ALL HISTORICAL BUILDINGS AND SOME OF THE ROADWAYS NO LONGER EXIST.

SCALE

0 300 600 FEET

FIGURE 1-5
TNT AREA C
GENERAL SITE FEATURES

GROUNDWATER FEASIBILITY STUDY
TNT AND RED WATER POND AREAS
FORMER PLUM BROOK ORDNANCE WORKS
NASA PLUM BROOK STATION
SANDUSKY, OHIO

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INITIATOR: C. ANGLIN
PROJ. MGR.: S. DOWNEY
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ENGR. CHCK. BY: C. ANGLIN
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DRAWN BY:
STARTING DATE: 11/06/06
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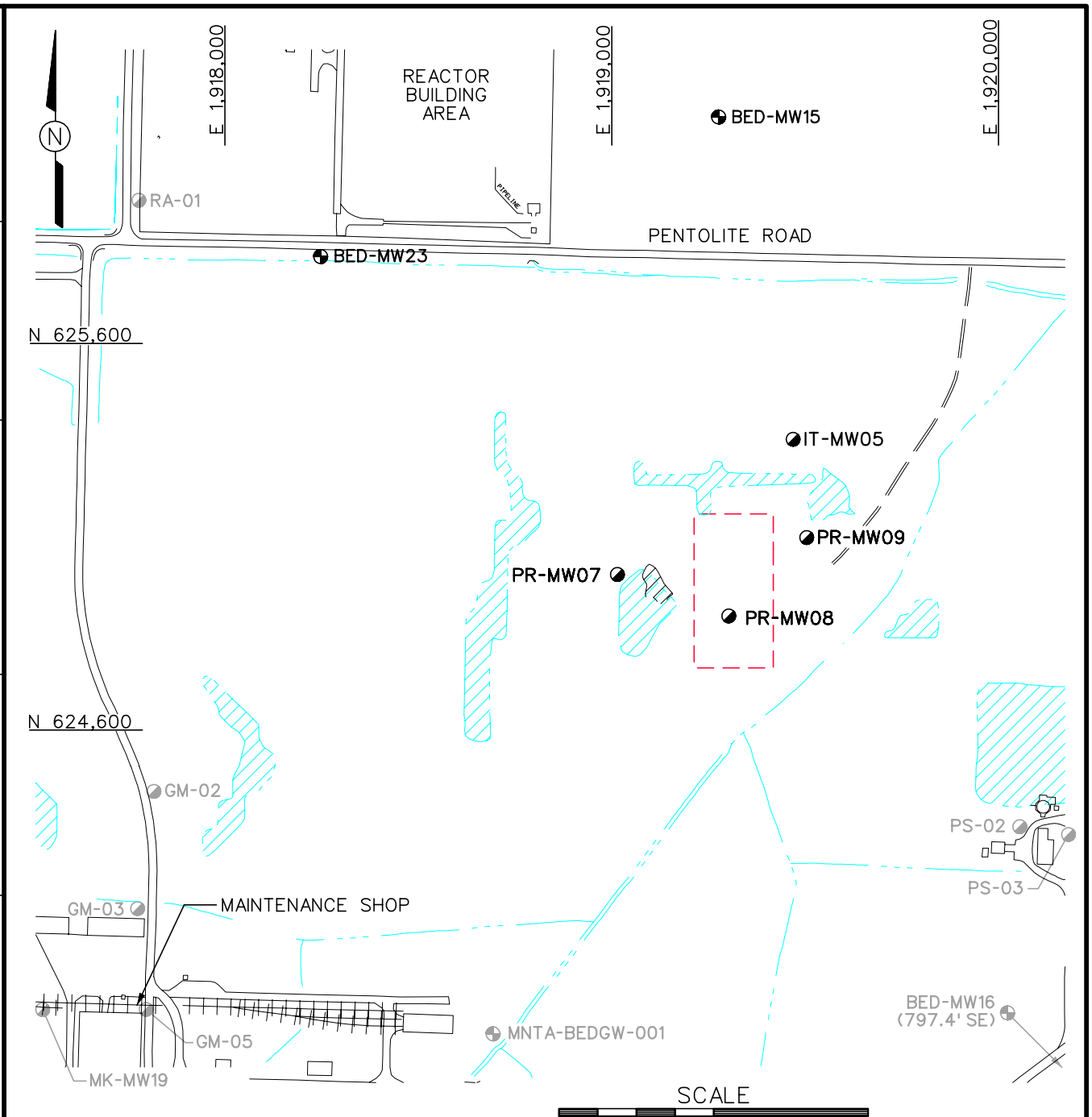

LEGEND:

- BUILDINGS
- RAILROAD
- APPROXIMATE HISTORICAL LOCATION OF POND
- SURFACE DRAINAGE
- SURFACE WATER
- OVERBURDEN/SHALE MONITORING WELL LOCATION
- BEDROCK MONITORING WELL LOCATION

FIGURE 1-6
PENTOLITE ROAD RED WATER POND AREA GENERAL SITE FEATURES

GROUNDWATER FEASIBILITY STUDY
TNT AND RED WATER POND AREAS
FORMER PLUM BROOK ORDNANCE WORKS
NASA PLUM BROOK STATION
SANDUSKY, OHIO

Shaw® Shaw Environmental, Inc.

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PROJ. NO.: 119268
INITIATOR: C. ANGLIN
PROJ. MGR.: S. DOWNEY
DRAFT. CHCK. BY:
ENGR. CHCK. BY: C. ANGLIN
DATE LAST REV.:
DRAWN BY:
STARTING DATE: 11/07/06
DRAWN BY: D. BOMAR

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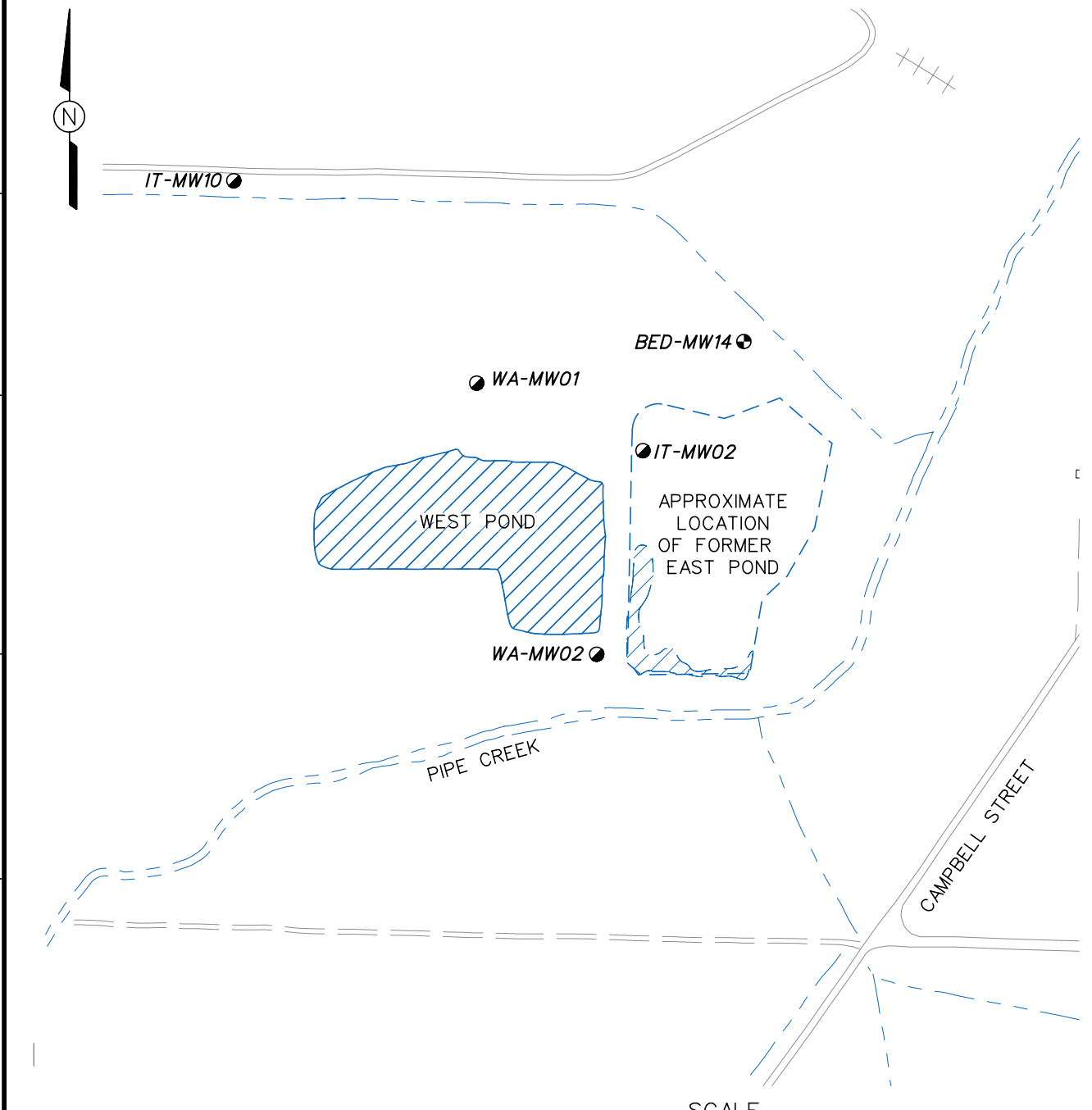

SCALE

0 300 600 FEET

LEGEND:

- RAILROAD
- SURFACE WATER
- SURFACE DRAINAGE
- APPROXIMATE HISTORICAL LOCATION OF PONDS
- UNPAVED ROADS/DRIVES
- PAVED ROADS
- OVERBURDEN/SHALE MONITORING WELL LOCATION
- BEDROCK MONITORING WELL LOCATION

FIGURE 1-7
WEST AREA RED WATER PONDS AREA GENERAL SITE FEATURES

GROUNDWATER FEASIBILITY STUDY
TNT AND RED WATER POND AREAS
FORMER PLUM BROOK ORDNANCE WORKS
NASA PLUM BROOK STATION
SANDUSKY, OHIO

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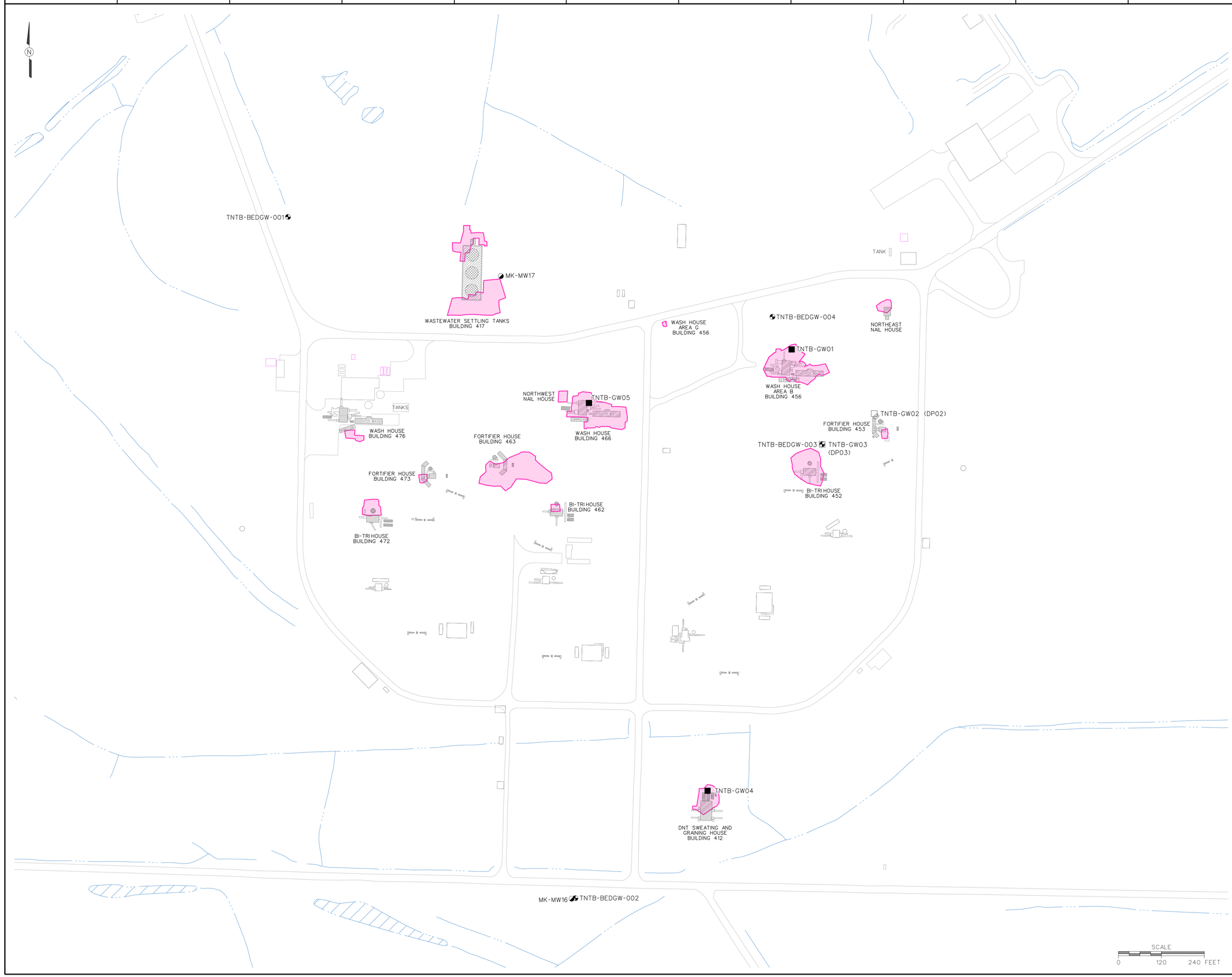

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STARTING DATE 01/24/07 | INITIATOR T. SIARD / CHKD | DRAWN D. BOMAR / CHKD | PROJECT MNGR S. DOWNEY

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GROUNDWATER FEASIBILITY STUDY
TNT AND RED WATER POND AREAS
FORMER PLUM BROOK ORDNANCE WORKS
NASA PLUM BROOK STATION
SANDUSKY, OHIO

FIGURE 1-8
TNT AREA B COMPLETED SOIL REMEDIATION AREAS

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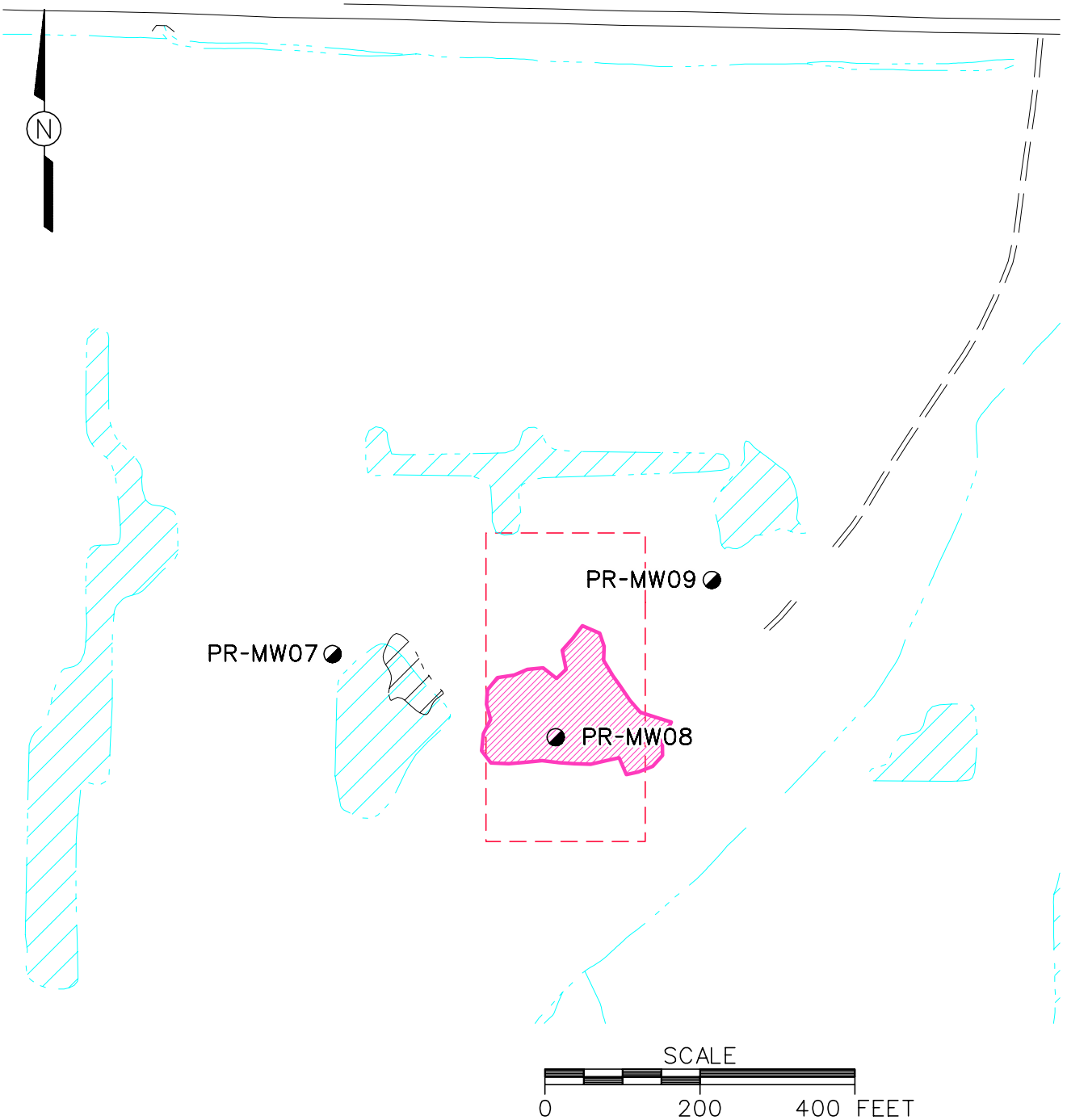

LEGEND

- BUILDINGS
- APPROXIMATE HISTORICAL LOCATION OF POND
- SURFACE DRAINAGE
- SURFACE WATER
- OVERBURDEN/SHALE MONITORING WELLLOCATION
- PLANNED TNT SOIL REMEDIATION AREA

FIGURE 1-9
PREVIOUSLY IDENTIFIED AREAS REQUIRING SOIL REMEDIATION IN PENTOLITE ROAD RED WATER POND AREA

GROUNDWATER FEASIBILITY STUDY
TNT AND RED WATER POND AREAS
FORMER PLUM BROOK ORDNANCE WORKS
NASA PLUM BROOK STATION
SANDUSKY, OHIO

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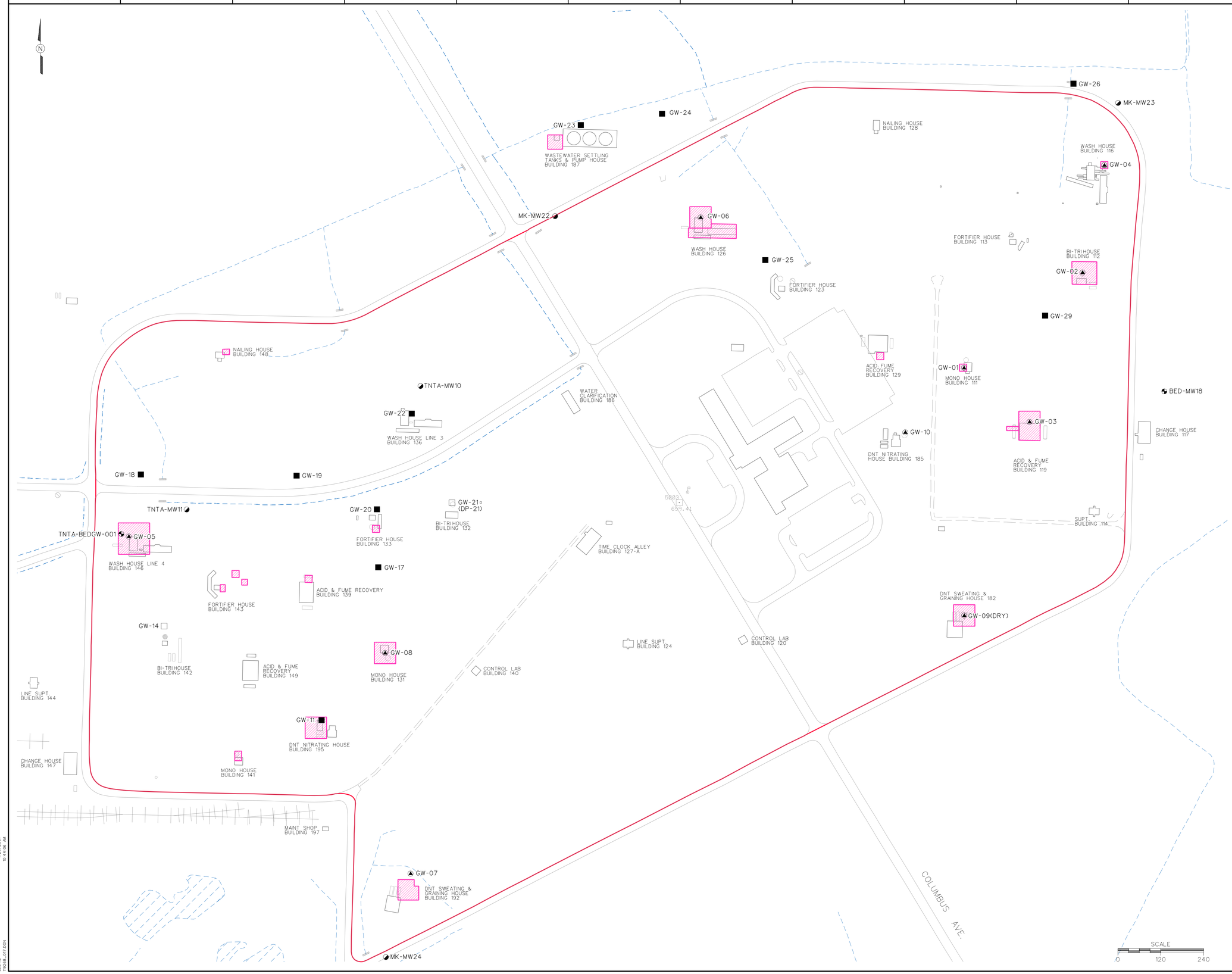

LEGEND:

- BUILDING OR STRUCTURE
- STORAGE TANK
- RAILROAD
- SURFACE DRAINAGE
- SURFACE WATER
- OVERBURDEN/SHALE MONITORING WELL LOCATION
- BEDROCK MONITORING WELL LOCATION
- 2000 GROUNDWATER SAMPLING LOCATION
- 2001 DIRECT-PUSH GROUNDWATER SAMPLING LOCATION
- 2001 DIRECT-PUSH GROUNDWATER SAMPLING LOCATION (DRILLED TO REFUSAL, NO GROUNDWATER ENCOUNTERED)
- AREA OF CONCERN
- PLANNED NITROAROMATIC/PBC SOIL REMEDIATION AREA

NO	DATE	REVISION	BY	CHKD	DSGN ENGR	ENGR	PROJ MGR	APPR

STARTING DATE 01/24/07 | INITIATOR T. SIARD | CHKD | DRAWN D. BOMAR | CHKD | PROJECT MNGR S. DOWNEY

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GROUNDWATER FEASIBILITY STUDY
TNT AND RED WATER POND AREAS
FORMER PLUM BROOK ORDNANCE WORKS
NASA PLUM BROOK STATION
SANDUSKY, OHIO

FIGURE 1-10
PREVIOUSLY IDENTIFIED AREAS
REQUIRING SOIL REMEDIATION IN TNT AREA A

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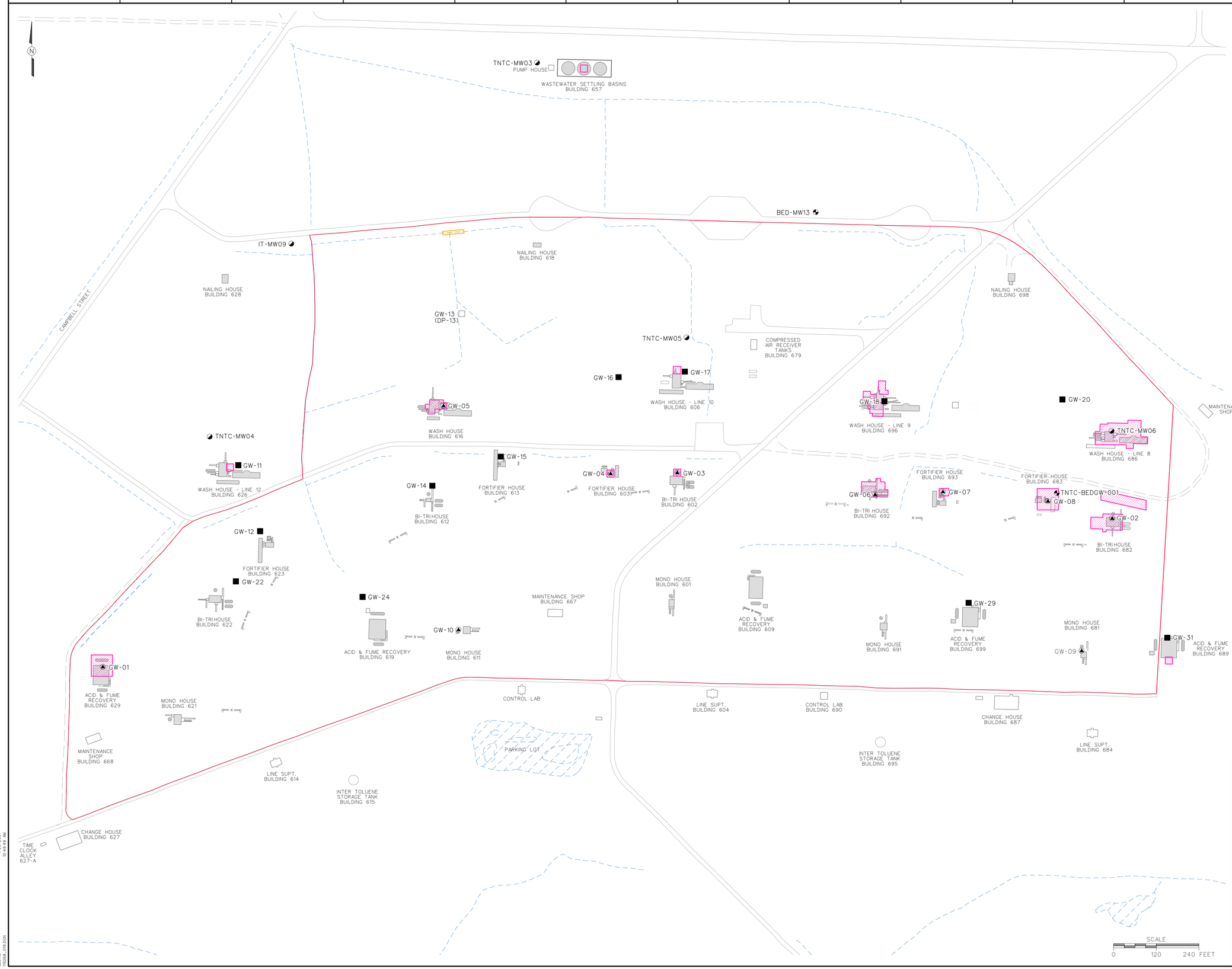

LEGEND:

- FORMER BUILDING OR STRUCTURE
- FORMER STORAGE TANK
- SURFACE DRAINAGE
- SURFACE WATER
- OVERBURDEN/SHALE MONITORING WELL LOCATION
- BEDROCK MONITORING WELL LOCATION
- 2000 GROUNDWATER SAMPLING LOCATION
- 2001 DIRECT-PUSH GROUNDWATER SAMPLING LOCATION
- 2001 DIRECT-PUSH GROUNDWATER SAMPLING LOCATION (DRILLED TO REFUSAL, NO GROUNDWATER ENCOUNTERED)
- AREA OF CONCERN
- PLANNED NITROAROMATIC/PAH/PBC SOIL REMEDIATION AREA
- PLANNED NITROAROMATIC SEDIMENT REMEDIATION AREA

NO	DATE	REVISION	BY	CHKD	DSGN ENGR	ENGR	PROJ MGR	APPR

STARTING DATE	INITIATOR	CHKD	DRAWN	CHKD	PROJECT MNGR
01/24/07	T. SIARD		D. BOMAR		S. DOWNEY

Shaw® Shaw Environmental, Inc.
KNOXVILLE, TENNESSEE

GROUNDWATER FEASIBILITY STUDY
TNT AND RED WATER POND AREAS
FORMER PLUM BROOK ORDNANCE WORKS
NASA PLUM BROOK STATION
SANDUSKY, OHIO

FIGURE 1-11
PREVIOUSLY IDENTIFIED AREAS
REQUIRING SOIL REMEDIATION IN TNT AREA C

AREA	JOB NO.	DRAWING NO.	REV
SITEWIDE	119268	119268_019.DGN	

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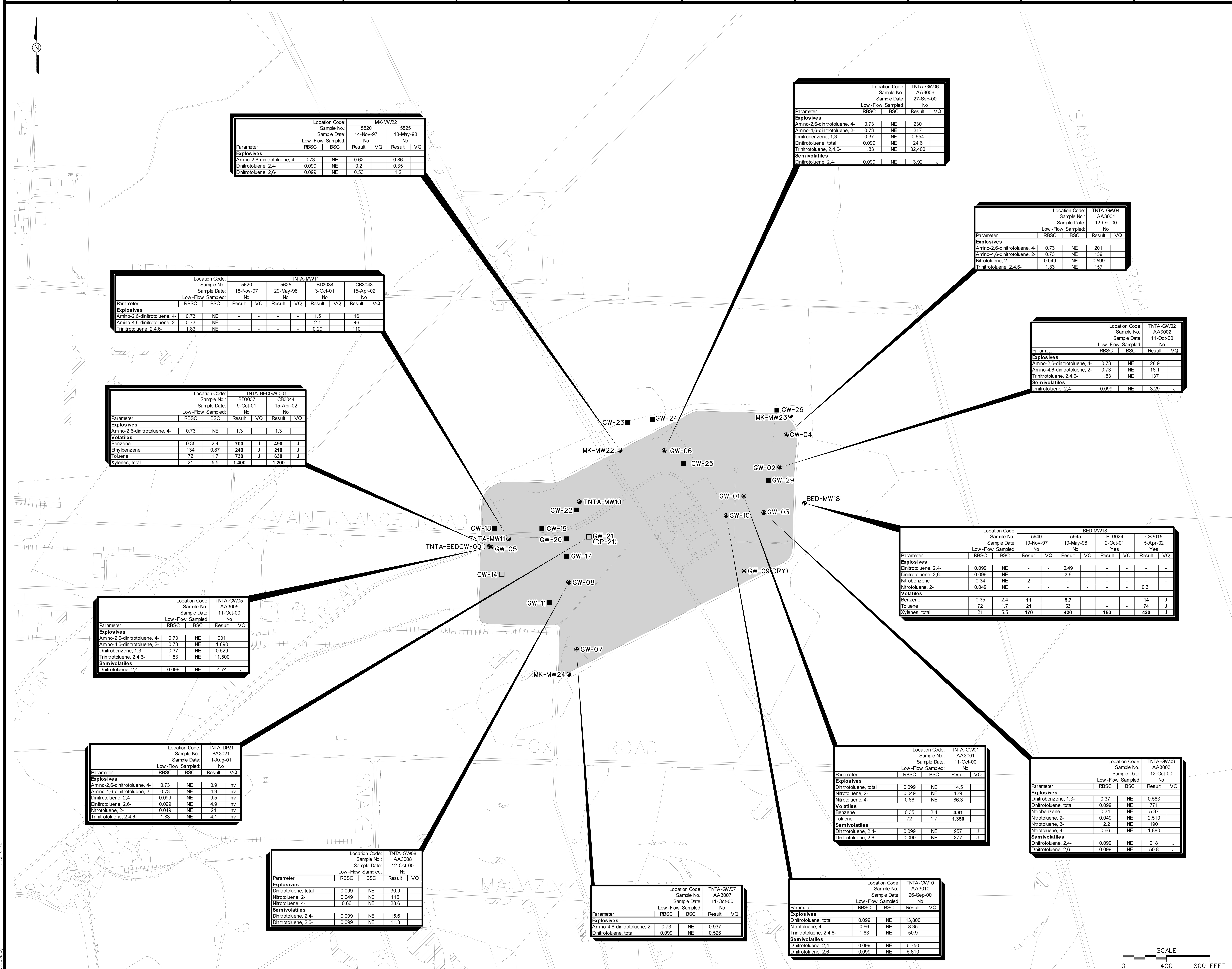


Location Code:			MK-MW22			
Sample No.:			5820		5825	
Sample Date:			14-Nov-97		18-May-98	
Low-Flow Sampled:			No		No	
Parameter	RBSC	BSC	Result	VQ	Result	VQ
Explosives						
Amino-2,6-dinitrotoluene, 4-	0.73	NE	0.62		0.86	
Dinitrotoluene, 2,4-	0.099	NE	0.2		0.35	
Dinitrotoluene, 2,6-	0.099	NE	0.53		1.2	

Location Code:			TNTA-MW11							
Sample No.:			5620		5625		BD3034		CB3043	
Sample Date:			18-Nov-97		29-May-98		3-Oct-01		15-Apr-02	
Low-Flow Sampled:			No		No		No		No	
Parameter	RBSC	BSC	Result	VQ	Result	VQ	Result	VQ	Result	VQ
Explosives										
Amino-2,6-dinitrotoluene, 4-	0.73	NE	-	-	-	-	1.5		16	
Amino-4,6-dinitrotoluene, 2-	0.73	NE					2.1		46	
Trinitrotoluene, 2,4,6-	1.83	NE	-	-	-	-	0.29		110	

Location Code:			TNTA-BEDGW-001			
Sample No.:			BD3037		CB3044	
Sample Date:			9-Oct-01		15-Apr-02	
Low-Flow Sampled:			No		No	
Parameter	RBSC	BSC	Result	VQ	Result	VQ
Explosives						
Amino-2,6-dinitrotoluene, 4-	0.73	NE	1.3		1.3	
Volatiles						
Benzene	0.35	2.4	**700**	J	**490**	J
Ethylbenzene	134	0.87	**240**	J	**210**	J
Toluene	72	1.7	**730**	J	**630**	J
Xylenes, total	21	5.5	**1,400**		**1,200**	

Location Code:			TNTA-GW06	
Sample No.:			AA3006	
Sample Date:			27-Sep-00	
Low-Flow Sampled:			No	
Parameter	RBSC	BSC	Result	VQ
Explosives				
Amino-2,6-dinitrotoluene, 4-	0.73	NE	230	
Amino-4,6-dinitrotoluene, 2-	0.73	NE	217	
Dinitrobenzene, 1,3-	0.37	NE	0.654	
Dinitrotoluene, total	0.099	NE	24.6	
Trinitrotoluene, 2,4,6-	1.83	NE	32,400	
Semivolatiles				
Dinitrotoluene, 2,4-	0.099	NE	3.92	J

Location Code:			TNTA-GW04	
Sample No.:			AA3004	
Sample Date:			12-Oct-00	
Low-Flow Sampled:			No	
Parameter	RBSC	BSC	Result	VQ
Explosives				
Amino-2,6-dinitrotoluene, 4-	0.73	NE	201	
Amino-4,6-dinitrotoluene, 2-	0.73	NE	139	
Nitrotoluene, 2-	0.049	NE	0.599	
Trinitrotoluene, 2,4,6-	1.83	NE	157	

Location Code:			TNTA-GW02	
Sample No.:			AA3002	
Sample Date:			11-Oct-00	
Low-Flow Sampled:			No	
Parameter	RBSC	BSC	Result	VQ
Explosives				
Amino-2,6-dinitrotoluene, 4-	0.73	NE	28.9	
Amino-4,6-dinitrotoluene, 2-	0.73	NE	16.1	
Trinitrotoluene, 2,4,6-	1.83	NE	137	
Semivolatiles				
Dinitrotoluene, 2,4-	0.099	NE	3.29	J

Location Code:			BED-MW18							
Sample No.:			5940		5945		BD3024		CB3015	
Sample Date:			19-Nov-97		19-May-98		2-Oct-01		5-Apr-02	
Low-Flow Sampled:			No		No		Yes		Yes	
Parameter	RBSC	BSC	Result	VQ	Result	VQ	Result	VQ	Result	VQ
Explosives										
Dinitrotoluene, 2,4-	0.099	NE	-	-	0.49		-	-	-	-
Dinitrotoluene, 2,6-	0.099	NE	-	-	3.6		-	-	-	-
Nitrobenzene	0.34	NE	2		-	-	-	-	-	-
Nitrotoluene, 2-	0.049	NE	-	-	-	-	-	-	0.31	
Volatiles										
Benzene	0.35	2.4	**11**		**5.7**		-	-	**14**	J
Toluene	72	1.7	**21**		**53**		-	-	**74**	J
Xylenes, total	21	5.5	**170**		**420**		**150**		**420**	J

Location Code:			TNTA-GW05	
Sample No.:			AA3005	
Sample Date:			11-Oct-00	
Low-Flow Sampled:			No	
Parameter	RBSC	BSC	Result	VQ
Explosives				
Amino-2,6-dinitrotoluene, 4-	0.73	NE	931	
Amino-4,6-dinitrotoluene, 2-	0.73	NE	1,890	
Dinitrobenzene, 1,3-	0.37	NE	0.529	
Trinitrotoluene, 2,4,6-	1.83	NE	11,500	
Semivolatiles				
Dinitrotoluene, 2,4-	0.099	NE	4.74	J

Location Code:			TNTA-DP21	
Sample No.:			BA3021	
Sample Date:			1-Aug-01	
Low-Flow Sampled:			No	
Parameter	RBSC	BSC	Result	VQ
Explosives				
Amino-2,6-dinitrotoluene, 4-	0.73	NE	3.9	nv
Amino-4,6-dinitrotoluene, 2-	0.73	NE	4.3	nv
Dinitrotoluene, 2,4-	0.099	NE	9.5	nv
Dinitrotoluene, 2,6-	0.099	NE	4.9	nv
Nitrotoluene, 2-	0.049	NE	24	nv
Trinitrotoluene, 2,4,6-	1.83	NE	4.1	nv

Location Code:			TNTA-GW08	
Sample No.:			AA3008	
Sample Date:			12-Oct-00	
Low-Flow Sampled:			No	
Parameter	RBSC	BSC	Result	VQ
Explosives				
Dinitrotoluene, total	0.099	NE	30.9	
Nitrotoluene, 2-	0.049	NE	115	
Nitrotoluene, 4-	0.66	NE	28.6	
Semivolatiles				
Dinitrotoluene, 2,4-	0.099	NE	15.6	
Dinitrotoluene, 2,6-	0.099	NE	11.8	

Location Code:			TNTA-GW07	
Sample No.:			AA3007	
Sample Date:			11-Oct-00	
Low-Flow Sampled:			No	
Parameter	RBSC	BSC	Result	VQ
Explosives				
Amino-4,6-dinitrotoluene, 2-	0.73	NE	0.937	
Dinitrotoluene, total	0.099	NE	0.526	

Location Code:			TNTA-GW10	
Sample No.:			AA3010	
Sample Date:			26-Sep-00	
Low-Flow Sampled:			No	
Parameter	RBSC	BSC	Result	VQ
Explosives				
Dinitrotoluene, total	0.099	NE	13,800	
Nitrotoluene, 4-	0.66	NE	8.35	
Trinitrotoluene, 2,4,6-	1.83	NE	50.9	
Semivolatiles				
Dinitrotoluene, 2,4-	0.099	NE	5,750	
Dinitrotoluene, 2,6-	0.099	NE	5,610	

Location Code:			TNTA-GW01	
Sample No.:			AA3001	
Sample Date:			11-Oct-00	
Low-Flow Sampled:			No	
Parameter	RBSC	BSC	Result	VQ
Explosives				
Dinitrotoluene, total	0.099	NE	14.5	
Nitrotoluene, 2-	0.049	NE	129	
Nitrotoluene, 4-	0.66	NE	86.3	
Volatiles				
Benzene	0.35	2.4	**4.81**	
Toluene	72	1.7	**1,350**	
Semivolatiles				
Dinitrotoluene, 2,4-	0.099	NE	957	J
Dinitrotoluene, 2,6-	0.099	NE	377	J

Location Code:			TNTA-GW03	
Sample No.:			AA3003	
Sample Date:			12-Oct-00	
Low-Flow Sampled:			No	
Parameter	RBSC	BSC	Result	VQ
Explosives				
Dinitrobenzene, 1,3-	0.37	NE	0.563	
Dinitrotoluene, total	0.099	NE	771	
Nitrobenzene	0.34	NE	5.37	
Nitrotoluene, 2-	0.049	NE	2,510	
Nitrotoluene, 3-	12.2	NE	190	
Nitrotoluene, 4-	0.66	NE	1,880	
Semivolatiles				
Dinitrotoluene, 2,4-	0.099	NE	218	J
Dinitrotoluene, 2,6-	0.099	NE	50.8	J

LEGEND:

- RAILROAD
- SURFACE DRAINAGE
- SURFACE WATER
- OVERBURDEN/SHALE MONITORING WELL LOCATION
- BEDROCK MONITORING WELL LOCATION
- 2000 GROUNDWATER PIEZOMETER LOCATION
- 2001 DIRECT-PUSH GROUNDWATER SAMPLING LOCATION
- 2001 DIRECT-PUSH GROUNDWATER SAMPLING LOCATION (DRILLED TO REFUSAL, NO GROUNDWATER ENCOUNTERED)
- AOC TNTA

NOTES:

1. ALL UNITS ARE IN MICROGRAMS PER LITER (ug/L).
2. RBSC VALUES REFLECT AN INCREMENTAL LIFETIME CANCER RISK (ILCR) OF 1E-6 OR A NONCANCER HAZARD QUOTIENT (HQ) OF 0.1 FOR CHEMICALS THAT EXHIBIT BOTH CANCER AND NONCANCER EFFECTS, WHICHEVER TYPE OF EFFECT RESULTS IN A LOWER CONCENTRATION (USING AN ILCR OF 1E-6 AND AN HQ OF 0.1), THAT CONCENTRATION IS SELECTED AS THE RBSC.
3. ONLY RESULTS OF ANALYTES THAT EXCEED RBSC IN AT LEAST ONE SAMPLE FROM EACH LOCATION SHOWN.
4. "-" ANALYTE WAS NOT DETECTED IN THIS SAMPLE.
5. BSC - BACKGROUND SCREENING CONCENTRATION.
6. NE - NOT EVALUATED FOR BSC.
7. BOLD TEXT INDICATES VALUE IS GREATER THAN BSC.
8. VALIDATION QUALIFIERS (VQ):
   - J - THE COMPOUND WAS POSITIVELY IDENTIFIED; THE REPORTED VALUE IS AN ESTIMATED CONCENTRATION.
   - nv - NOT VALIDATED

NO	DATE	REVISION	BY	CHKD	DSGN ENGR	ENGR	PROJ MGR	APPR

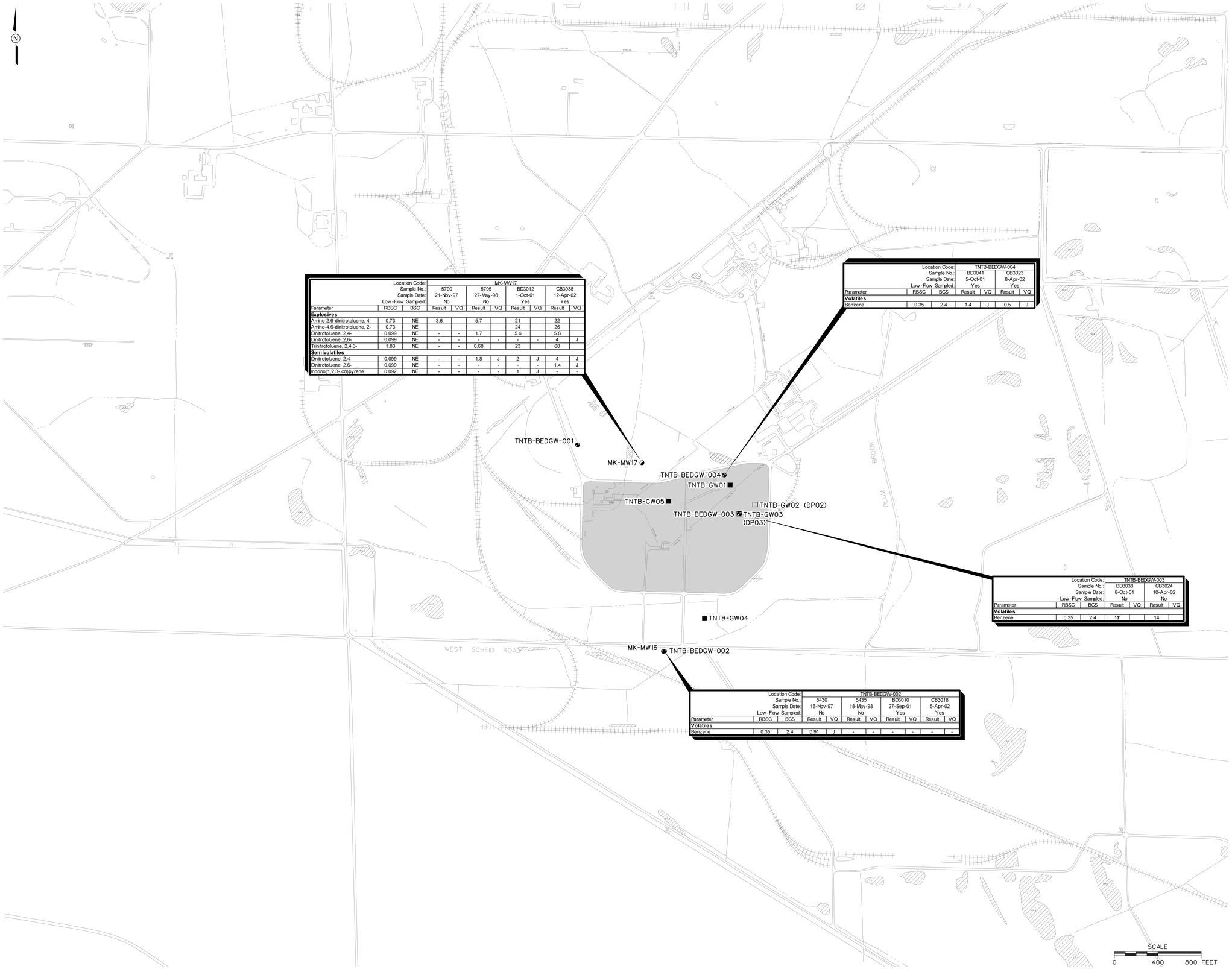
STARTING DATE 11/09/06 INITIATOR C. ANGLIN CHKD DRAWN D. BOMAR CHKD PROJECT MNGR S. DOWNEY

Shaw® Shaw Environmental, Inc.
KNOXVILLE, TENNESSEE

GROUNDWATER FEASIBILITY STUDY
TNT AND RED WATER POND AREAS
FORMER PLUM BROOK ORDNANCE WORKS
NASA PLUM BROOK STATION
SANDUSKY, OHIO

FIGURE 1-12
COMPOUNDS DETECTED AT CONCENTRATIONS EXCEEDING RBSCs IN TNTA OVERBURDEN/SHALE AND BEDROCK GROUNDWATER (NOVEMBER 1997 THROUGH APRIL 2002)

AREA	JOB NO.	DRAWING NO.	REV
SITEWIDE	119268	119268_008.DGN	



	Location Code:		MK-MW17							
	Sample No.:		5790		5795		BD3012		CB3038	
	Sample Date:		21-Nov-97		27-May-98		1-Oct-01		12-Apr-02	
	Low-Flow Sampled:		No		No		Yes		Yes	
Parameter	RBSC	BSC	Result	VQ	Result	VQ	Result	VQ	Result	VQ
Explosives										
Amino-2,6-dinitrotoluene, 4-	0.73	NE	3.6		5.7		21		22	
Amino-4,6-dinitrotoluene, 2-	0.73	NE					24		26	
Dinitrotoluene, 2,4-	0.099	NE	-	-	1.7		5.6		5.8	
Dinitrotoluene, 2,6-	0.099	NE	-	-	-	-	-	-	4	J
Trinitrotoluene, 2,4,6-	1.83	NE	-	-	0.68		23		68	
Semivolatiles										
Dinitrotoluene, 2,4-	0.099	NE	-	-	1.8	J	2	J	4	J
Dinitrotoluene, 2,6-	0.099	NE	-	-	-	-	-	-	1.4	J
Indono(1,2,3- cd)pyrene	0.092	NE	-	-	-	-	1	J	-	-

	Location Code:		TNTB-BEDGW-004			
	Sample No.:		BD3041		CB3023	
	Sample Date:		5-Oct-01		8-Apr-02	
	Low-Flow Sampled:		Yes		Yes	
Parameter	RBSC	BCS	Result	VQ	Result	VQ
Volatiles						
Benzene	0.35	2.4	1.4	J	0.5	J

	Location Code:		TNTB-BEDGW-003			
	Sample No.:		BD3038		CB3024	
	Sample Date:		8-Oct-01		10-Apr-02	
	Low-Flow Sampled:		No		No	
Parameter	RBSC	BCS	Result	VQ	Result	VQ
Volatiles						
Benzene	0.35	2.4	**17**		**14**	

	Location Code:		TNTB-BEDGW-002							
	Sample No.:		5430		5435		BD3010		CB3018	
	Sample Date:		16-Nov-97		18-May-98		27-Sep-01		5-Apr-02	
	Low-Flow Sampled:		No		No		Yes		Yes	
Parameter	RBSC	BCS	Result	VQ	Result	VQ	Result	VQ	Result	VQ
Volatiles										
Benzene	0.35	2.4	0.91	J	-	-	-	-	-	-

LEGEND:

- RAILROAD
- SURFACE DRAINAGE
- SURFACE WATER
- OVERBURDEN/SHALE MONITORING WELL LOCATION
- BEDROCK MONITORING WELL LOCATION
- 2000 GROUNDWATER PIEZOMETER LOCATION
- 2001 DIRECT-PUSH GROUNDWATER SAMPLING LOCATION
- 2001 DIRECT-PUSH GROUNDWATER SAMPLING LOCATION (DRILLED TO REFUSAL, NO GROUNDWATER ENCOUNTERED)
- AOC TNTB

NOTES:

1. ALL UNITS ARE IN MICROGRAMS PER LITER (ug/L).
2. RBSC VALUES REFLECT AN INCREMENTAL LIFETIME CANCER RISK (ILCR) OF 1E-6 OR A NONCANCER HAZARD QUOTIENT (HQ) OF 0.1 FOR CHEMICALS THAT EXHIBIT BOTH CANCER AND NONCANCER EFFECTS, WHICHEVER TYPE OF EFFECT RESULTS IN A LOWER CONCENTRATION (USING AN ILCR OF 1E-6 AND AN HQ OF 0.1), THAT CONCENTRATION IS SELECTED AS THE RBSC.
3. ONLY RESULTS OF ANALYTES THAT EXCEED RBSC IN AT LEAST ONE SAMPLE FROM EACH LOCATION SHOWN.
4. "-" ANALYTE WAS NOT DETECTED IN THIS SAMPLE.
5. BSC - BACKGROUND SCREENING CONCENTRATION.
6. NE - NOT EVALUATED FOR BSC.
7. BOLD TEXT INDICATES VALUE IS GREATER THAN BSC.
8. VALIDATION QUALIFIERS (VQ):

   J - THE COMPOUND WAS POSITIVELY IDENTIFIED; THE REPORTED VALUE IS AN ESTIMATED CONCENTRATION

NO	DATE	REVISION	BY	CHKD	DSGN DNGR	ENGR	PROJ MGR	APPR

STARTING DATE 11/20/06 | INITIATOR C. ANGLIN | CHKD | DRAWN D. BOMAR | CHKD | PROJECT MNGR S. DOWNEY

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GROUNDWATER FEASIBILITY STUDY
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FORMER PLUM BROOK ORDNANCE WORKS
NASA PLUM BROOK STATION
SANDUSKY, OHIO

FIGURE 1-13
COMPOUNDS DETECTED AT CONCENTRATIONS EXCEEDING RBSCs IN TNTB OVERBURDEN/SHALE AND BEDROCK GROUNDWATER (NOVEMBER 1997 THROUGH APRIL 2002)

AREA	JOB NO.	DRAWING NO.	REV
SITEWIDE	119268	119268_009.DGN	

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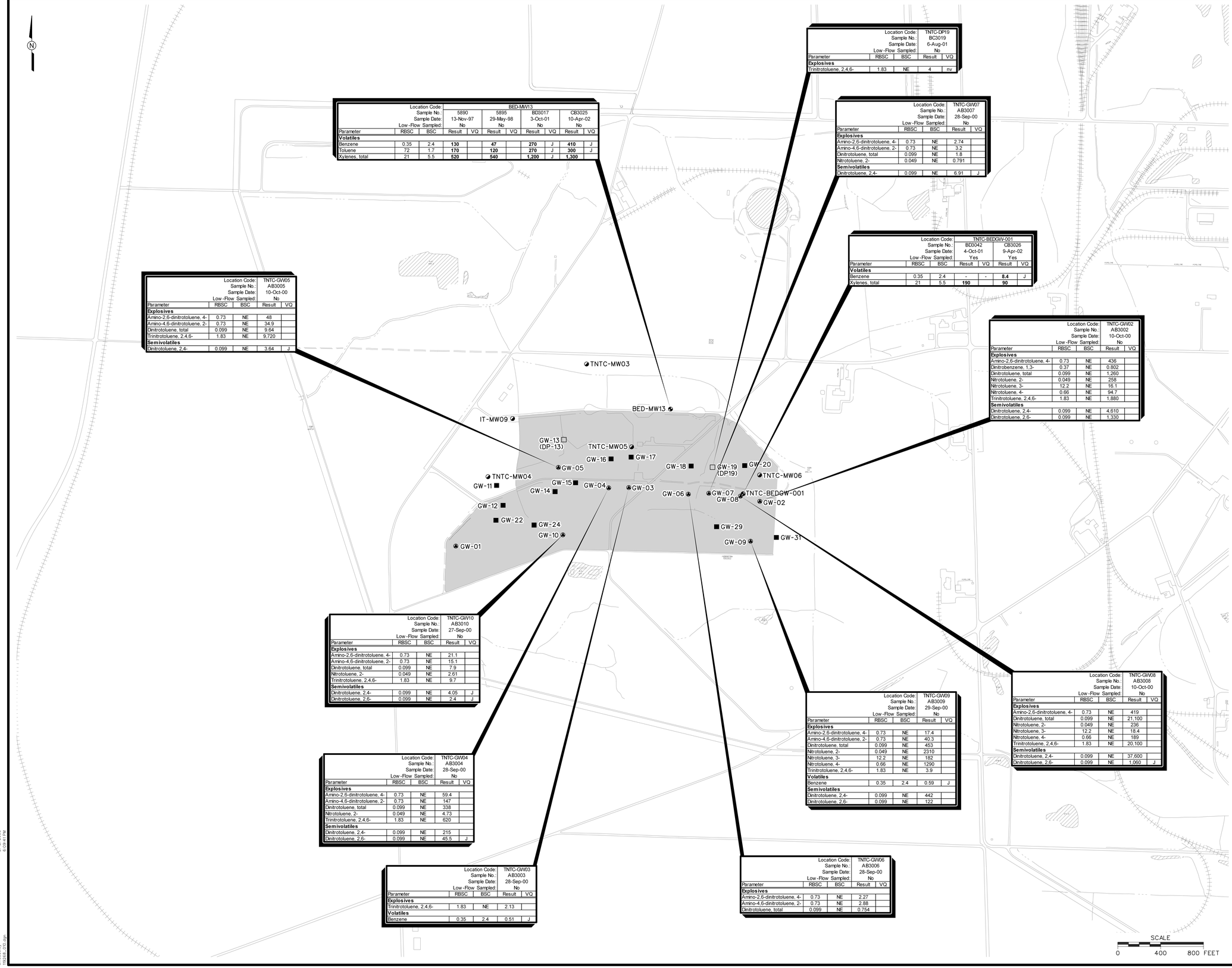

	Location Code:	TNTC-DP19		
	Sample No.:	BC3019		
	Sample Date:	6-Aug-01		
	Low-Flow Sampled:	No		
Parameter	RBSC	BSC	Result	VQ
Explosives				
Trinitrotoluene, 2,4,6-	1.83	NE	4	nv

	Location Code:	BED-MW13								
	Sample No.:	5890		5895		BD3017		CB3025		
	Sample Date:	13-Nov-97		29-May-98		3-Oct-01		10-Apr-02		
	Low-Flow Sampled:	No		No		No		No		
Parameter	RBSC	BSC	Result	VQ	Result	VQ	Result	VQ	Result	VQ
Volatiles										
Benzene	0.35	2.4	**130**		**47**		**270**	J	**410**	J
Toluene	72	1.7	**170**		**120**		**270**	J	**300**	J
Xylenes, total	21	5.5	**520**		**540**		**1,200**	J	**1,300**	

	Location Code:	TNTC-GW07			
	Sample No.:	AB3007			
	Sample Date:	28-Sep-00			
	Low-Flow Sampled:	No			
Parameter	RBSC	BSC	Result	VQ	
Explosives					
Amino-2,6-dinitrotoluene, 4-	0.73	NE	2.74		
Amino-4,6-dinitrotoluene, 2-	0.73	NE	3.2		
Dinitrotoluene, total	0.099	NE	1.8		
Nitrotoluene, 2-	0.049	NE	0.791		
Semivolatiles					
Dinitrotoluene, 2,4-	0.099	NE	6.91	J	

	Location Code:	TNTC-BEDGW-001			
	Sample No.:	BD3042		CB3026	
	Sample Date:	4-Oct-01		9-Apr-02	
	Low-Flow Sampled:	Yes		Yes	
Parameter	RBSC	BSC	Result	VQ	Result	VQ
Volatiles						
Benzene	0.35	2.4	-	-	**8.4**	J
Xylenes, total	21	5.5	**190**		**90**	

	Location Code:	TNTC-GW05		
	Sample No.:	AB3005		
	Sample Date:	10-Oct-00		
	Low-Flow Sampled:	No		
Parameter	RBSC	BSC	Result	VQ
Explosives				
Amino-2,6-dinitrotoluene, 4-	0.73	NE	48	
Amino-4,6-dinitrotoluene, 2-	0.73	NE	34.9	
Dinitrotoluene, total	0.099	NE	9.64	
Trinitrotoluene, 2,4,6-	1.83	NE	9,720	
Semivolatiles				
Dinitrotoluene, 2,4-	0.099	NE	3.64	J

	Location Code:	TNTC-GW02		
	Sample No.:	AB3002		
	Sample Date:	10-Oct-00		
	Low-Flow Sampled:	No		
Parameter	RBSC	BSC	Result	VQ
Explosives				
Amino-2,6-dinitrotoluene, 4-	0.73	NE	436	
Dinitrobenzene, 1,3-	0.37	NE	0.802	
Dinitrotoluene, total	0.099	NE	1,260	
Nitrotoluene, 2-	0.049	NE	258	
Nitrotoluene, 3-	12.2	NE	16.1	
Nitrotoluene, 4-	0.66	NE	94.7	
Trinitrotoluene, 2,4,6-	1.83	NE	1,880	
Semivolatiles				
Dinitrotoluene, 2,4-	0.099	NE	4,610	
Dinitrotoluene, 2,6-	0.099	NE	1,330	

	Location Code:	TNTC-GW10		
	Sample No.:	AB3010		
	Sample Date:	27-Sep-00		
	Low-Flow Sampled:	No		
Parameter	RBSC	BSC	Result	VQ
Explosives				
Amino-2,6-dinitrotoluene, 4-	0.73	NE	21.1	
Amino-4,6-dinitrotoluene, 2-	0.73	NE	15.1	
Dinitrotoluene, total	0.099	NE	7.9	
Nitrotoluene, 2-	0.049	NE	2.61	
Trinitrotoluene, 2,4,6-	1.83	NE	9.7	
Semivolatiles				
Dinitrotoluene, 2,4-	0.099	NE	4.05	J
Dinitrotoluene, 2,6-	0.099	NE	2.4	J

	Location Code:	TNTC-GW09		
	Sample No.:	AB3009		
	Sample Date:	29-Sep-00		
	Low-Flow Sampled:	No		
Parameter	RBSC	BSC	Result	VQ
Explosives				
Amino-2,6-dinitrotoluene, 4-	0.73	NE	17.4	
Amino-4,6-dinitrotoluene, 2-	0.73	NE	40.3	
Dinitrotoluene, total	0.099	NE	453	
Nitrotoluene, 2-	0.049	NE	2310	
Nitrotoluene, 3-	12.2	NE	182	
Nitrotoluene, 4-	0.66	NE	1290	
Trinitrotoluene, 2,4,6-	1.83	NE	3.9	
Volatiles				
Benzene	0.35	2.4	0.59	J
Semivolatiles				
Dinitrotoluene, 2,4-	0.099	NE	442	
Dinitrotoluene, 2,6-	0.099	NE	122	

	Location Code:	TNTC-GW08		
	Sample No.:	AB3008		
	Sample Date:	10-Oct-00		
	Low-Flow Sampled:	No		
Parameter	RBSC	BSC	Result	VQ
Explosives				
Amino-2,6-dinitrotoluene, 4-	0.73	NE	419	
Dinitrotoluene, total	0.099	NE	21,100	
Nitrotoluene, 2-	0.049	NE	236	
Nitrotoluene, 3-	12.2	NE	18.4	
Nitrotoluene, 4-	0.66	NE	189	
Trinitrotoluene, 2,4,6-	1.83	NE	20,100	
Semivolatiles				
Dinitrotoluene, 2,4-	0.099	NE	37,600	
Dinitrotoluene, 2,6-	0.099	NE	1,060	J

	Location Code:	TNTC-GW04		
	Sample No.:	AB3004		
	Sample Date:	28-Sep-00		
	Low-Flow Sampled:	No		
Parameter	RBSC	BSC	Result	VQ
Explosives				
Amino-2,6-dinitrotoluene, 4-	0.73	NE	59.4	
Amino-4,6-dinitrotoluene, 2-	0.73	NE	147	
Dinitrotoluene, total	0.099	NE	338	
Nitrotoluene, 2-	0.049	NE	4.73	
Trinitrotoluene, 2,4,6-	1.83	NE	620	
Semivolatiles				
Dinitrotoluene, 2,4-	0.099	NE	215	
Dinitrotoluene, 2,6-	0.099	NE	45.5	J

	Location Code:	TNTC-GW03		
	Sample No.:	AB3003		
	Sample Date:	28-Sep-00		
	Low-Flow Sampled:	No		
Parameter	RBSC	BSC	Result	VQ
Explosives				
Trinitrotoluene, 2,4,6-	1.83	NE	2.13	
Volatiles				
Benzene	0.35	2.4	0.51	J

	Location Code:	TNTC-GW06		
	Sample No.:	AB3006		
	Sample Date:	28-Sep-00		
	Low-Flow Sampled:	No		
Parameter	RBSC	BSC	Result	VQ
Explosives				
Amino-2,6-dinitrotoluene, 4-	0.73	NE	2.27	
Amino-4,6-dinitrotoluene, 2-	0.73	NE	2.88	
Dinitrotoluene, total	0.099	NE	0.754	

LEGEND:

- RAILROAD
- SURFACE DRAINAGE
- SURFACE WATER
- OVERBURDEN/SHALE MONITORING WELL LOCATION
- BEDROCK MONITORING WELL LOCATION
- 2000 GROUNDWATER PIEZOMETER LOCATION
- 2001 DIRECT-PUSH GROUNDWATER SAMPLING LOCATION
- 2001 DIRECT-PUSH GROUNDWATER SAMPLING LOCATION (DRILLED TO REFUSAL, NO GROUNDWATER ENCOUNTERED)
- AOC TNTC

NOTES:

1. ALL UNITS ARE IN MICROGRAMS PER LITER (ug/L).
2. RBSC VALUES REFLECT AN INCREMENTAL LIFETIME CANCER RISK (ILCR) OF 1E-6 OR A NONCANCER HAZARD QUOTIENT (HQ) OF 0.1 FOR CHEMICALS THAT EXHIBIT BOTH CANCER AND NONCANCER EFFECTS, WHICHEVER TYPE OF EFFECT RESULTS IN A LOWER CONCENTRATION (USING AN ILCR OF 1E-6 AND AN HQ OF 0.1), THAT CONCENTRATION IS SELECTED AS THE RBSC.
3. ONLY RESULTS OF ANALYTES THAT EXCEED RBSC IN AT LEAST ONE SAMPLE FROM EACH LOCATION SHOWN.
4. "-" ANALYTE WAS NOT DETECTED IN THIS SAMPLE.
5. BSC - BACKGROUND SCREENING CONCENTRATION.
6. NE - NOT EVALUATED FOR BSC.
7. BOLD TEXT INDICATES VALUE IS GREATER THAN BSC.
8. VALIDATION QUALIFIERS (VQ):
   - J - THE COMPOUND WAS POSITIVELY IDENTIFIED; THE REPORTED VALUE IS AN ESTIMATED CONCENTRATION.
   - nv - NOT VALIDATED

NO	DATE	REVISION	BY	CHKD	DSGN ENGR	ENGR	PROJ MGR	APPR

STARTING DATE	INITIATOR	CHKD	DRAWN	CHKD	PROJECT MNGR
11/27/06	C. ANGLIN		D. BOMAR		S. DOWNEY

Shaw® Shaw Environmental, Inc.
KNOXVILLE, TENNESSEE

GROUNDWATER FEASIBILITY STUDY
TNT AND RED WATER POND AREAS
FORMER PLUM BROOK ORDNANCE WORKS
NASA PLUM BROOK STATION
SANDUSKY, OHIO

FIGURE 1-14
COMPOUNDS DETECTED AT CONCENTRATIONS EXCEEDING RBSCs IN TNTC OVERBURDEN/SHALE AND BEDROCK GROUNDWATER (NOVEMBER 1997 THROUGH APRIL 2002)

AREA	JOB NO.	DRAWING NO.	REV
SITEWIDE	119268	119268_010.DGN	

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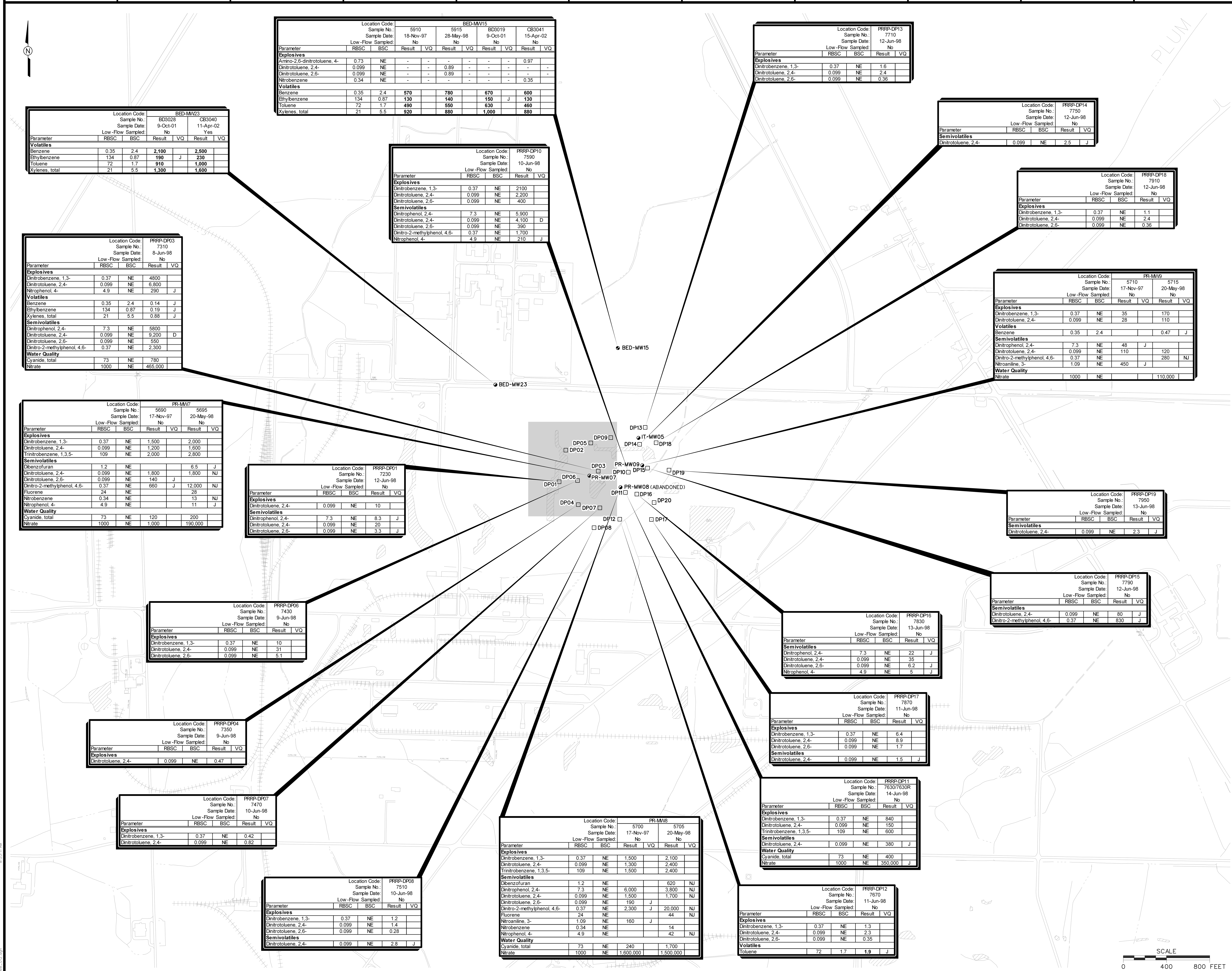
2/12/2008
3:09:41 PM

400,000 FT / IN.
smccowey
119268_010.dgn



Location Code:			BED-MW15							
Sample No.:			5910		5915		BD3019		CB3041	
Sample Date:			18-Nov-97		28-May-98		9-Oct-01		15-Apr-02	
Low-Flow Sampled:			No		No		No		No	
Parameter	RBSC	BSC	Result	VQ	Result	VQ	Result	VQ	Result	VQ
Explosives										
Amino-2,6-dinitrotoluene, 4-	0.73	NE	-	-	-	-	-	-	0.97	
Dinitrotoluene, 2,4-	0.099	NE	-	-	0.89	-	-	-	-	-
Dinitrotoluene, 2,6-	0.099	NE	-	-	0.89	-	-	-	-	-
Nitrobenzene	0.34	NE	-	-	-	-	-	-	0.35	
Volatiles										
Benzene	0.35	2.4	**570**		**780**		**670**		**600**	
Ethylbenzene	134	0.87	**130**		**140**		**150**	J	**130**	
Toluene	72	1.7	**490**		**550**		**630**		**460**	
Xylenes, total	21	5.5	**920**		**880**		**1,000**		**880**	

Location Code:			BED-MW23			
Sample No.:			BD3028		CB3040	
Sample Date:			9-Oct-01		11-Apr-02	
Low-Flow Sampled:			No		Yes	
Parameter	RBSC	BSC	Result	VQ	Result	VQ
Volatiles						
Benzene	0.35	2.4	**2,100**		**2,500**	
Ethylbenzene	134	0.87	**190**	J	**230**	
Toluene	72	1.7	**910**		**1,000**	
Xylenes, total	21	5.5	**1,300**		**1,600**	

Location Code:			PRRP-DP10	
Sample No.:			7590	
Sample Date:			10-Jun-98	
Low-Flow Sampled:			No	
Parameter	RBSC	BSC	Result	VQ
Explosives				
Dinitrobenzene, 1,3-	0.37	NE	2100	
Dinitrotoluene, 2,4-	0.099	NE	2,200	
Dinitrotoluene, 2,6-	0.099	NE	400	
Semivolatiles				
Dinitrophenol, 2,4-	7.3	NE	5,900	
Dinitrotoluene, 2,4-	0.099	NE	4,100	D
Dinitrotoluene, 2,6-	0.099	NE	390	
Dinitro-2-methylphenol, 4,6-	0.37	NE	1,700	
Nitrophenol, 4-	4.9	NE	210	J

Location Code:			PRRP-DP13	
Sample No.:			7710	
Sample Date:			12-Jun-98	
Low-Flow Sampled:			No	
Parameter	RBSC	BSC	Result	VQ
Explosives				
Dinitrobenzene, 1,3-	0.37	NE	1.6	
Dinitrotoluene, 2,4-	0.099	NE	2.4	
Dinitrotoluene, 2,6-	0.099	NE	0.36	

Location Code:			PRRP-DP14	
Sample No.:			7750	
Sample Date:			12-Jun-98	
Low-Flow Sampled:			No	
Parameter	RBSC	BSC	Result	VQ
Semivolatiles				
Dinitrotoluene, 2,4-	0.099	NE	2.5	J

Location Code:			PRRP-DP18	
Sample No.:			7910	
Sample Date:			12-Jun-98	
Low-Flow Sampled:			No	
Parameter	RBSC	BSC	Result	VQ
Explosives				
Dinitrobenzene, 1,3-	0.37	NE	1.1	
Dinitrotoluene, 2,4-	0.099	NE	2.4	
Dinitrotoluene, 2,6-	0.099	NE	0.36	

Location Code:			PRRP-DP03	
Sample No.:			7310	
Sample Date:			8-Jun-98	
Low-Flow Sampled:			No	
Parameter	RBSC	BSC	Result	VQ
Explosives				
Dinitrobenzene, 1,3-	0.37	NE	4800	
Dinitrotoluene, 2,4-	0.099	NE	6,800	
Nitrophenol, 4-	4.9	NE	290	J
Volatiles				
Benzene	0.35	2.4	0.14	J
Ethylbenzene	134	0.87	0.19	J
Xylenes, total	21	5.5	0.88	J
Semivolatiles				
Dinitrophenol, 2,4-	7.3	NE	5800	
Dinitrotoluene, 2,4-	0.099	NE	9,200	D
Dinitrotoluene, 2,6-	0.099	NE	550	
Dinitro-2-methylphenol, 4,6-	0.37	NE	2,300	
Water Quality				
Cyanide, total	73	NE	780	
Nitrate	1000	NE	465,000	

Location Code:			PR-MW9			
Sample No.:			5710		5715	
Sample Date:			17-Nov-97		20-May-98	
Low-Flow Sampled:			No		No	
Parameter	RBSC	BSC	Result	VQ	Result	VQ
Explosives						
Dinitrobenzene, 1,3-	0.37	NE	35		170	
Dinitrotoluene, 2,4-	0.099	NE	28		110	
Volatiles						
Benzene	0.35	2.4			0.47	J
Semivolatiles						
Dinitrophenol, 2,4-	7.3	NE	48	J		
Dinitrotoluene, 2,4-	0.099	NE	110		120	
Dinitro-2-methylphenol, 4,6-	0.37	NE			280	NJ
Nitroaniline, 3-	1.09	NE	450	J		
Water Quality						
Nitrate	1000	NE			110,000	

Location Code:			PR-MW7			
Sample No.:			5690		5695	
Sample Date:			17-Nov-97		20-May-98	
Low-Flow Sampled:			No		No	
Parameter	RBSC	BSC	Result	VQ	Result	VQ
Explosives						
Dinitrobenzene, 1,3-	0.37	NE	1,500		2,000	
Dinitrotoluene, 2,4-	0.099	NE	1,200		1,600	
Trinitrobenzene, 1,3,5-	109	NE	2,000		2,800	
Semivolatiles						
Dibenzofuran	1.2	NE			6.5	J
Dinitrotoluene, 2,4-	0.099	NE	1,800		1,800	NJ
Dinitrotoluene, 2,6-	0.099	NE	140	J		
Dinitro-2-methylphenol, 4,6-	0.37	NE	660	J	12,000	NJ
Fluorene	24	NE			28	
Nitrobenzene	0.34	NE			13	NJ
Nitrophenol, 4-	4.9	NE			11	J
Water Quality						
Cyanide, total	73	NE	120		200	
Nitrate	1000	NE	1,000		190,000	

Location Code:			PRRP-DP01	
Sample No.:			7230	
Sample Date:			12-Jun-98	
Low-Flow Sampled:			No	
Parameter	RBSC	BSC	Result	VQ
Explosives				
Dinitrotoluene, 2,4-	0.099	NE	10	
Semivolatiles				
Dinitrophenol, 2,4-	7.3	NE	8.3	J
Dinitrotoluene, 2,4-	0.099	NE	20	
Dinitrotoluene, 2,6-	0.099	NE	3.3	J

Location Code:			PRRP-DP19	
Sample No.:			7950	
Sample Date:			13-Jun-98	
Low-Flow Sampled:			No	
Parameter	RBSC	BSC	Result	VQ
Semivolatiles				
Dinitrotoluene, 2,4-	0.099	NE	2.3	J

Location Code:			PRRP-DP15	
Sample No.:			7790	
Sample Date:			12-Jun-98	
Low-Flow Sampled:			No	
Parameter	RBSC	BSC	Result	VQ
Semivolatiles				
Dinitrotoluene, 2,4-	0.099	NE	80	J
Dinitro-2-methylphenol, 4,6-	0.37	NE	830	J

Location Code:			PRRP-DP06	
Sample No.:			7430	
Sample Date:			9-Jun-98	
Low-Flow Sampled:			No	
Parameter	RBSC	BSC	Result	VQ
Explosives				
Dinitrobenzene, 1,3-	0.37	NE	10	
Dinitrotoluene, 2,4-	0.099	NE	31	
Dinitrotoluene, 2,6-	0.099	NE	5.1	

Location Code:			PRRP-DP16	
Sample No.:			7830	
Sample Date:			13-Jun-98	
Low-Flow Sampled:			No	
Parameter	RBSC	BSC	Result	VQ
Semivolatiles				
Dinitrophenol, 2,4-	7.3	NE	22	J
Dinitrotoluene, 2,4-	0.099	NE	35	
Dinitrotoluene, 2,6-	0.099	NE	6.2	J
Nitrophenol, 4-	4.9	NE	5	J

Location Code:			PRRP-DP17	
Sample No.:			7870	
Sample Date:			11-Jun-98	
Low-Flow Sampled:			No	
Parameter	RBSC	BSC	Result	VQ
Explosives				
Dinitrobenzene, 1,3-	0.37	NE	6.4	
Dinitrotoluene, 2,4-	0.099	NE	8.9	
Dinitrotoluene, 2,6-	0.099	NE	1.7	
Semivolatiles				
Dinitrotoluene, 2,4-	0.099	NE	1.5	J

Location Code:			PRRP-DP04	
Sample No.:			7350	
Sample Date:			9-Jun-98	
Low-Flow Sampled:			No	
Parameter	RBSC	BSC	Result	VQ
Explosives				
Dinitrotoluene, 2,4-	0.099	NE	0.47	

Location Code:			PRRP-DP11	
Sample No.:			7630/7630R	
Sample Date:			14-Jun-98	
Low-Flow Sampled:			No	
Parameter	RBSC	BSC	Result	VQ
Explosives				
Dinitrobenzene, 1,3-	0.37	NE	840	
Dinitrotoluene, 2,4-	0.099	NE	150	
Trinitrobenzene, 1,3,5-	109	NE	600	
Semivolatiles				
Dinitrotoluene, 2,4-	0.099	NE	380	J
Water Quality				
Cyanide, total	73	NE	400	
Nitrate	1000	NE	350,000	J

Location Code:			PRRP-DP07	
Sample No.:			7470	
Sample Date:			10-Jun-98	
Low-Flow Sampled:			No	
Parameter	RBSC	BSC	Result	VQ
Explosives				
Dinitrobenzene, 1,3-	0.37	NE	0.42	
Dinitrotoluene, 2,4-	0.099	NE	0.82	

Location Code:			PR-MW8			
Sample No.:			5700		5705	
Sample Date:			17-Nov-97		20-May-98	
Low-Flow Sampled:			No		No	
Parameter	RBSC	BSC	Result	VQ	Result	VQ
Explosives						
Dinitrobenzene, 1,3-	0.37	NE	1,500		2,100	
Dinitrotoluene, 2,4-	0.099	NE	1,300		2,400	
Trinitrobenzene, 1,3,5-	109	NE	1,500		2,400	
Semivolatiles						
Dibenzofuran	1.2	NE			620	NJ
Dinitrophenol, 2,4-	7.3	NE	6,000		3,800	NJ
Dinitrotoluene, 2,4-	0.099	NE	1,500		1,700	NJ
Dinitrotoluene, 2,6-	0.099	NE	190	J		
Dinitro-2-methylphenol, 4,6-	0.37	NE	2,300	J	20,000	NJ
Fluorene	24	NE			44	NJ
Nitroaniline, 3-	1.09	NE	160	J		
Nitrobenzene	0.34	NE			14	
Nitrophenol, 4-	4.9	NE			42	NJ
Water Quality						
Cyanide, total	73	NE	240		1,700	
Nitrate	1000	NE	1,600,000		1,500,000	

Location Code:			PRRP-DP08	
Sample No.:			7510	
Sample Date:			10-Jun-98	
Low-Flow Sampled:			No	
Parameter	RBSC	BSC	Result	VQ
Explosives				
Dinitrobenzene, 1,3-	0.37	NE	1.2	
Dinitrotoluene, 2,4-	0.099	NE	1.4	
Dinitrotoluene, 2,6-	0.099	NE	0.28	
Semivolatiles				
Dinitrotoluene, 2,4-	0.099	NE	2.8	J

Location Code:			PRRP-DP12	
Sample No.:			7670	
Sample Date:			11-Jun-98	
Low-Flow Sampled:			No	
Parameter	RBSC	BSC	Result	VQ
Explosives				
Dinitrobenzene, 1,3-	0.37	NE	1.3	
Dinitrotoluene, 2,4-	0.099	NE	2.3	
Dinitrotoluene, 2,6-	0.099	NE	0.35	
Volatiles				
Toluene	72	1.7	**1.9**	J

SCALE

0 400 800 FEET

LEGEND:

- RAILROAD
- SURFACE DRAINAGE
- SURFACE WATER
- OVERBURDEN/SHALE MONITORING WELL LOCATION
- BEDROCK MONITORING WELL LOCATION
- DIRECT-PUSH GROUNDWATER SAMPLING LOCATION
- AOC PRRWP

NOTES:

1. ALL UNITS ARE IN MICROGRAMS PER LITER (ug/L).
2. RBSC VALUES REFLECT AN INCREMENTAL LIFETIME CANCER RISK (ILCR) OF 1E-6 OR A NONCANCER HAZARD QUOTIENT (HQ) OF 0.1 FOR CHEMICALS THAT EXHIBIT BOTH CANCER AND NONCANCER EFFECTS, WHICHEVER TYPE OF EFFECT RESULTS IN A LOWER CONCENTRATION (USING AN ILCR OF 1E-6 AND AN HQ OF 0.1), THAT CONCENTRATION IS SELECTED AS THE RBSC.
3. ONLY RESULTS OF ANALYTES THAT EXCEED RBSC IN AT LEAST ONE SAMPLE FROM EACH LOCATION SHOWN.
4. "-" ANALYTE WAS NOT DETECTED IN THIS SAMPLE.
5. BSC - BACKGROUND SCREENING CONCENTRATION.
6. NE - NOT EVALUATED FOR BSC.
7. BOLD TEXT INDICATES VALUE IS GREATER THAN BSC.
8. VALIDATION QUALIFIERS (VQ):
   - D - DILUTION REQUIRED
   - J - THE COMPOUND WAS POSITIVELY IDENTIFIED; THE REPORTED VALUE IS AN ESTIMATED CONCENTRATION.
   - NJ - THE ANALYTE WAS ONLY TENTATIVELY IDENTIFIED;THE REPORTED VALUE IS AN ESTIMATED CONCENTRATION
   - nv - NOT VALIDATED

NO	DATE	REVISION	BY	CHKD	DSGN ENGR	ENGR	PROJ MGR	APPR

STARTING DATE 11/27/06 | INITIATOR C. ANGLIN | CHKD | DRAWN D. BOMAR | CHKD | PROJECT MNGR S. DOWNEY

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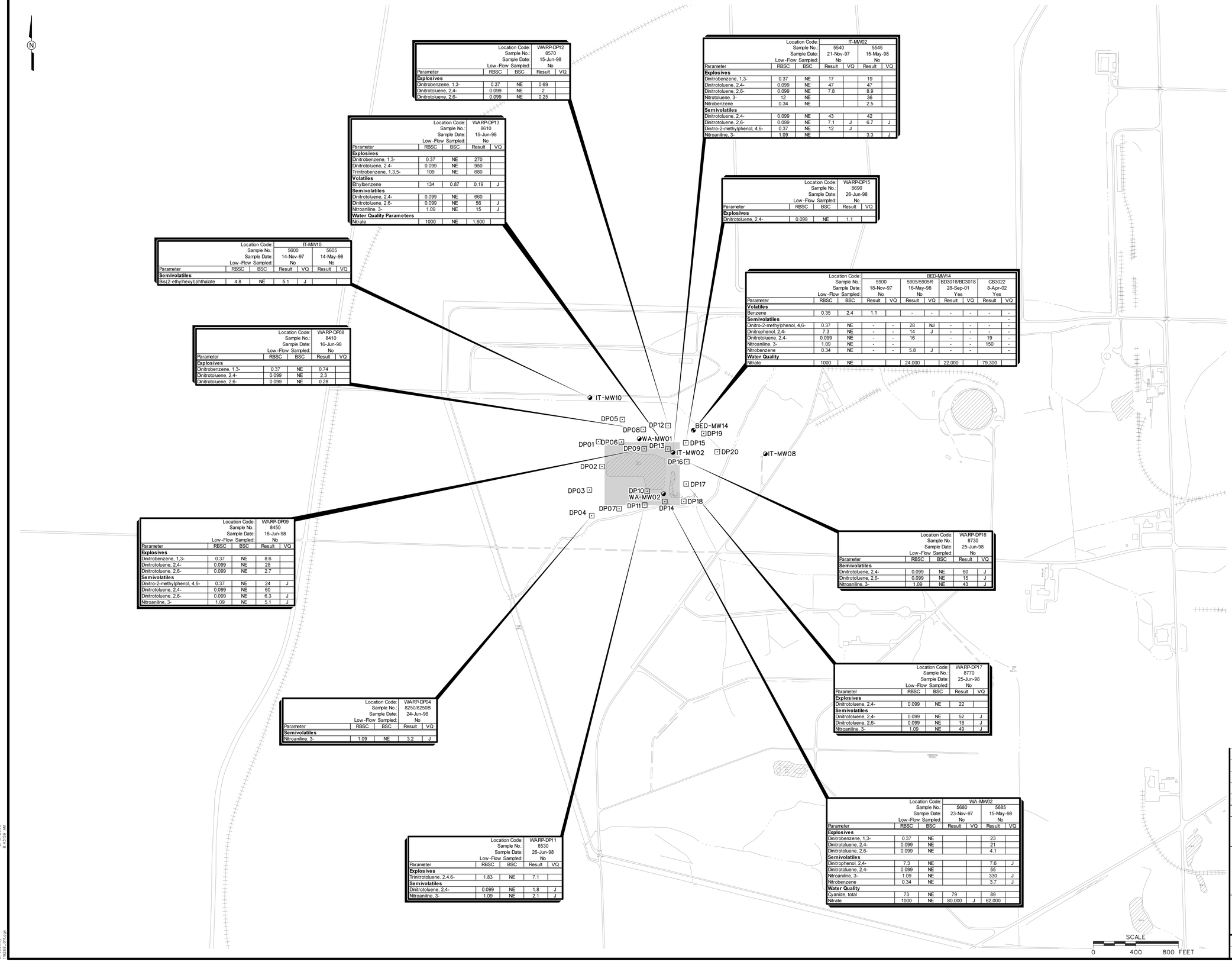
KNOXVILLE, TENNESSEE

GROUNDWATER FEASIBILITY STUDY
TNT AND RED WATER POND AREAS
FORMER PLUM BROOK ORDNANCE WORKS
NASA PLUM BROOK STATION
SANDUSKY, OHIO

FIGURE 1-15
COMPOUNDS DETECTED AT CONCENTRATIONS EXCEEDING RBSCs IN PENTOLITE ROAD RED WATER POND OVERBURDEN/SHALE AND BEDROCK GROUNDWATER (JUNE 1998)

AREA	JOB NO.	DRAWING NO.	REV
SITEWIDE	119268	119268_012.DGN	



	Location Code:	WARP-DP12
	Sample No.:	8570
	Sample Date:	15-Jun-98
	Low-Flow Sampled:	No

Parameter	RBSC	BSC	Result	VQ
Explosives				
Dinitrobenzene, 1,3-	0.37	NE	0.69	
Dinitrotoluene, 2,4-	0.099	NE	2	
Dinitrotoluene, 2,6-	0.099	NE	0.25	

	Location Code:	WARP-DP13
	Sample No.:	8610
	Sample Date:	15-Jun-98
	Low-Flow Sampled:	No

Parameter	RBSC	BSC	Result	VQ
Explosives				
Dinitrobenzene, 1,3-	0.37	NE	270	
Dinitrotoluene, 2,4-	0.099	NE	950	
Trinitrobenzene, 1,3,5-	109	NE	680	
Volatiles				
Ethylbenzene	134	0.87	0.19	J
Semivolatiles				
Dinitrotoluene, 2,4-	0.099	NE	660	
Dinitrotoluene, 2,6-	0.099	NE	56	J
Nitroaniline, 3-	1.09	NE	15	J
Water Quality Parameters				
Nitrate	1000	NE	1,600	

	Location Code:	IT-MW10			
	Sample No.:	5600		5605	
	Sample Date:	14-Nov-97		14-May-98	
	Low-Flow Sampled:	No		No	

Parameter	RBSC	BSC	Result	VQ	Result	VQ
Semivolatiles						
Bis(2-ethylhexyl)phthalate	4.8	NE	5.1	J		

	Location Code:	WARP-DP08
	Sample No.:	8410
	Sample Date:	16-Jun-98
	Low-Flow Sampled:	No

Parameter	RBSC	BSC	Result	VQ
Explosives				
Dinitrobenzene, 1,3-	0.37	NE	0.74	
Dinitrotoluene, 2,4-	0.099	NE	2.3	
Dinitrotoluene, 2,6-	0.099	NE	0.28	

	Location Code:	WARP-DP09
	Sample No.:	8450
	Sample Date:	16-Jun-98
	Low-Flow Sampled:	No

Parameter	RBSC	BSC	Result	VQ
Explosives				
Dinitrobenzene, 1,3-	0.37	NE	8.6	
Dinitrotoluene, 2,4-	0.099	NE	28	
Dinitrotoluene, 2,6-	0.099	NE	2.7	
Semivolatiles				
Dinitro-2-methylphenol, 4,6-	0.37	NE	24	J
Dinitrotoluene, 2,4-	0.099	NE	60	
Dinitrotoluene, 2,6-	0.099	NE	6.3	J
Nitroaniline, 3-	1.09	NE	5.1	J

	Location Code:	WARP-DP04
	Sample No.:	8250/8250B
	Sample Date:	24-Jun-98
	Low-Flow Sampled:	No

Parameter	RBSC	BSC	Result	VQ
Semivolatiles				
Nitroaniline, 3-	1.09	NE	3.2	J

	Location Code:	WARP-DP11
	Sample No.:	8530
	Sample Date:	26-Jun-98
	Low-Flow Sampled:	No

Parameter	RBSC	BSC	Result	VQ
Explosives				
Trinitrotoluene, 2,4,6-	1.83	NE	7.1	
Semivolatiles				
Dinitrotoluene, 2,4-	0.099	NE	1.8	J
Nitroaniline, 3-	1.09	NE	2.1	J

	Location Code:	IT-MW02			
	Sample No.:	5540		5545	
	Sample Date:	21-Nov-97		15-May-98	
	Low-Flow Sampled:	No		No	

Parameter	RBSC	BSC	Result	VQ	Result	VQ
Explosives						
Dinitrobenzene, 1,3-	0.37	NE	17		19	
Dinitrotoluene, 2,4-	0.099	NE	47		47	
Dinitrotoluene, 2,6-	0.099	NE	7.8		8.9	
Nitrotoluene, 3-	12	NE			36	
Nitrobenzene	0.34	NE			2.5	
Semivolatiles						
Dinitrotoluene, 2,4-	0.099	NE	43		42	
Dinitrotoluene, 2,6-	0.099	NE	7.1	J	6.7	J
Dinitro-2-methylphenol, 4,6-	0.37	NE	12	J		
Nitroaniline, 3-	1.09	NE			3.3	J

	Location Code:	WARP-DP15
	Sample No.:	8690
	Sample Date:	26-Jun-98
	Low-Flow Sampled:	No

Parameter	RBSC	BSC	Result	VQ
Explosives				
Dinitrotoluene, 2,4-	0.099	NE	1.1	

	Location Code:	BED-MW14									
	Sample No.:	5900		5905/5905R		BD3018/BD3018		CB3022			
	Sample Date:	18-Nov-97		16-May-98		28-Sep-01		8-Apr-02			
	Low-Flow Sampled:	No		No		Yes		Yes			

Parameter	RBSC	BSC	Result	VQ	Result	VQ	Result	VQ	Result	VQ
Volatiles										
Benzene	0.35	2.4	1.1		-	-	-	-	-	-
Semivolatiles										-
Dinitro-2-methylphenol, 4,6-	0.37	NE	-	-	28	NJ	-	-	-	-
Dinitrophenol, 2,4-	7.3	NE	-	-	14	J	-	-	-	-
Dinitrotoluene, 2,4-	0.099	NE	-	-	16		-	-	19	-
Nitroaniline, 3-	1.09	NE	-	-			-	-	150	-
Nitrobenzene	0.34	NE	-	-	5.8	J	-	-		-
Water Quality										
Nitrate	1000	NE			24,000		22,000		79,300	

	Location Code:	WARP-DP16
	Sample No.:	8730
	Sample Date:	25-Jun-98
	Low-Flow Sampled:	No

Parameter	RBSC	BSC	Result	VQ
Semivolatiles				
Dinitrotoluene, 2,4-	0.099	NE	60	J
Dinitrotoluene, 2,6-	0.099	NE	15	J
Nitroaniline, 3-	1.09	NE	43	J

	Location Code:	WARP-DP17
	Sample No.:	8770
	Sample Date:	25-Jun-98
	Low-Flow Sampled:	No

Parameter	RBSC	BSC	Result	VQ
Explosives				
Dinitrotoluene, 2,4-	0.099	NE	22	
Semivolatiles				
Dinitrotoluene, 2,4-	0.099	NE	52	J
Dinitrotoluene, 2,6-	0.099	NE	18	J
Nitroaniline, 3-	1.09	NE	49	J

	Location Code:	WA-MW02			
	Sample No.:	5680		5685	
	Sample Date:	23-Nov-97		15-May-98	
	Low-Flow Sampled:	No		No	

Parameter	RBSC	BSC	Result	VQ	Result	VQ
Explosives						
Dinitrobenzene, 1,3-	0.37	NE			23	
Dinitrotoluene, 2,4-	0.099	NE			21	
Dinitrotoluene, 2,6-	0.099	NE			4.1	
Semivolatiles						
Dinitrophenol, 2,4-	7.3	NE			7.6	J
Dinitrotoluene, 2,4-	0.099	NE			55	
Nitroaniline, 3-	1.09	NE			330	J
Nitrobenzene	0.34	NE			3.7	J
Water Quality						
Cyanide, total	73	NE	79		89	
Nitrate	1000	NE	80,000	J	62,000	

LEGEND:

- RAILROAD
- SURFACE DRAINAGE
- SURFACE WATER
- OVERBURDEN/SHALE MONITORING WELL LOCATION
- BEDROCK MONITORING WELL LOCATION
- DIRECT-PUSH GROUNDWATER SAMPLING LOCATION
- AOC WARWP

NOTES:

1. ALL UNITS ARE IN MICROGRAMS PER LITER (ug/L).
2. RBSC VALUES REFLECT AN INCREMENTAL LIFETIME CANCER RISK (ILCR) OF 1E-6 OR A NONCANCER HAZARD QUOTIENT (HQ) OF 0.1 FOR CHEMICALS THAT EXHIBIT BOTH CANCER AND NONCANCER EFFECTS, WHICHEVER TYPE OF EFFECT RESULTS IN A LOWER CONCENTRATION (USING AN ILCR OF 1E-6 AND AN HQ OF 0.1), THAT CONCENTRATION IS SELECTED AS THE RBSC.
3. ONLY RESULTS OF ANALYTES THAT EXCEED RBSC IN AT LEAST ONE SAMPLE FROM EACH LOCATION SHOWN.
4. "-" ANALYTE WAS NOT DETECTED IN THIS SAMPLE.
5. BSC - BACKGROUND SCREENING CONCENTRATION.
6. NE - NOT EVALUATED FOR BSC.
7. BOLD TEXT INDICATES VALUE IS GREATER THAN BSC.
8. VALIDATION QUALIFIERS (VQ):

   J - THE COMPOUND WAS POSITIVELY IDENTIFIED; THE REPORTED VALUE IS AN ESTIMATED CONCENTRATION.

NO	DATE	REVISION	BY	CHKD	DSGN ENGR	ENGR	PROJ MGR	APPR

STARTING DATE	INITIATOR	CHKD	DRAWN	CHKD	PROJECT MNGR
11/27/06	C. ANGLIN		D. BOMAR		S. DOWNEY

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GROUNDWATER FEASIBILITY STUDY
TNT AND RED WATER POND AREAS
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FIGURE 1-16
COMPOUNDS DETECTED AT CONCENTRATIONS EXCEEDING RBSCs IN WEST AREA RED WATER PONDS OVERBURDEN/SHALE AND BEDROCK GROUNDWATER (NOVEMBER 1997 THROUGH APRIL 2002)

AREA	JOB NO.	DRAWING NO.	REV
SITEWIDE	119268	119268_011.DGN	

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PBDN_sitestandard.tbl
7/13/2008
8:14:52 AM

400.000 FT / IN.
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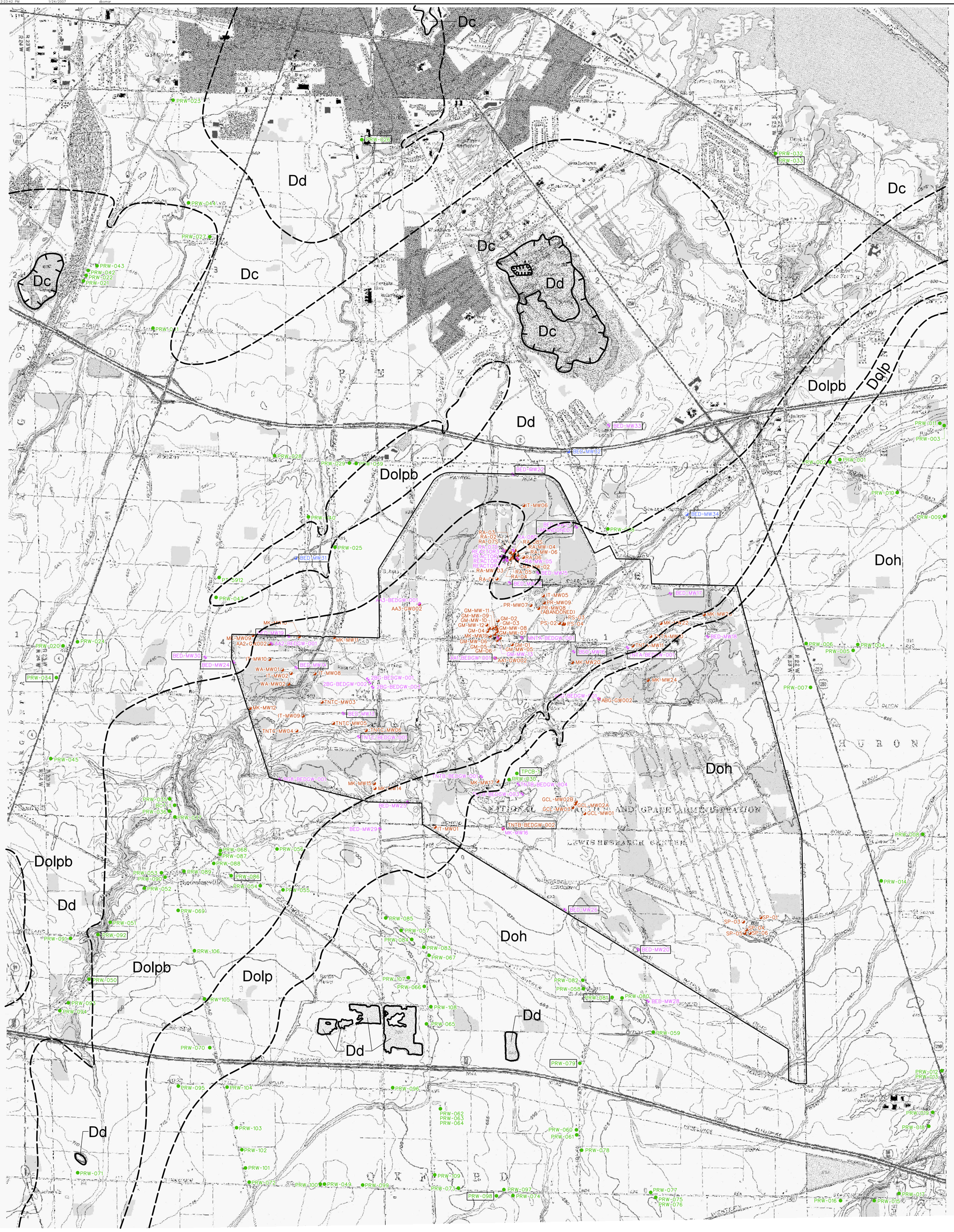
119268_011.dgn



LEGEND:

- PRIVATE WELL LOCATION
- OVERBURDEN WELL LOCATION
- BEDROCK WELL LOCATION
- SOIL BORING LOCATION
- H_2S AND/OR NATURAL GAS, AND/OR PETROLEUM HYDROCARBON WERE NOTED DURING DRILLING
- CONTACT SOLID LINE WHERE EXPOSED; DASHED WHERE CONCEALED BY SEDIMENTS

AGE	FORMATION/GROUP	ROCK DESCRIPTION
DEVONIAN	Doh - Ohio Shale	Shale: black, thin-bedded with bituminous and carboneous material, pyrite, natural gas pockets.
	Dolp - Prout Limestone Member (Olentangy Shale)	Limestone: light gray, calcareous.
	Dolpb - Plum Brook Member (Olentangy Shale)	Shale: dark gray, thin-bedded.
	Dd - Delaware Limestone	Limestone: buff, earthy, interbedded with brown crystalline dolomite, fossiliferous, hydrogen sulfide, petroleum hydrocarbon.
	Dc - Columbus Limestone	Limestone: brown to gray, fine crystalline, fossiliferous with tan to buff gray, partly sandy dolomite at base.

REFERENCE:

PRELIMINARY BEDROCK GEOLOGY OF THE KIMBALL AND SANDUSKY, OHIO, QUADRANGLES, STATE OF OHIO, DEPARTMENT OF NATURAL RESOURCES, DIVISION OF GEOLOGICAL SURVEY, 1995.

BASE MAPS (COMBINED BY SHAW) FROM KIMBALL AND SANDUSKY QUADRANGLES, 7.5 MINUTE SERVICES, (TOPOGRAPHIC), 1969. SANDUSKY MAP WAS PHOTOREVISED 1979.

NOTE:

1. CONTACT LINES WERE ADJUSTED BASED ON 2004 MONITORING WELLS/SOIL BORING AND GIS DATA.

SCALE
0 1250 2500 FEET

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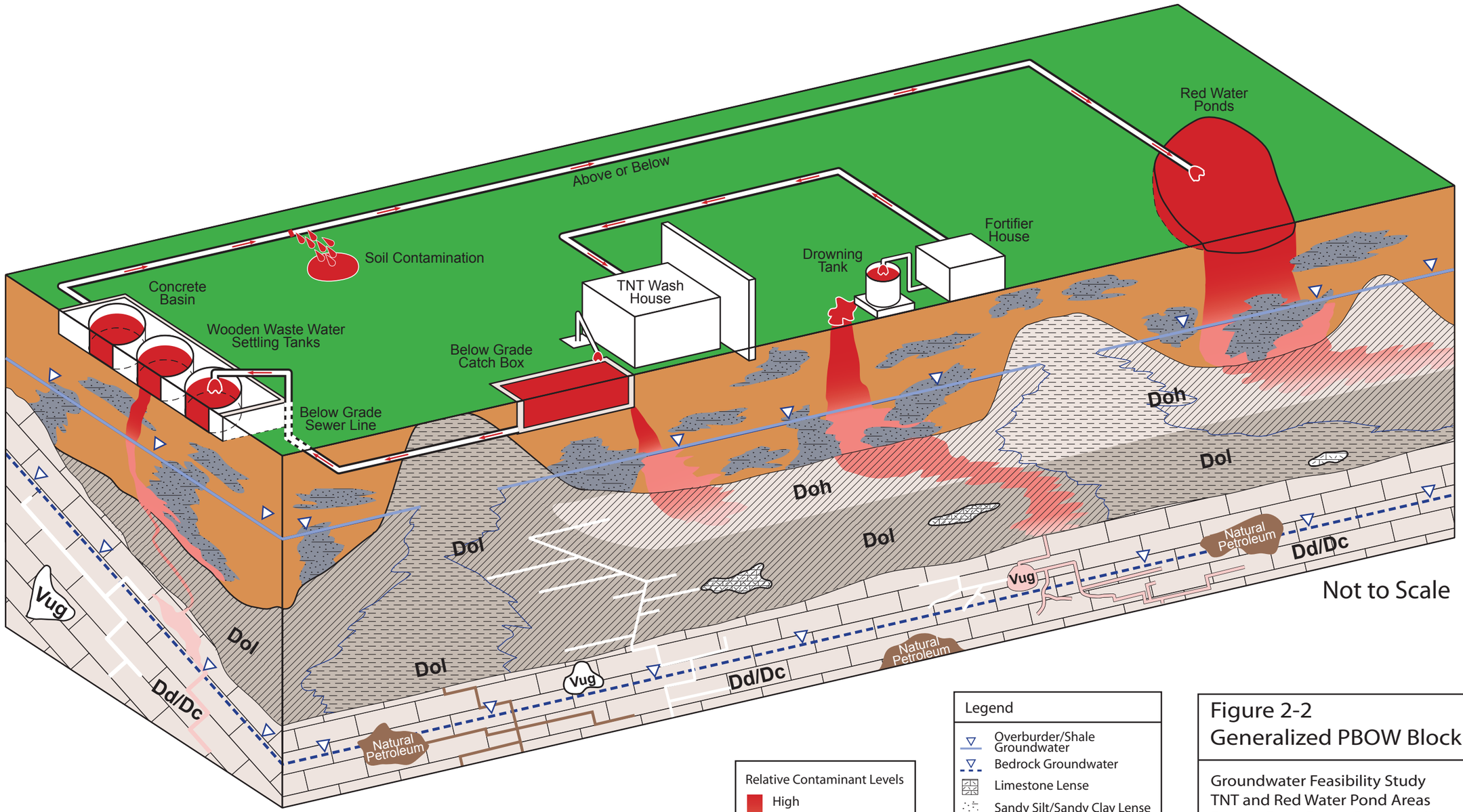
GROUNDWATER FEASIBILITY STUDY
TNT AND RED WATER POND AREAS
FORMER PLUM BROOK ORDNANCE WORKS
NASA PLUM BROOK STATION
SANDUSKY, OHIO

FIGURE 2-1
REGIONAL GEOLOGIC MAP
WITH SITE TOPOGRAPHY

AREA	JOB NO.	DRAWING NO.	REV
SITEWIDE	119268	119268_016.DGN	



Relative Contaminant Levels

High

Low

Legend

- Overburder/Shale Groundwater
- Bedrock Groundwater
- Limestone Lense
- Sandy Silt/Sandy Clay Lense
- Silt/Clay/Shale Fragments
- Weathered Shale

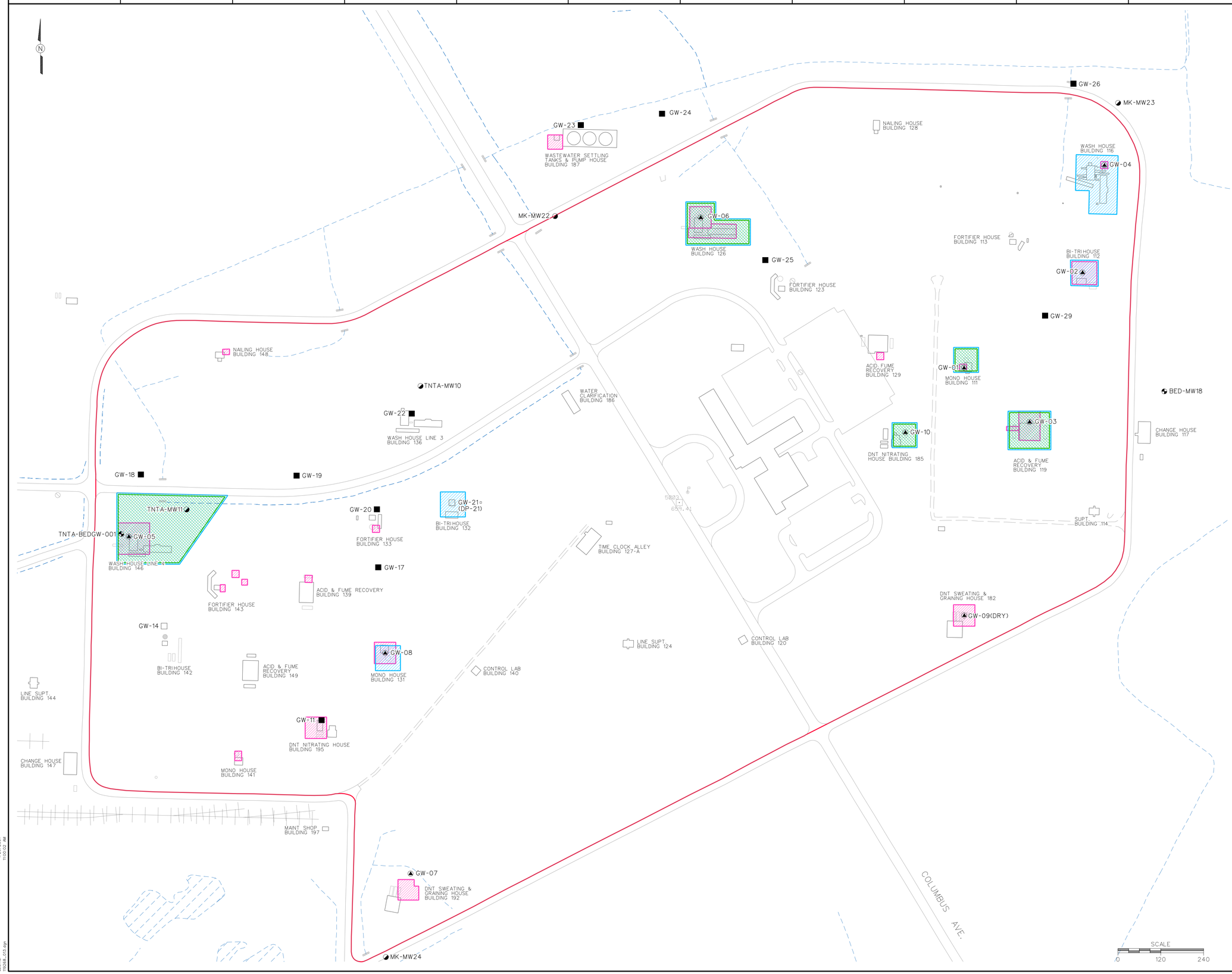
Doh - Ohio Shale
Dol - Olentangy Shale (Prout and Olentangy Shale Members)
Dd- Delaware Limestone
Dc- Columbus Limestone

Figure 2-2
Generalized PBOW Block Diagram

Groundwater Feasibility Study
TNT and Red Water Pond Areas
Former Plum Brook Ordnance Works
Sandusky, Ohio

Shaw™ Shaw Environmental, Inc.

X:\PlumBrook\GISWorkspace\dpack\Illustrator Files\plumbrook_csm_112904.ai



LEGEND:

- BUILDING OR STRUCTURE
- STORAGE TANK
- RAILROAD
- SURFACE DRAINAGE
- SURFACE WATER
- OVERBURDEN/SHALE MONITORING WELL LOCATION
- BEDROCK MONITORING WELL LOCATION
- 2000 GROUNDWATER SAMPLING LOCATION
- 2001 DIRECT-PUSH GROUNDWATER SAMPLING LOCATION
- 2001 DIRECT-PUSH GROUNDWATER SAMPLING LOCATION (DRILLED TO REFUSAL, NO GROUNDWATER ENCOUNTERED)
- AREA OF CONCERN
- PLANNED NITROAROMATIC/PBC SOIL REMEDIATION AREA
- POTENTIAL AREA OF OVERBURDEN/SHALE GROUNDWATER REMEDIATION FOR PROTECTION/RESTORATION OF THE DELAWARE LIMESTONE BEDROCK GROUNDWATER TO DRINKING WATER QUALITY
- POTENTIAL AREA OF OVERBURDEN/SHALE GROUNDWATER REMEDIATION FOR RESTORATION OF THE OVERBURDEN/SHALE GROUNDWATER TO DRINKING WATER QUALITY

NOTE:

1. ONLY AREAS WITH MEASURED OR PREDICTED (BASED ON THE SITE GROUNDWATER MODEL) CONCENTRATIONS OF CHEMICALS OF CONCERN EXCEEDING GROUNDWATER REMEDIAL GOAL OPTIONS ARE TARGETED FOR POTENTIAL GROUNDWATER REMEDIATION.

NO	DATE	REVISION	BY	CHKD	DSGN ENGR	ENGR	PROJ MGR	APPR

STARTING DATE	INITIATOR	CHKD	DRAWN	CHKD	PROJECT MNGR
01/04/07	T. SIARD		D. BOMAR		S. DOWNEY

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GROUNDWATER FEASIBILITY STUDY
TNT AND RED WATER POND AREAS
FORMER PLUM BROOK ORDNANCE WORKS
NASA PLUM BROOK STATION
SANDUSKY, OHIO

FIGURE 3-1
AREAS POTENTIALLY REQUIRING REMEDIATION OF GROUNDWATER IN TNT AREA A

AREA	JOB NO.	DRAWING NO.	REV
SITEWIDE	119268	119268_013.DGN	

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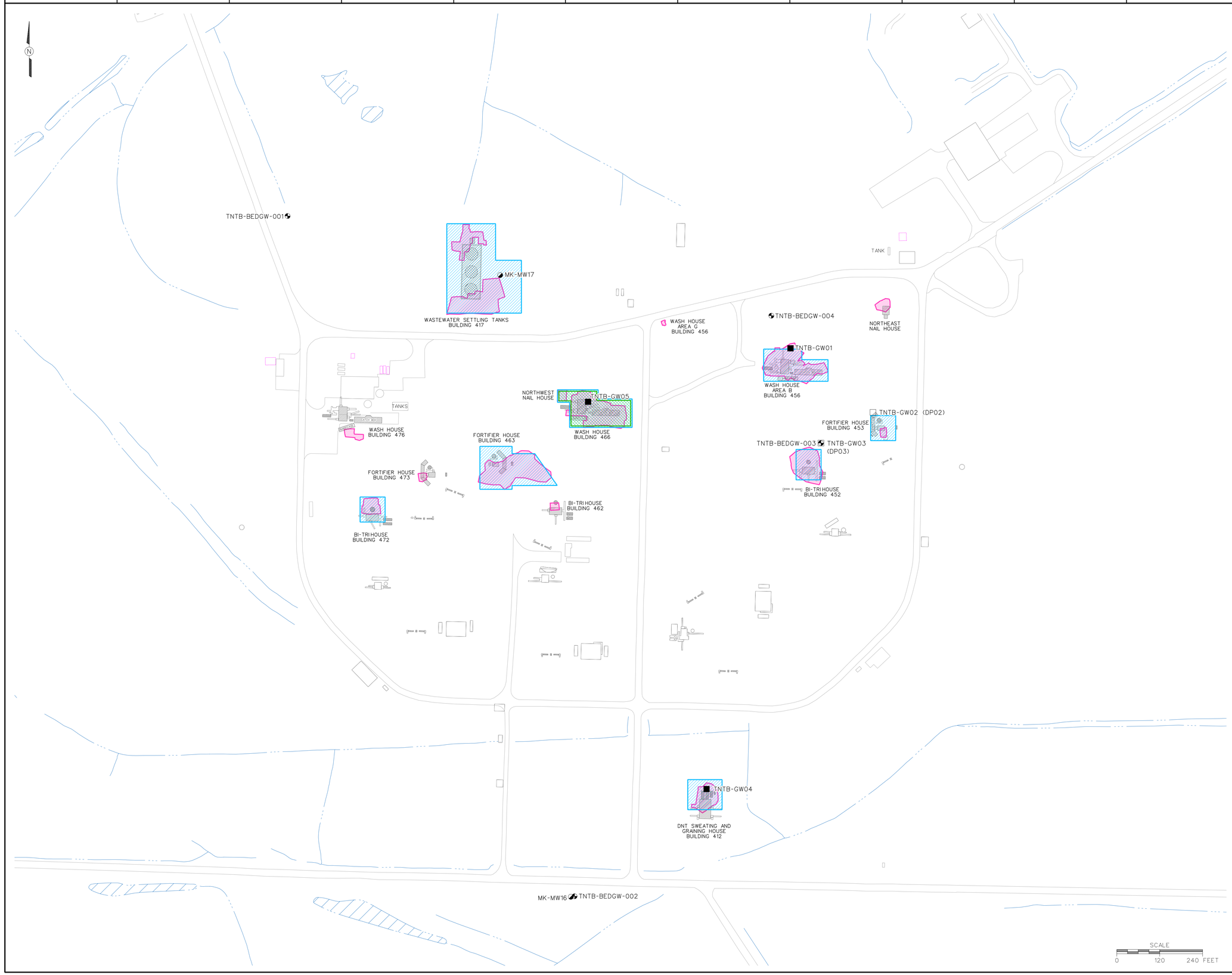

LEGEND:

- BUILDING OR STRUCTURE
- STORAGE TANK
- SURFACE DRAINAGE
- SURFACE WATER
- OVERBURDEN/SHALE MONITORING WELL LOCATION
- BEDROCK MONITORING WELL LOCATION
- 2000 GROUNDWATER SAMPLING LOCATION
- 2001 DIRECT-PUSH GROUNDWATER SAMPLING LOCATION
- 2001 DIRECT-PUSH GROUNDWATER SAMPLING LOCATION (DRILLED TO REFUSAL, NO GROUNDWATER ENCOUNTERED)
- COMPLETED NITROAROMATIC/PAH/PBC SOIL REMEDIATION AREA
- POTENTIAL AREA OF OVERBURDEN/SHALE GROUNDWATER REMEDIATION FOR PROTECTION/RESTORATION OF THE DELAWARE LIMESTONE BEDROCK GROUNDWATER TO DRINKING WATER QUALITY
- POTENTIAL AREA OF OVERBURDEN/SHALE GROUNDWATER REMEDIATION FOR RESTORATION OF THE OVERBURDEN/SHALE GROUNDWATER TO DRINKING WATER QUALITY

NOTE:

1. ONLY AREAS WITH MEASURED OR PREDICTED (BASED ON THE SITE GROUNDWATER MODEL) CONCENTRATIONS OF CHEMICALS OF CONCERN EXCEEDING GROUNDWATER REMEDIAL GOAL OPTIONS ARE TARGETED FOR POTENTIAL GROUNDWATER REMEDIATION.

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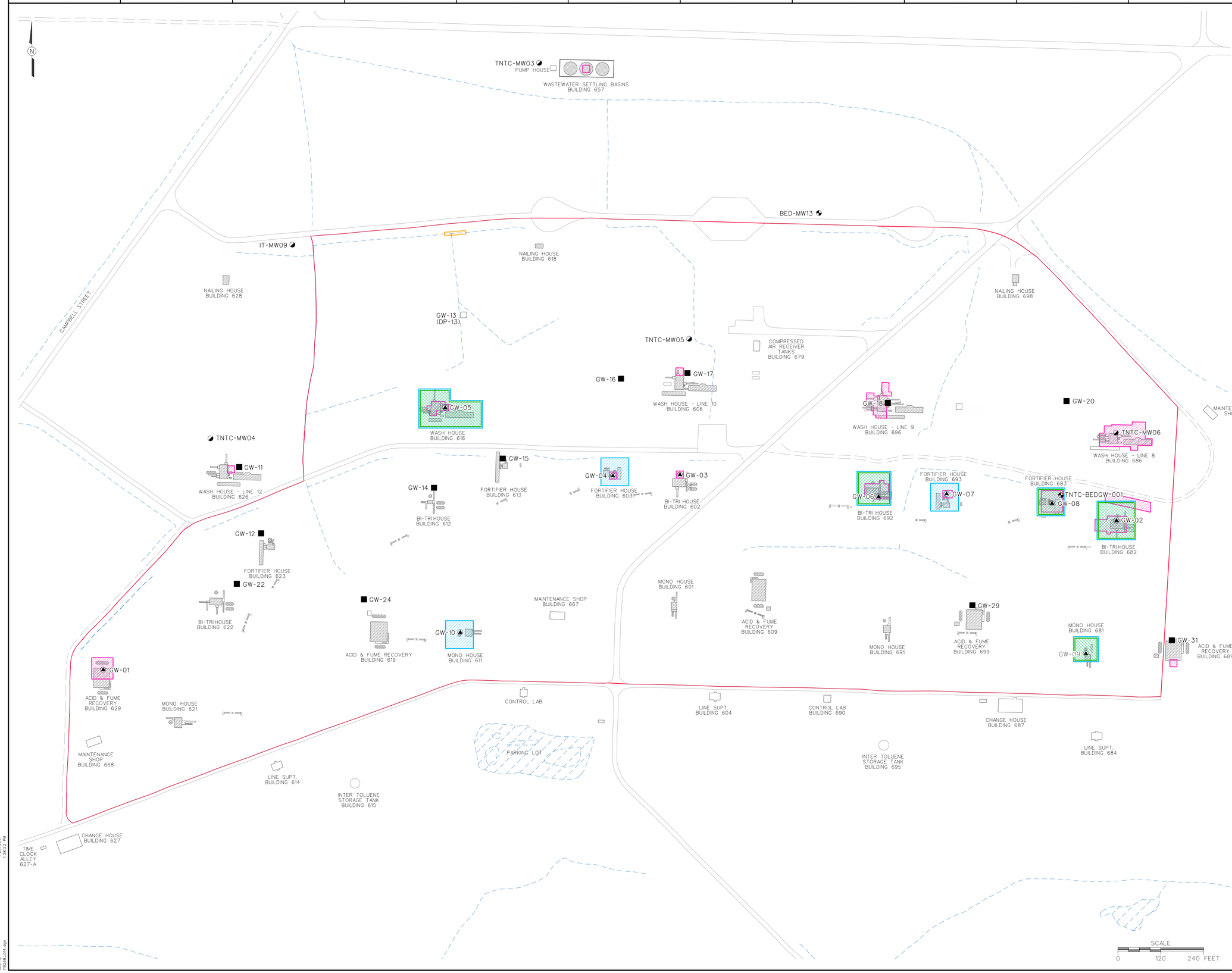
GROUNDWATER FEASIBILITY STUDY
TNT AND RED WATER POND AREAS
FORMER PLUM BROOK ORDNANCE WORKS
NASA PLUM BROOK STATION
SANDUSKY, OHIO

FIGURE 3-2
AREAS POTENTIALLY REQUIRING REMEDIATION OF GROUNDWATER IN TNT AREA B

AREA	JOB NO.	DRAWING NO.	REV
SITEWIDE	119268	119268_015.DGN	



LEGEND:

- FORMER BUILDING OR STRUCTURE
- FORMER STORAGE TANK
- SURFACE DRAINAGE
- SURFACE WATER
- OVERBURDEN/SHALE MONITORING WELL LOCATION
- BEDROCK MONITORING WELL LOCATION
- 2000 GROUNDWATER SAMPLING LOCATION
- 2001 DIRECT-PUSH GROUNDWATER SAMPLING LOCATION
- 2001 DIRECT-PUSH GROUNDWATER SAMPLING LOCATION (DRILLED TO REFUSAL, NO GROUNDWATER ENCOUNTERED)
- AREA OF CONCERN
- PLANNED NITROAROMATIC/PAH/PBC SOIL REMEDIATION AREA
- PLANNED NITROAROMATIC SEDIMENT REMEDIATION AREA
- POTENTIAL AREA OF OVERBURDEN/SHALE GROUNDWATER REMEDIATION FOR PROTECTION/RESTORATION OF THE DELAWARE LIMESTONE BEDROCK GROUNDWATER TO DRINKING WATER QUALITY
- POTENTIAL AREA OF OVERBURDEN/SHALE GROUNDWATER REMEDIATION FOR RESTORATION OF THE OVERBURDEN/SHALE GROUNDWATER TO DRINKING WATER QUALITY

NOTE:

1. ONLY AREAS WITH MEASURED OR PREDICTED (BASED ON THE SITE GROUNDWATER MODEL) CONCENTRATIONS OF CHEMICALS OF CONCERN EXCEEDING GROUNDWATER REMEDIAL GOAL OPTIONS ARE TARGETED FOR POTENTIAL GROUNDWATER REMEDIATION.

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STARTING DATE 01/04/07 | INITIATOR T. SIARD | CHKD | DRAWN D. BOMAR | CHKD | PROJECT MNGR S. DOWNEY

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GROUNDWATER FEASIBILITY STUDY
TNT AND RED WATER POND AREAS
FORMER PLUM BROOK ORDNANCE WORKS
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FIGURE 3-3
AREAS POTENTIALLY REQUIRING REMEDIATION OF GROUNDWATER IN TNT AREA C

AREA	JOB NO.	DRAWING NO.	REV
SITEWIDE	119268	119268_014.DGN	

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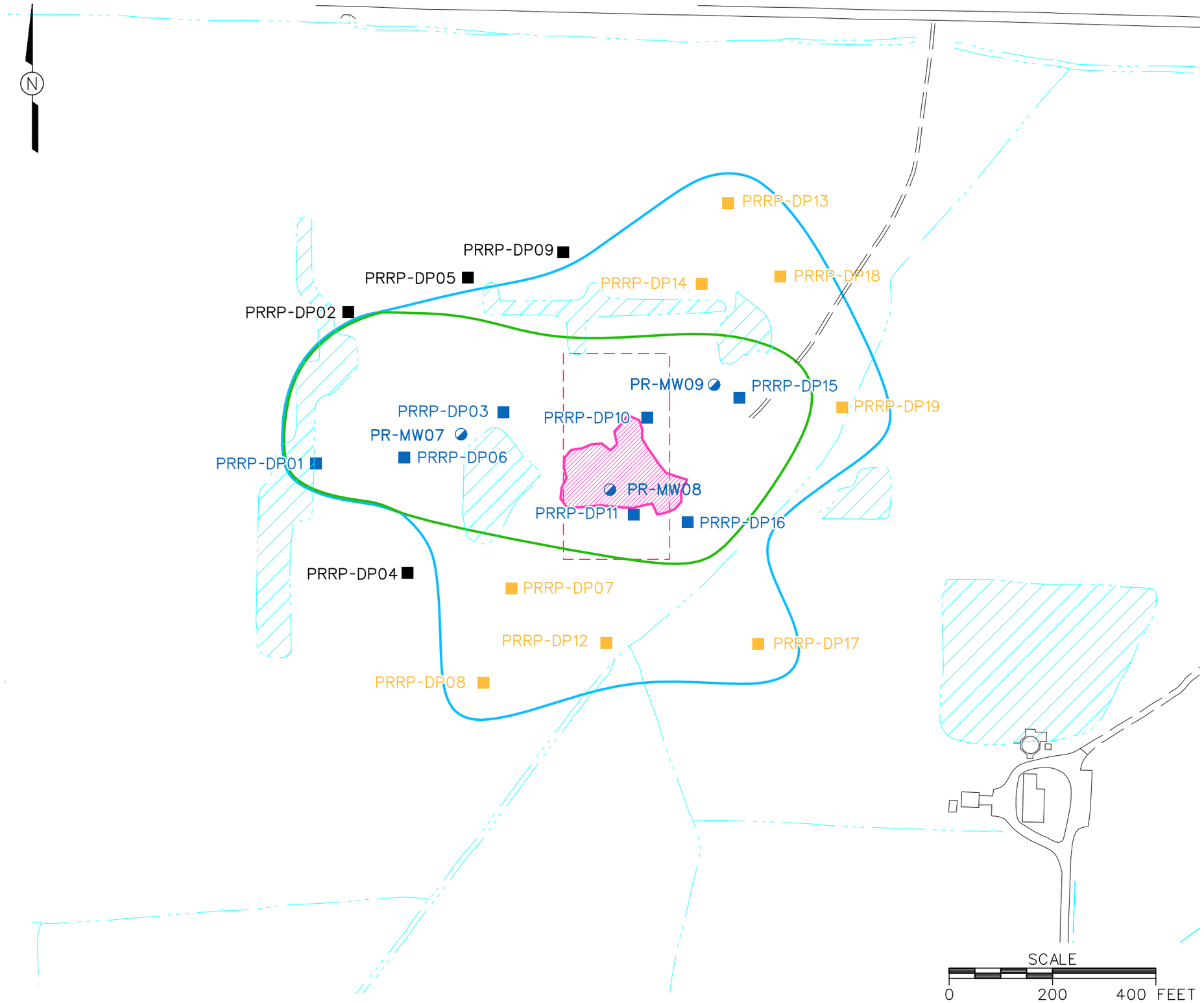

LEGEND

- BUILDINGS
- APPROXIMATE HISTORICAL LOCATION OF POND
- SURFACE DRAINAGE
- SURFACE WATER
- OVERBURDEN/SHALE MONITORING WELL LOCATION
- DIRECT-PUSH GROUNDWATER SAMPLING LOCATION
- PLANNED TNT SOIL REMEDIATION AREA
- POTENTIAL AREA OF OVERBURDEN/ SHALE GROUNDWATER REMEDIATION FOR PROTECTION/RESTORATION OF THE DELAWARE LIMESTONE BEDROCK GROUNDWATER TO DRINKING WATER QUALITY
- POTENTIAL AREA OF OVERBURDEN/ SHALE GROUNDWATER REMEDIATION FOR RESTORATION OF THE OVERBURDEN/ SHALE GROUNDWATER TO DRINKING WATER QUALITY
- SAMPLE EXCEEDS AT LEAST ONE RGO, AND 40 ug/L TOTAL COCs
- SAMPLE EXCEEDS AT LEAST ONE RGO, BUT TOTAL COCs ARE LESS THAN 20 ug/L
- ALL COCs ARE LESS THAN RGOs

NOTES:

1. ALL CONCENTRATIONS ARE IN MICROGRAMS PER LITER (ug/L).
2. RGO = REMEDIAL GOAL OPTION
3. COC = CHEMICAL OF CONCERN
4. POTENTIAL REMEDIATION AREAS DETERMINED USING CONCENTATION DATA AND SITE GROUNDWATER MODEL.

FIGURE 3-4
AREAS POTENTIALLY REQUIRING REMEDIATION OF GROUNDWATER IN PENTOLITE ROAD RED WATER POND AREA

GROUNDWATER FEASIBILITY STUDY
TNT AND RED WATER POND AREAS
FORMER PLUM BROOK ORDNANCE WORKS
NASA PLUM BROOK STATION
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DRAWN BY: D. BOMAR	DRAWN BY:	ENGR. CHCK. BY: T. SIARD	PROJ. MGR.: S. DOWNEY
			DWG. NO.:119268_022.DGN
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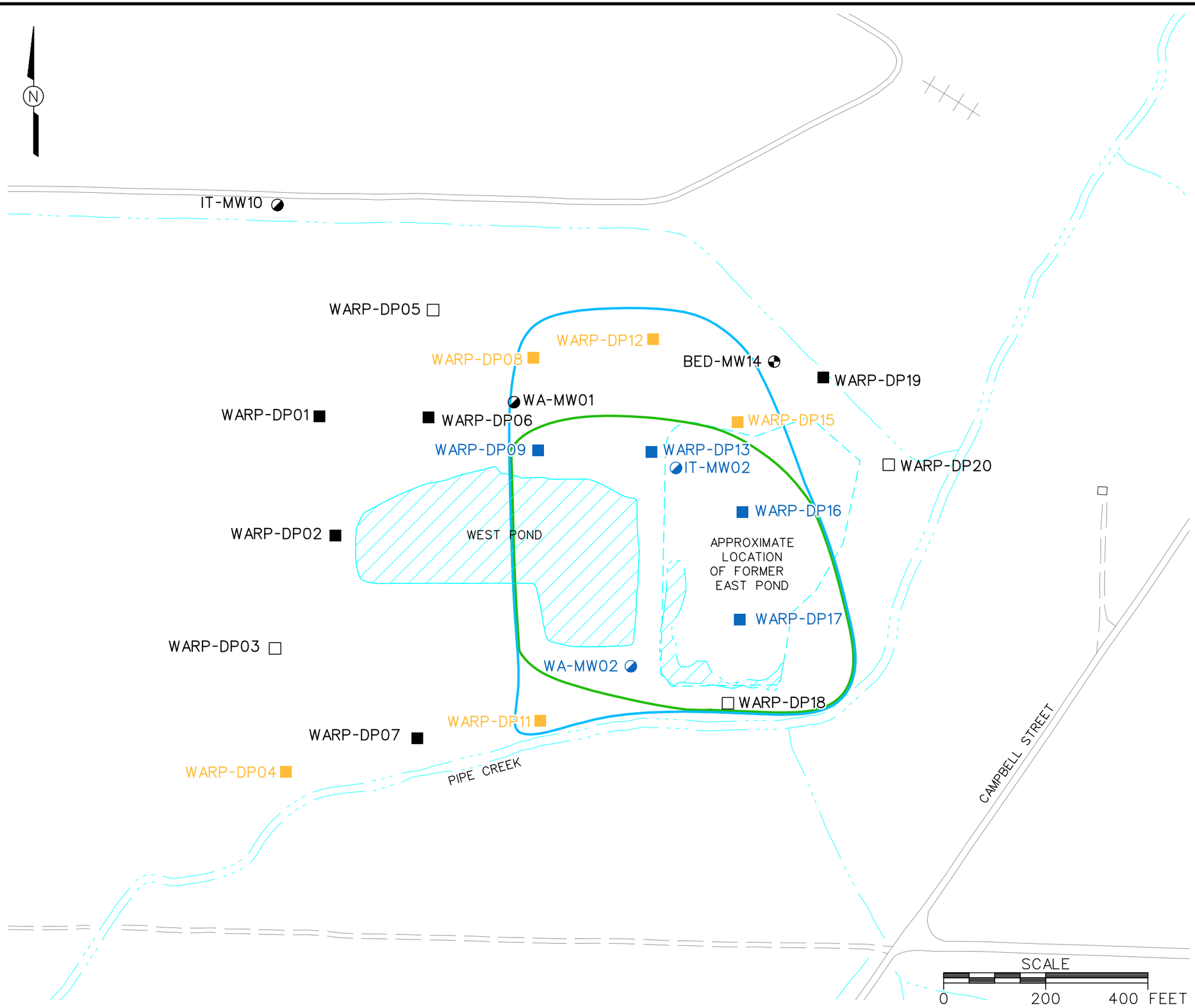

LEGEND

- SURFACE WATER
- SURFACE DRAINAGE
- UNPAVED ROADS/DRIVES
- PAVED ROADS
- OVERBURDEN/SHALE MONITORING WELL LOCATION
- BEDROCK MONITORING WELL LOCATION
- DIRECT-PUSH GROUNDWATER SAMPLING LOCATION
- PLANNED DIRECT-PUSH GROUNDWATER SAMPLING LOCATION (INSUFFICIENT YIELD TO COLLECT SAMPLE)
- POTENTIAL AREA OF OVERBURDEN/ SHALE GROUNDWATER REMEDIATION FOR PROTECTION/RESTORATION OF THE DELAWARE LIMESTONE BEDROCK GROUNDWATER TO DRINKING WATER QUALITY
- POTENTIAL AREA OF OVERBURDEN/ SHALE GROUNDWATER REMEDIATION FOR RESTORATION OF THE OVERBURDEN/ SHALE GROUNDWATER TO DRINKING WATER QUALITY
- SAMPLE EXCEEDS AT LEAST ONE RGO, AND 80 ug/L TOTAL COCs
- SAMPLE EXCEEDS AT LEAST ONE RGO, BUT TOTAL COCs ARE LESS THAN 20 ug/L
- ALL COCs ARE LESS THAN RGOs

NOTES:

1. ALL CONCENTRATIONS ARE IN MICROGRAMS PER LITER (ug/L).
2. RGO = REMEDIAL GOAL OPTION
3. COC = CHEMICAL OF CONCERN
4. POTENTIAL REMEDIATION AREAS DETERMINED USING CONCENTRATION DATA AND SITE GROUNDWATER MODEL.
5. AT WARP-DP04, ONLY 3-NITRO ANILINE (3.2 ug/L) EXCEED THE RGO (2 ug/L). THIS SINGLE MARGINAL EXCEEDANCE WOULD NOT CONNOTE A HUMAN HEALTH THREAT.

FIGURE 3-5

AREAS POTENTIALLY REQUIRING REMEDIATION OF GROUNDWATER WEST AREA RED WATER PONDS AREA

GROUNDWATER FEASIBILITY STUDY
TNT AND RED WATER POND AREAS
FORMER PLUM BROOK ORDNANCE WORKS
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DWG. NO.:119268_024.DGN
PROJ. NO.: 119268
INITIATOR: T. SIARD
PROJ. MGR.: S. DOWNEY
DRAFT. CHCK. BY:
ENGR. CHCK. BY: T. SIARD
DATE LAST REV.:
DRAWN BY:
STARTING DATE: 01/29/07
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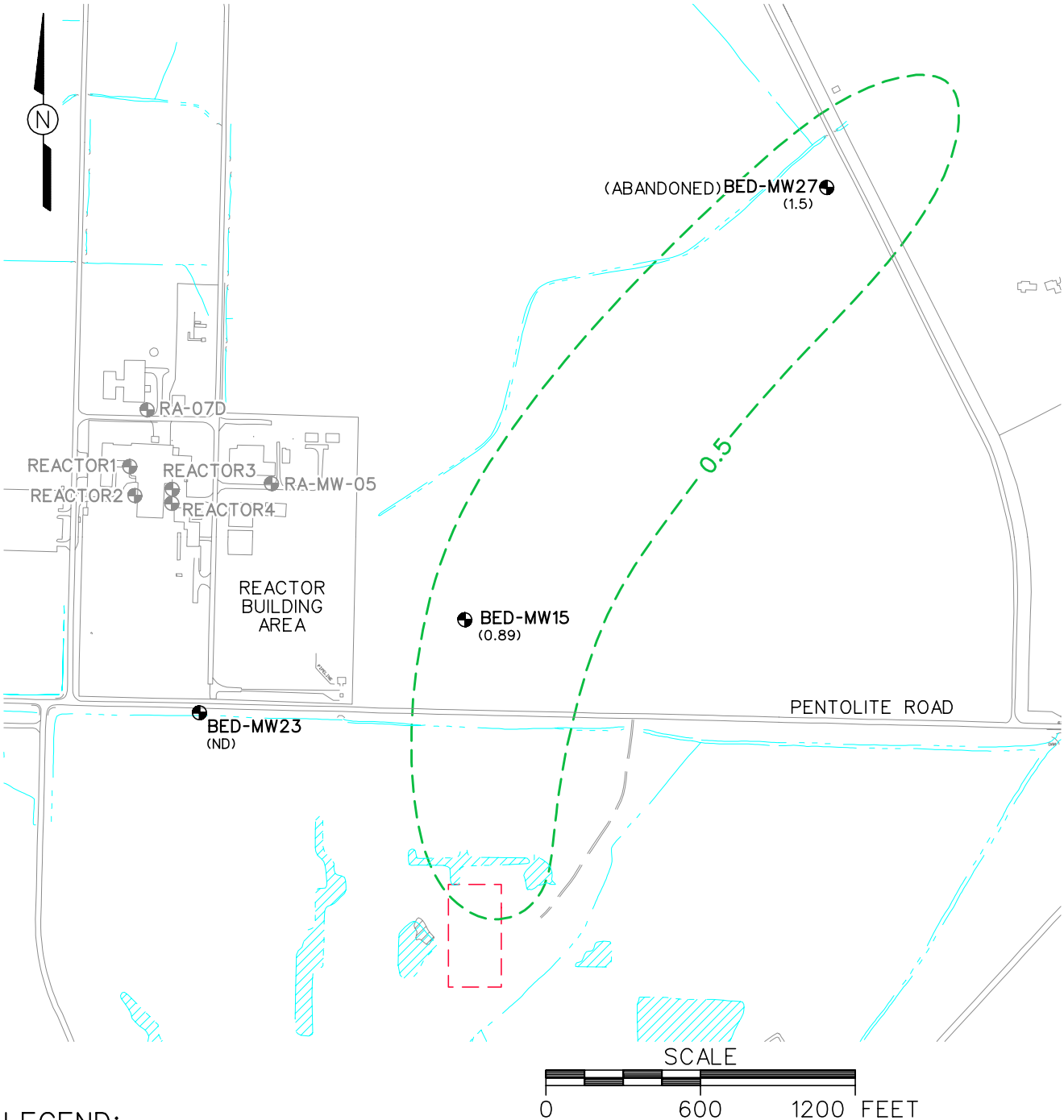

LEGEND:

- BUILDINGS
- APPROXIMATE HISTORICAL LOCATION OF POND
- SURFACE DRAINAGE
- SURFACE WATER
- BEDROCK MONITORING WELL LOCATION
- (1.5) 2,4-DNT CONCENTRATION (ug/L)
- 0.5 2,4-DNT CONTOUR (ug/L) (DASHED WHERE INFERRED)
- (ND) NOT DETECTED

FIGURE 3-6
LIMESTONE BEDROCK GROUNDWATER 2,4-DNT/2,6-DNT PLUME PENTOLITE ROAD RED WATER POND AREA

GROUNDWATER FEASIBILITY STUDY
TNT AND RED WATER POND AREAS
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DWG. NO: 119268_020.DGN	INITIATOR: D. KESSLER
PROJ. NO.: 119268	PROJ. MGR.: S. DOWNEY
DRAFT. CHCK. BY:	DATE LAST REV.:
ENGR. CHCK. BY: T. SIARD	DRAWN BY:
STARTING DATE: 01/25/07	Canon-color-Letter.plt
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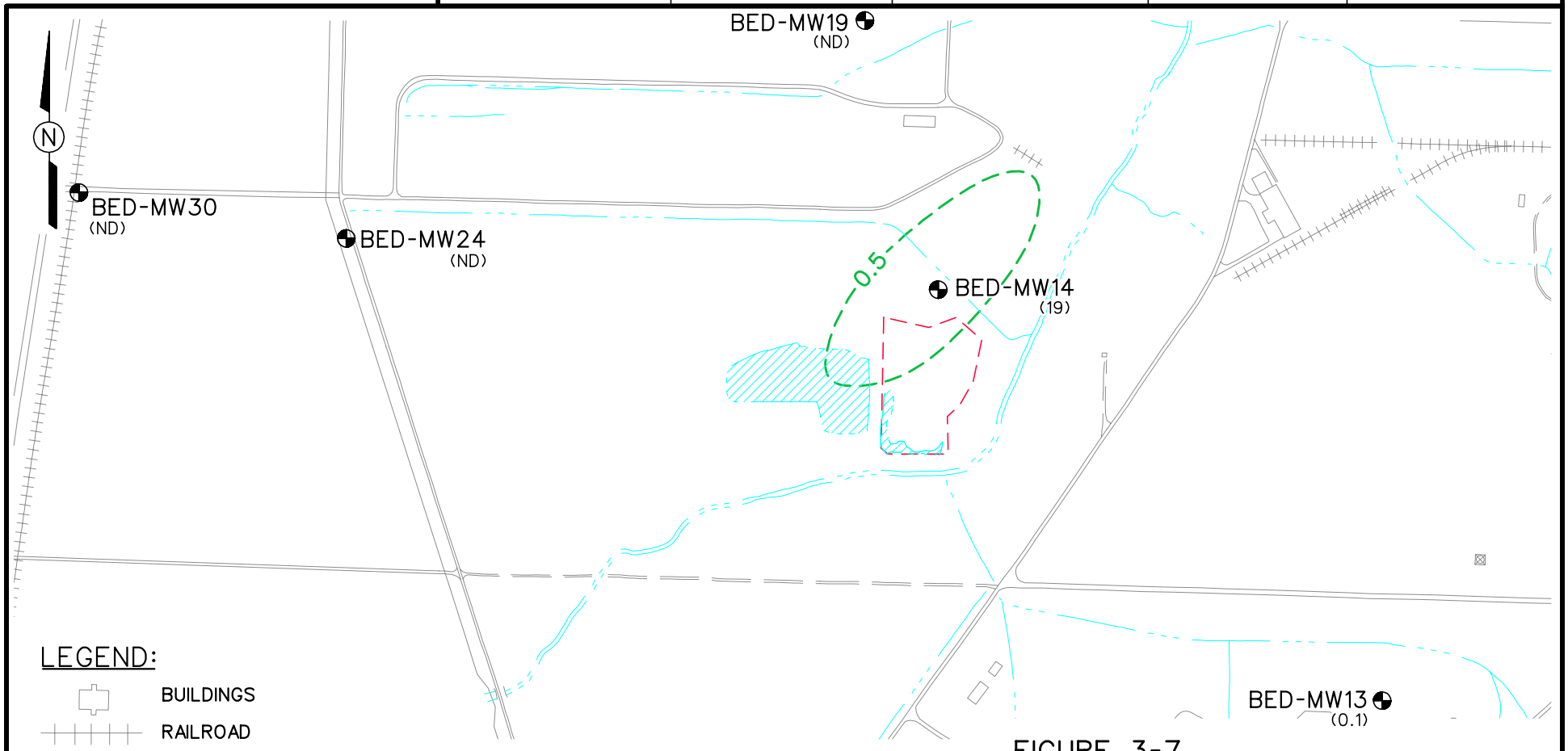
119268_021.DGN	2/12/2008	DRAWN BY: D. BOMAR	DRAWN BY:	ENGR. CHCK. BY: T. SIARD	PROJ. MGR.: S. DOWNEY	PROJ. NO.: 119268



LEGEND:

- BUILDINGS
- RAILROAD
- APPROXIMATE HISTORICAL LOCATION OF POND
- SURFACE DRAINAGE
- SURFACE WATER
- BEDROCK MONITORING WELL LOCATION
- (1.5) 2,4-DNT CONCENTRATION (ug/L)
- 0.5 2,4-DNT CONTOUR (ug/L) (DASHED WHERE INFERRED)
- (ND) NOT DETECTED

SCALE

0 600 1200 FEET

FIGURE 3-7
LIMESTONE BEDROCK GROUNDWATER 2,4-DNT PLUME WEST AREA RED WATER PONDS AREA

GROUNDWATER FEASIBILITY STUDY
TNT AND RED WATER POND AREAS
FORMER PLUM BROOK ORDNANCE WORKS
NASA PLUM BROOK STATION
SANDUSKY, OHIO

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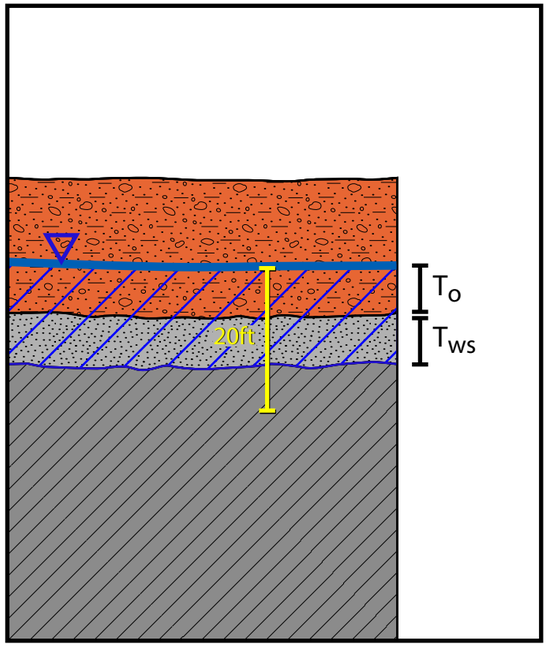
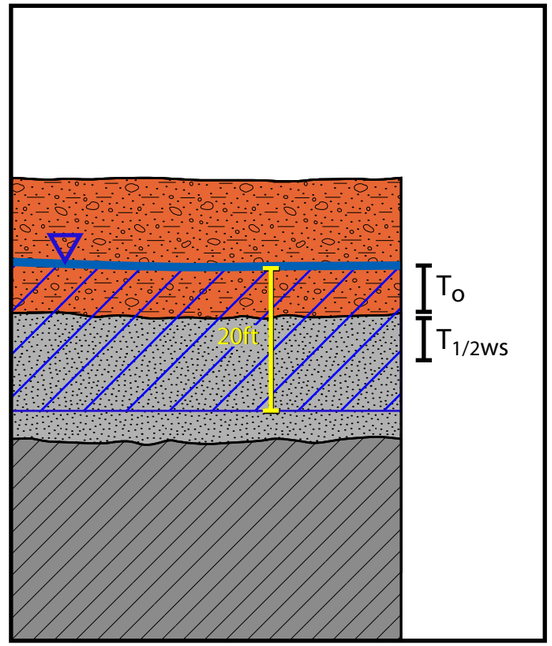
STANDARD_COLOR_MOD.TBL CANON-COLOR-LETTER.PLT

Example 1
(Assumptions 1 and 2)



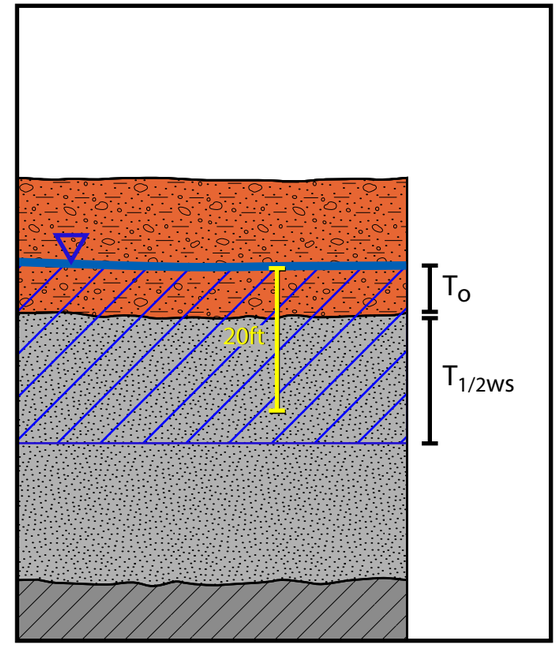
$T_o + T_{ws} < 20ft$

Example 2
(Assumptions 1 and 3)



$T_o + T_{ws} > 20ft$ and
$T_o + T_{1/2ws} < 20ft$

Example 3
(Assumptions 1 and 4)



Not to Scale

$T_o + T_{1/2ws} > 20ft$

Four Depth Assumptions Used to Determine Contamination Volume

1. All groundwater (when present) within the saturated overburden layer is assumed to be contaminated.
2. If the combined thickness of the saturated overburden and saturated weathered shale layers are less than 20 feet, all groundwater above the competent shale is assumed to be contaminated.
3. If the thickness of the saturated overburden plus one-half the thickness of the saturated weathered shale layer is less than 20 feet, then groundwater within the combined overburden and weathered shale layers is assumed to be contaminated to a depth of 20 feet below the water table.
4. If the thickness of the saturated overburden plus one-half the thickness of the saturated weathered shale layer is greater than 20 feet, then groundwater (when present) within the saturated weathered shale layer is assumed to be contaminated to a depth of one-half the thickness of the weathered shale layer.

Notes:
1. In each of the three examples, the water table extends above the base of the overburden layer. This is not the case for all site areas. The above assumptions still apply regardless of the relative depth to the water table.
2. Refer to Section 3.7 for the appropriate context of the four assumptions.

LEGEND

- Estimated Thickness of Overburden/Shale Groundwater Contamination.
- Water Table
- Overburden
- Weathered Shale
- Competent Shale
- T_o - Thickness of Saturated Overburden
- T_{ws} - Thickness of Saturated Weathered Shale
- $T_{1/2ws}$ - Vertical Midpoint of Saturated Weathered Shale

Figure 3-8
Methodology for Estimating Depth of Groundwater Contamination

Groundwater Feasibility Study
TNT and Red Water Pond Areas
Former Plum Brook Ordnance Works
Sandusky, Ohio

Shaw™ Shaw Environmental, Inc.

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Figure 4-1

Metabolic Pathways and Reaction Products of Aerobic Trinitrotoluene Biodegradation

Former Plum Brook Ordnance Works
Sandusky, Ohio

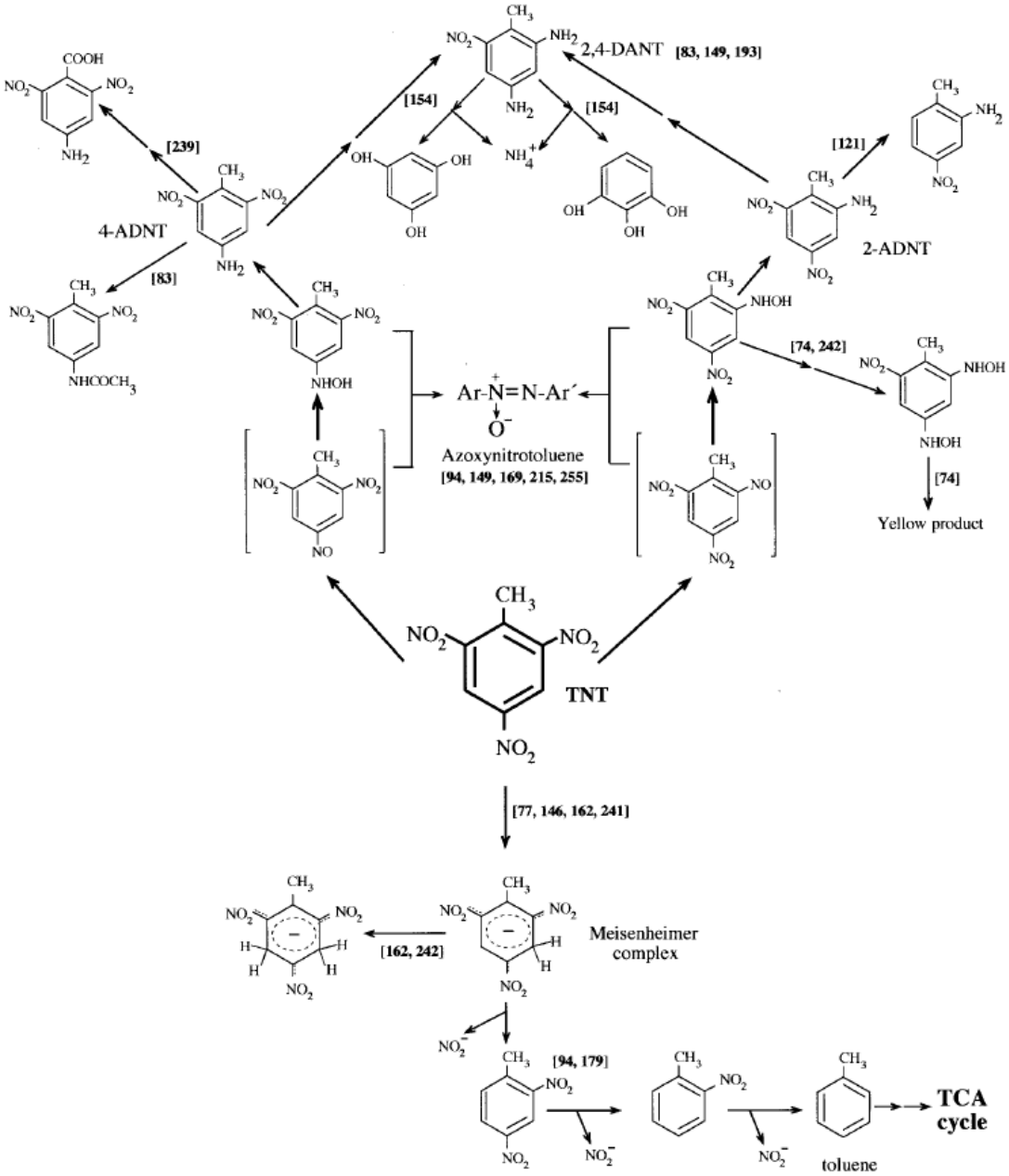

Figure 4-2

Structure of 3-Methyl-4,6-Dinitrocatechol
Former Plum Brook Ordnance Works
Sandusky, Ohio

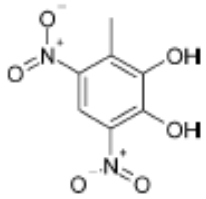

Figure 4-3

Metabolic Pathways and Reaction Products of Anaerobic Trinitrotoluene Biodegradation

Former Plum Brook Ordnance Works
Sandusky, Ohio

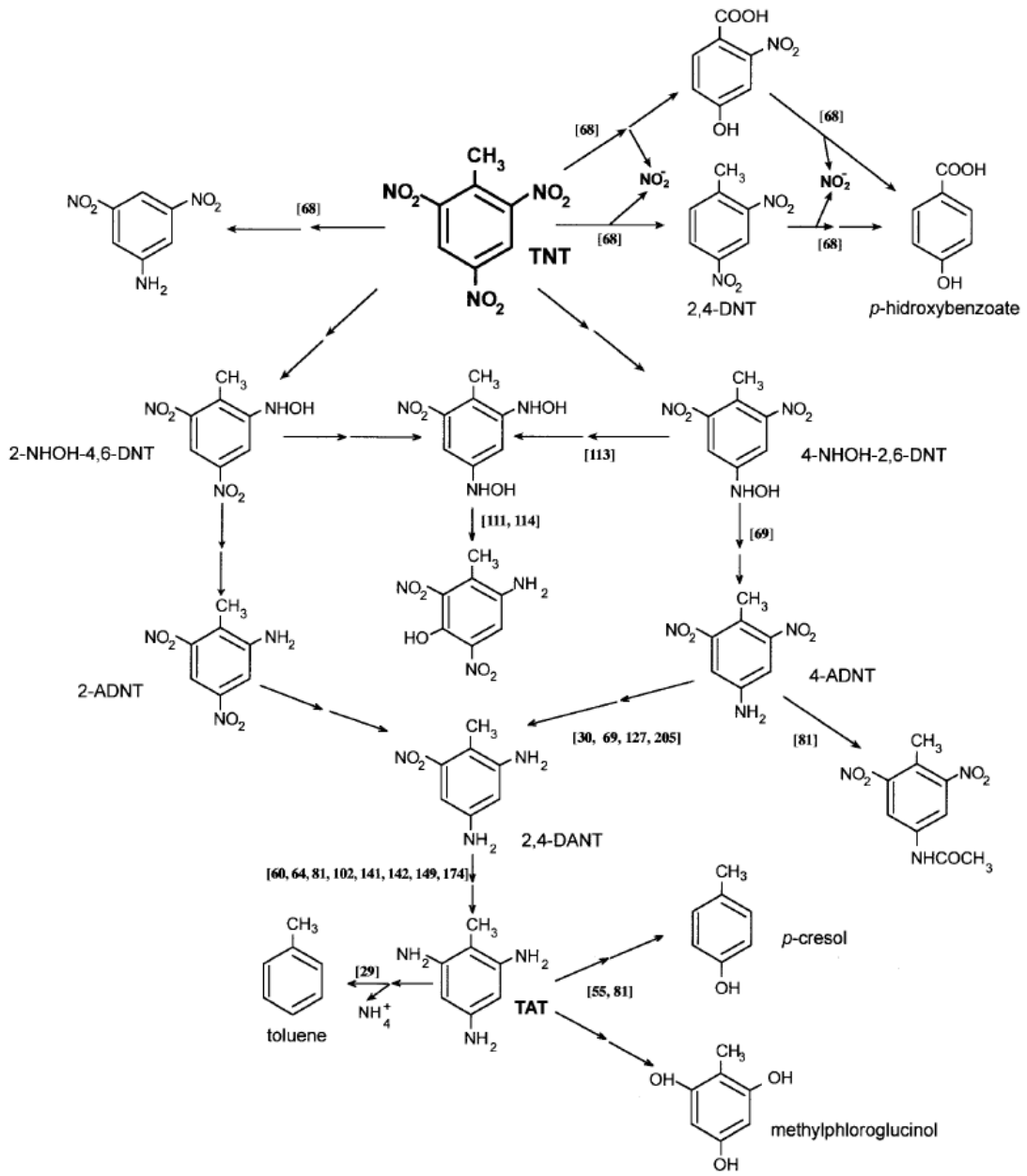

Figure 5-1
Block Flow Diagram for West Area Red Water Pond Groundwater Treatment System
Former Plum Brook Ordnance Works, Sandusky, Ohio

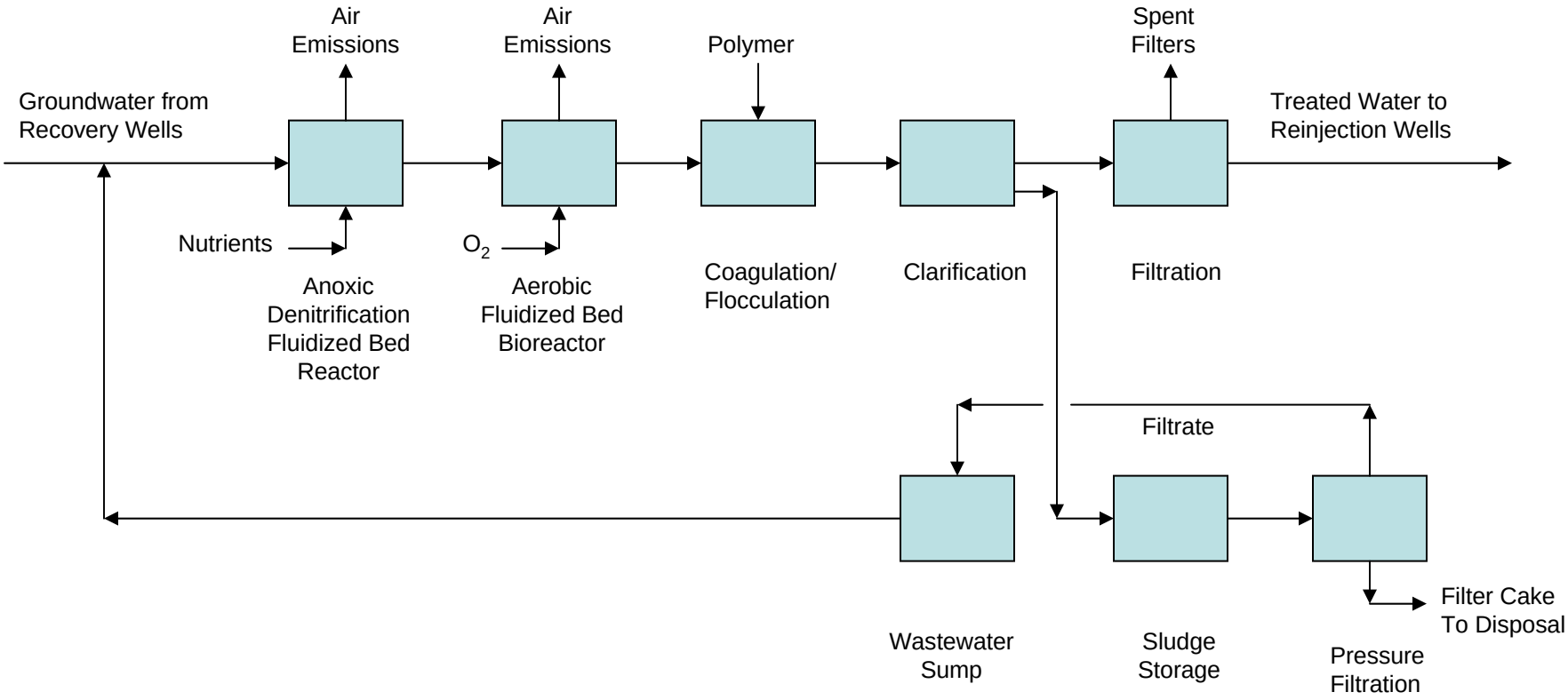

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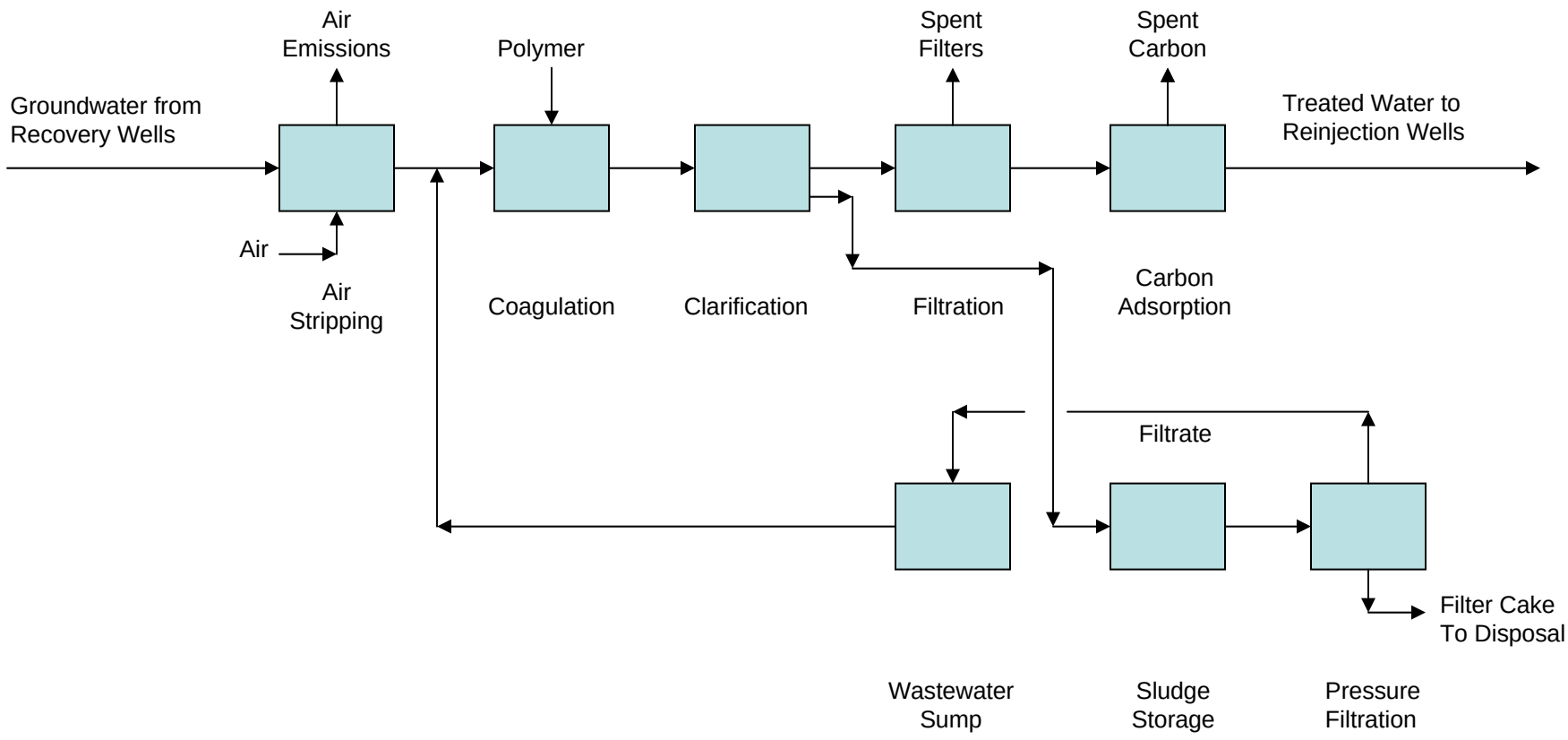
Figure 5-2
Block Flow Diagram for Pentolite Road Red Water Pond Groundwater Treatment System
Former Plum Brook Ordnance Works, Sandusky, Ohio



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APPENDIX A

GROUNDWATER FATE AND TRANSPORT MODELING

APPENDIX A

GROUNDWATER FATE AND TRANSPORT MODELING

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GROUNDWATER FATE AND TRANSPORT MODELING TO SUPPORT THE FEASIBILITY STUDY FOR GROUNDWATER TNT AND RED WATER POND AREAS FORMER PLUM BROOK ORDNANCE WORKS SANDUSKY, OHIO

JANUARY 2007

1.0 Introduction

A groundwater fate-and-transport model has been developed for the former Plum Brook Ordnance Works (PBOW) facility in Sandusky, Ohio. Nitroaromatics-contaminated soil and shallow groundwater were identified at the following five PBOW sites: TNT Area A (TNTA), TNT Area B (TNTB), TNT Area C (TNTC), the Pentolite Road Red Water Pond (PRRWP) Area, and the West Area Red Water Ponds (WARWP) Area. The shallow groundwater is located in the overburden/shale unit. Deeper groundwater is found within the limestone bedrock unit; only low concentrations of nitroaromatics have been detected in the limestone bedrock groundwater. A groundwater feasibility study (FS) is being performed at each of these five areas (refer to Figure 1-2 of the FS). Note that contamination has been found at other PBOW sites, but the FS and this modeling effort focus only on these five sites.

This model is used to help determine areas and environmental media that may be targeted for remediation. To support the FS, various modeling simulations were developed to determine the effect that various remedial approaches might have on future groundwater concentrations. The results, together with analytical data and site-specific information, are used as a guide for estimating potential groundwater concentrations, potential extent of groundwater contamination, plume migration, and developing remedial alternatives.

2.0 Previous Modeling

Groundwater fate and transport modeling was performed previously for PBOW to support the Baseline Human Health Risk Assessment for Groundwater (BHHRA) (Shaw Environmental, Inc. [Shaw], 2006). In that modeling effort, soil leachate concentrations were estimated using VLEACHSM (EPA, 1997). The modeling effort simulated the leachate concentrations

combining with the nitroaromatic plumes over time, and contaminant plumes were predicted within 150 years using a combination of MODFLOW (McDonald and Harbaugh, 1988) and MT3D (Zheng, 1992). Leaching and transport were modeled for the three primary contaminants associated with former PBOW activities: 2,4,6-trinitrotoluene (TNT), 2,4-dinitrotoluene (2,4-DNT), and 2,6-dinitrotoluene (2,6-DNT). The modeling effort for the BHHRA was performed assuming completion of the TNTB soil removal effort (WTI, 2005a) and removal of the small soil "hot spot" from the PRRWP Area (WTI, 2005b). No portion of the planned soil remediation actions to be taken at TNTA (USACE, 2004a) and TNTC (USACE, 2004b) was assumed to have been completed under the BHHRA modeling effort. Each of these soil remediation efforts is being performed primarily to reduce the potential impact for humans and ecological receptors who may contact site soil. However, these remediation efforts also represent vadose-zone source removals with respect to groundwater contamination.

The FS modeling effort is focused on supporting the development of remedial alternatives. Therefore, detailed descriptions of input parameters, conceptual model, model design, site physical condition (geology, hydrogeology and surface water bodies, etc), soil transport calibrations, and groundwater flow calibration, are not included in this report. Detailed information on these parameters can be referenced in the BHHRA modeling report (Appendix E of Shaw, 2006).

3.0 Review of Current Soil and Groundwater Concentrations____

This section provides a brief synopsis of the maximum concentrations of TNT, 2,4-DNT, and 2,6-DNT found in soil and groundwater at the three TNT and two Red Water Pond Areas. The text of the FS provides detailed information on the concentrations of contaminants detected in environmental media.

Soil. TNT was detected in soil at a maximum concentration of 54,969 mg/kg at TNTC Building 682 (boring TNTA-SO0165). Maximum concentrations of 2,4-DNT (8,912 mg/kg) and 2,6-DNT (10,274 mg/kg) were detected at TNTA Building 195 (boring TNTA-SO012). Slightly higher DNT concentrations were previously detected in a surface soil sample from Building 412, but soil from this TNTB area has already been removed and was not included in the BHHRA or FS modeling efforts. The locations of each soil boring used in the model, as well as the associated depth to water, soil concentration profile, and the excavation depth where soil excavation occurred or proposed are listed in Attachment A.

Groundwater. The highest overburden/shale groundwater concentrations of the three nitroaromatics evaluated in this model are as follows:

- TNT: 32,400 μg/L at TNTA location GW-06, 11,500 μg/L at TNTA location GW-05; 20,100 μg/L at TNTC location GW-08, and 9720 μg/L at TNTC location GW-05.

- 2,4-DNT: 37,600 μg/L at TNTC location GW-08, 4,610 μg/L at TNTC location GW-02; 6,900 μg/L at TNTA location GW-10; and 9,200 μg/L at abandoned PRRWP Area well PRRP-DP03.

- 2,6-DNT: 10,550 μg/L at TNTC location GW-08, 1,330 μg/L at TNTC location GW-02; 6,900 μg/L at TNTA location GW-10; and 550 μg/L at abandoned well PRRP-DP03 in the PRRWP Area

The three contaminants were not detected at high concentration in the limestone bedrock water-bearing zone. The maximum concentrations for each of the three main nitroaromatics in the limestone in the respective areas were as follows:

- TNT: 1.6 μg/L in the PRRWP Area;

- 2,4-DNT: 19 and 1.5 μg/L in the WARWP Area and PRRWP Area, respectively; and

- 2,6-DNT: 3.6 and 1.4 μg/L in TNTA and the PRRWP Area, respectively.

These plumes were presented on Figures 3-5 through 3-21 in Appendix E of the BHHRA (Shaw, 2006) and are again presented in this report as Figures 3-1 through 3-17.

4.0 Modeling Procedures

In the current modeling effort, the soil concentration profiles with respect to depth for the three contaminants (see Attachment A) under different remedial approaches were used as inputs in the VLEACHSM model. These approaches, described in the FS, were reflected in the model simulations that were used to predict the future soil concentration profiles and mixing concentrations from soil leachate. The mixing concentrations from soil leachate were added to the groundwater plumes over time using MT3DMS code. The transport model was then run for a 150-year period with virtually the same set of model parameters as were used to support the BHHRA.

Different soil excavation scenarios were used under the remedial approaches presented in the soil FS reports. The depth of soil excavation at each location varied based on contaminant depths and concentrations, and the total excavation depths proposed in the FS were based on an estimated depth to overburden/shale groundwater. This estimated depth to overburden/shale groundwater was based on the evaluation of historical data available at the time of the report. In the groundwater model, the depth to groundwater is simulated based on one data set that was deemed to be most representative of the general conditions at PBOW. In addition, the modeled and measured depths to water are similar but not identical because the nature of groundwater model calibration does not allow for exact matching of simulated water levels at most locations. Because of this scenario, it is possible that the estimated depths to groundwater used in the FS reports may be less than the modeled depths by 1 to 2 feet. This will result in a 1- or 2-foot-thick layer of residual soil below proposed or actual excavation depths and the top of the simulated saturated zone. The end result of this is that the residual soil layer, if contaminated, is in close proximity to the water table and may result in model simulations showing a long-term impact to the overburden/shale and possibly the limestone. This residual soil layer presents a difficulty in treating soil at or near the water table. In practice, overburden/shale groundwater elevations can fluctuate markedly at PBOW. If soil excavations are conducted during wet (high groundwater) conditions, and any in situ groundwater treatment is conducted at low water conditions, it is possible that some soil sources that potentially will impact overburden/shale groundwater may not be remediated. Optimally, soil excavations would be completed during drier periods of the year with a lower water table.

5.0 Model Simulations and Results

Five simulations were run using the fate and transport model. The FS remedial alternatives, or components thereof, are reflected in the model simulations, which are described in the following paragraphs.

Simulation No. 1: No Further Action (Partial Soil Remediation). Remediation at TNTB and the small hot spot at the PRRWP Area are assumed to be complete. The modeling assumptions/results are those presented in the BHHRA. It is assumed that all soil within the remediated areas of TNTB and the PRRWP Area hot spot is clean. Residual soil underlying these excavations is assumed to be at the concentrations detected in confirmation floor samples or other representative samples where floor samples are not available. The representative samples include deeper samples underlying the excavation or samples collected at the most appropriate depth and location if samples underlying the excavation are not available. Because

Simulation No. 1 does not include the planned remediation of TNTA, TNTC, and the PRRWP, this model run represents less remedial action than that included for FS Alternative GW-1.

Simulation No. 2: No Further Action (Complete Soil Remediation). All planned soil remediation at the five areas is assumed to be complete, including the dark layer delineated at the PRRWP Area. This simulation represents FS Alternatives GW-1 and GW-2. Note that Alternative GW-2 also includes groundwater monitoring and groundwater use restrictions. Residual soil underlying these excavations is assumed to be at the concentrations detected in confirmation floor samples (TNTB and PRRWP only) or other representative samples where floor samples are not available. The representative samples include deeper samples underlying the (planned) excavation or samples collected at the most appropriate depth and location if samples underlying the excavation were not collected.

Simulation No. 3: Completed Soil Remediation and In Situ Enhanced Bioremediation (ISEB) of the Overburden/Shale. This simulation includes all conditions under Simulation No. 2, plus ISEB for treatment of contamination in the overburden/shale groundwater. Simulation No. 3 reflects the soil remediation and ISEB components of the FS Alternatives GW-3 and GW-4. In the model, the water quality in the overburden was assumed clean after implementation of ISEB. Note that this simulation includes essentially the same areas for ISEB treatment as FS Alternative GW-4, but includes greater areas for ISEB treatment than does Alternative GW-3. Note that Alternatives GW-3 and GW-4 also includes groundwater monitoring and use restrictions.

Simulation No. 4: Completed Soil Removal, ISEB of the Overburden/Shale, and Pump and Treat (P&T). This simulation includes all conditions under Simulation No. 3, plus P&T in the limestone bedrock groundwater at the PRRWP and WARWP Areas, and P&T in the overburden/shale at the WARWP Area. This simulation reflects FS Alternative GW-4. In the model, the groundwater in the overburden was assumed to be clean after implementation of ISEB. The overburden/shale P&T was introduced in the WARWP Area to minimize drawn-down of potential future contamination associated with leachate from residual soil contamination. As noted in the previous section, this is an example of deep, low-level soil contamination near the water table. While it does present a potential for leaching, it likely can be addressed by groundwater treatment in the overburden during wet periods of the year. The inclusion of P&T in the overburden (little or no shale is present in the WARWP area) was used in the simulation to eliminate impact to the bedrock due to drawdown caused by proposed P&T in the limestone. By eliminating the potential leaching sources and overburden groundwater, an unbiased evaluation of the long-term effectiveness could be performed. As noted in the FS, P&T

in the overburden is not deemed to be a viable component because of the wide fluctuation in groundwater elevations in that unit. Alternative GW-4 also includes groundwater monitoring and groundwater use restrictions. Note that for reasons stated in Section 4.3.3 of the FS, Alternative GW-4 does not include groundwater P&T in the overburden/shale unit.

Simulation No. 5: Completed Soil Removal, ISEB of the Overburden/Shale, P&T, and Additional Soil Removal at the Red Water Pond Areas. This simulation includes all conditions under Simulation No. 3, P&T in the limestone bedrock groundwater, and removal of all residual contamination from PRRWP Area and WARWP Area soil. This component of the soil removal from the Red Water Pond Areas is not planned or recommended in for the FS. It was performed only to evaluate the effectiveness of P&T at removing contamination from the limestone bedrock aquifer under a "best case" scenario. In the model, the groundwater in the overburden was assumed to be clean after implementation of ISEB.

The following subsections describe the results and implications of each model simulation. Note that the groundwater model simulations assume that the groundwater plumes will be subject to natural attenuation with advection (dilution), dispersion, and adsorption (retardation); however, no biodegradation or abiotic degradation component was included in the model. As described in Section 2.7 of the FS text, the reducing conditions in the limestone bedrock groundwater are conducive to both biotic and abiotic degradation of nitroaromatics.

5.1 Results of Simulation No. 1 – No Further Action (Partial Soil Remediation)

Simulation No. 1 presents predicted future concentrations of the site as it currently exists: planned remedial activities at TNTA, TNTC, and the PRRWP Area are not included. The results of Simulation No.1 (Tables 5-1[a] through 5-1[f]) clearly show that the three nitroaromatic contaminants would decrease in maximum concentrations over time in the overburden/shale (Layer 1) but increase in the limestone bedrock (Layer 3) due to vertical migration from the overburden/shale to the bedrock. Tables 5-1(a) through 5-1(f) present the modeling results in the four layers included in the model; Layers 1 and 2 are the overburden/shale water-bearing unit and Layers 3 and 4 are limestone bedrock unit. Most of the overburden/shale groundwater contamination appears to be in Layer 1, and leachate from soil would more directly affect Layer 1 (shallow overburden/shale) than Layer 2 (deeper overburden/shale). With respect to areas of groundwater contamination in the limestone bedrock unit, greater impact is modeled for Layer 3 (uppermost portion of the limestone) than the deeper Layer 4 (deeper limestone). Therefore, the focus of this evaluation is on Layers 1 and 3 because these are the respective overburden/shale and limestone bedrock layers that, in general, are most impacted or have the greatest potential for impact by site contaminants.

The maximum concentrations of TNT, 2,4-DNT and 2,6-DNT among the five sites are predicted to decrease from 32,400 to 18659.4 µg/L (TNT at TNTA), from 37,600 to 11391.8 µg/L (2,4-DNT at TNTC), and from 10,550 to 125.5 µg/L (2,6-DNT at TNTC) in the overburden/shale in 150 years. However, the maximum concentrations of these three nitroaromatics are predicted to increase from 1.6 to 13.1 µg/L (TNT), from 19 to 87 µg/L (2,4-DNT), and from 3.6 to 56.3 µg/L (2,6-DNT) in the limestone bedrock in 150 years. Further, this increasing trend in the limestone appears to continue after 150 years for TNT and 2,4-DNT as indicated in these tables. The representative figures showing different contaminant plumes at various time periods in the overburden/shale and limestone bedrock groundwater can be found in Appendix E of the BHHRA. As mentioned in Section 5.0, this simulation does not directly apply to any of the FS remedial approaches and is provided for comparison only.

5.2 Results of Simulation No. 2 – No Further Action (Completed Soil Remediation)

Simulation No. 2 presents predicted future groundwater concentrations assuming that all planned soil remedial actions have been completed. The results for Simulation No. 2 are presented in Tables 5-2(a) through 5-2(f). If the results of these tables are compared to those of Tables 5-1(a) through 5-1(f) for Simulation No. 1, it can be observed that the maximum concentrations of each contaminant are not predicted to decrease appreciably as a result of the soil remediation introduced for TNTA, TNTC, and the PRRWP. For example, at TNTC after 150 years in the overburden/shale (Layer 1) the Simulation No. 2 TNT concentration is 4681.7 versus 4702.8 µg/L for Simulation No. 1, the 2,4-DNT concentration under Simulation No. 2 is 8259.7 versus 11,391.8 µg/L under Simulation No. 1, and the 2,6-DNT concentration of 119.8 µg/L under Simulation No. 2 is only slightly less than the 125.5 µg/L predicted under Simulation No. 1. The comparisons between the predicted concentrations in Simulations Nos. 1 and 2 are similar for TNTA and the PRRWP Area, although at these two areas the 2,4-DNT concentrations of Simulation No. 2 were much closer to those of Simulation No. 1.

Within the limestone bedrock at TNTC, the results of Simulation No. 2 are again found to be very similar to those of Simulation No. 1 with respect to TNT and 2,4-DNT. For example, after 150 years in the limestone bedrock (Layer 3) at TNTC, the Simulation No. 2 TNT concentration is 12.24 versus 13.1 µg/L for Simulation No. 1, and the 2,4-DNT concentration under Simulation No. 2 is 86.8 versus 87 µg/L under Simulation No. 1. The 2,6-DNT concentration of 34.7 µg/L under Simulation No. 2 is appreciably less than the 56.3 µg/L predicted under Simulation No. 1 for TNTC, though still does not represent the major source of groundwater impact to the limestone bedrock. These observations of little difference between Simulations Nos. 1 and 2 for

TNT and 2,4-DNT, with greater differences in 2,6-DNT concentrations between the two model simulations were observed for TNTC and the PRRWP Area also. It is likely that the differences in 2,6-DNT concentrations between Simulations Nos. 1 and 2 are mostly due to a slight model adjustment of the soil adsorption constant for this compound after the BHHRA modeling effort.

These results indicate that groundwater migration is predominantly controlled by the contaminant plumes in the overburden/shale layers and not by the soil leachate. This is true even of 2,6-DNT because the differences in 2,6-DNT concentrations between Simulation No. 1 and Simulation No. 2 were not observed in the overburden/shale. Note that in the case of 2,4-DNT and 2,6-DNT, the simulation results in the tables show some increases over time as compared to Alternative 1 (e.g., WARWP Area 2,4-DNT concentrations in Layer 3 of Simulation No. 2 versus Simulation No.1; TNTB 2,6-DNT concentrations in Layers 2 and 3 of Simulation No. 2 versus Simulation No. 1). This was caused by slight model adjustments or correction of soil concentrations at some locations in this FS modeling effort. However, the nature of the simulation results remain unchanged.

5.3 Results of Simulation No. 3 – Completed Soil Remediation and ISEB of the Overburden/Shale

Simulation No. 3 presents the predicted concentrations of contaminants assuming that planned soil remedial efforts have been completed and the current overburden/shale groundwater plumes have been remediated (using ISEB). The goal of this model simulation is to eliminate the contamination in the overburden/shale that could potentially migrate vertically downward to the limestone bedrock and thereby exacerbate the current limestone bedrock contamination, especially in the PRRWP and WARWP Areas. Because this simulation eliminates overburden/shale plumes, it provides an insight as to the contribution of soil leachate to the overburden/shale layer in specific areas.

Simulation No. 3 results are presented in Tables 5-3(a) through 5-3(f). Plume maps for different contaminants in the overburden and bedrock were generated over different time periods of significance. Figures 5-1 through 5-4 show simulated TNT plume(s) in different areas after 150 years. Because TNT is not predicted to appear in the bedrock, no plume maps were generated. The appearance of TNT plume(s) in the overburden/shale in Simulation No. 3 is due to soil leachate since the overburden is assumed to be clean after ISEB treatment.

Figures 5-5 through 5-12 show the time at which maximum concentrations of 2,4-DNT appears in the overburden/shale and after 150 years under Simulation No. 3 in the five site areas. Again, the appearance of 2,4-DNT in the overburden/shale is due to soil leachate. These concentrations

may peak at sometime and subside thereafter during the 150-year period. No simulated 2,4-DNT plume is observed in bedrock at TNTA, TNTB, and TNTC. However, the currently observed limestone bedrock 2,4-DNT plume in the WARWP Area appears to move very slowly and is not reduced in extent as significantly as the plume in the PRRWP Area (Figures 5-10 and 5-12).

Figures 5-13 through 5-23 show the time at which maximum concentrations of 2,6-DNT appears in the overburden/shale and after 150 years under Simulation No. 3 in the five site areas. The appearance of 2,6-DNT is due to soil leachate. Currently, there are 2,6-DNT plumes existing in the bedrock in the areas of TNTA, TNTC, the PRRWP Area, and the WARWP Area (Figure 1-18). Due to the slow movement of groundwater in the bedrock and vertical migration of soil leachate into this layer, low levels of 2,6-DNT plumes still appear in TNTA, TNTB (note: no plume in this area currently), TNTC, and the PRRWP Area after 150 years. Even though a low level 2,6-DNT plume was detected in the bedrock in the western boundary of WARWP area, it is diluted to below its remedial goal objective (RGO) (i.e., 0.5 µg/L) in a relatively short period of time and is untraceable in the modeling result after 150 years. It is also noteworthy to see that soil leachate would migrate downwards from the overburden to this layer in TNTB and TNTC after 115 to 150 years as shown in Figure 5-17 and 5-20.

Results of Simulation No. 3 are described more specifically for each area in the following paragraphs.

TNTA. TNT concentrations in the overburden/shale are predicted to decrease and, after 70 years, reach their RGO (3 µg/L) and would continue to decrease thereafter. TNT is not predicted to reach the limestone bedrock groundwater. Concentrations of 2,4-DNT and 2,6-DNT are predicted to reach their maximum concentrations (10.9 and 23.8 µg/L, respectively) in the overburden/shale within 25 years and then decrease to concentrations approximating their RGO (0.5 µg/L) by Year 150 (0.8 and 0.9 µg/L, respectively). DNTs from the overburden/shale are not predicted to reach the limestone bedrock (Table 5-3[b]). The current 2,4-DNT plume (0.49 µg/L) is predicted to remain at or below its RGO of 0.5 µg/L throughout the 150-year model period. The 2,6-DNT plume is predicted to remain virtually constant at the current concentration of 3.6 µg/L (predicted to decrease negligibly to 3.5 µg/L at Year 150). Note that the current 3.6 µg/L 2,6-DNT plume is based on a sample collected from well TNTA-BEDMW-018 that was collected in 1998 and analyzed using Method 8330 explosives analysis. 2,6-DNT was not detected in the aliquot from this 1998 sample that was analyzed using Method 8270 for semivolatiles, nor was it detected in three other samples collected from this well. Therefore, this plume does not appear to be widespread or consistent with any known source area, and it may be the result of a laboratory artifact.

TNTB. TNT concentrations in the overburden/shale are predicted to reach a maximum (43.2 µg/L) after 45 years and then steadily decrease thereafter to a concentration of 8.2 µg/L (Table 5-3[c]). This would occur in the vicinity of Building 463; in no other overburden/shale area would the groundwater concentration exceed the RGO. TNT is not predicted to reach the limestone bedrock groundwater. Concentrations of 2,4-DNT and 2,6-DNT are predicted to reach their maximum concentrations (306.1 and 447.4 µg/L, respectively) in the overburden/shale within 45 years and then decrease to concentrations of 33.5 and 39.4 µg/L, respectively. 2,4-DNT from the overburden/shale is not predicted to reach the limestone bedrock (Table 5-3[c]). However, 2,6-DNT from the overburden/shale is predicted to reach the limestone bedrock groundwater at a concentration of 1.4 µg/L after 110 years, and the concentration is predicted to increase to 2.5 µg/L after 150 years. This exceeds the RGO of 0.5 µg/L. Note that the location of the maximum TNT, 2,4-DNT, and 2,6-DNT concentrations on each of the overburden/shale plumes shown on Figures 5-2, 5-6, and 5-15 result from a sample collected at Building 463 at a depth of 8 to 10 feet that was within the footprint of the excavation. No post-excavation floor sample could be taken from this location, because the excavation which was dug to a depth of approximately 10 feet filled with water. This 8 to 10 foot sample was conservatively used to estimate residual concentrations beneath the excavation. This sample actually was below the water table at the time of remediation. Therefore, contamination at this location should be viewed as leachate rather than soil. Each of the other plumes shown on these figures are associated with residual soil concentrations less than 10 mg/kg.

TNTC. TNT concentrations in the overburden/shale are predicted to reach a maximum (500.2 µg/L) after 1 year and then steadily decrease thereafter to a concentration of 40.8 µg/L after 140 years before increasing slightly to 42.7 µg/L at Year 150 (Table 5-3[d]). Both 2,4-DNT and 2,6-DNT are predicted to reach their maximum concentration at Year 10 (1388.2 and 1588.2 µg/L, respectively) and gradually decrease to concentrations of 34.6 and 1.2 µg/L throughout the 150-year duration. Neither TNT nor 2,4-DNT are predicted to reach the limestone bedrock groundwater (Layer 3). Thus, the current 0.1 µg/L 2,4-DNT plume would remain below the RGO of 0.5 µg/L. 2,6-DNT was detected in the limestone bedrock groundwater at 0.7 µg/L. The limestone 2,6-DNT concentration is predicted to rise above the RGO from 1.1 µg/L at Year 50 and then gradually increase to 1.7 µg/L after 150 years. The maximum concentration of 2,4-DNT in the overburden/shale, and the maximum concentrations of 2,6-DNT in the overburden/shale and the limestone bedrock groundwater, are predicted to occur in the area (or downgradient) of Building 603. These concentrations result from soil concentrations of 2,4-DNT and 2,6-DNT at 28.05 mg/kg at a depth of 8 to 10 feet. The location of this sample underlies the planned excavation of 8 feet, which was based on the depth to groundwater. If

groundwater is not encountered at 8 feet during excavation of Building Area 603, this 8 to 10 foot soil interval would be removed until soil meets the soil cleanup criteria or groundwater is encountered. If groundwater were to be encountered at or before the 8 to 10 foot interval, then this contamination would be viewed as leachate rather than soil.

PRRWP Area. TNT concentrations in the overburden/shale are predicted to reach a maximum of 138.9 µg/L after 20 years and then steadily decrease thereafter to a concentration of 18.5 µg/L after 150 years (Table 5-3[e]). Both 2,4-DNT and 2,6-DNT are predicted to reach their maximum concentrations at 1 year (4215.9 µg/L and 324.3, respectively) and gradually decrease to respective concentrations of 205.8 and 6.6 µg/L throughout the 150-year duration. These overburden/shale groundwater concentrations are based on leaching from soil at TNT concentrations not exceeding 1.4 mg/kg and 2,6-DNT not exceeding 3.6 mg/kg. 2,4-DNT soil concentrations were detected at up to 26 mg/kg, but the higher concentrations were near or possibly below the water table. TNT from the overburden/shale is not predicted to affect the limestone bedrock groundwater. The current 2,4-DNT limestone plume is predicted to decrease from 1.5 to 1.3 µg/L throughout the 150-year simulation period; there is no discernible effect from the overburden/shale groundwater contamination on the limestone with respect to 2,4-DNT. 2,6-DNT from the overburden/shale is affecting the 2,6-DNT concentration in the limestone; the current 1.4 µg/L 2,6-DNT plume in the limestone is predicted to decrease to 0.9 µg/L after 65 years but begins to increase at 95 years to a maximum of 1.7 µg/L at Years 130 to 145, before decreasing to 1.2 µg/L at Year 150. Figure 5-12 shows that the extent of this plume would decrease.

WARWP Area. TNT concentrations in the overburden/shale are predicted to reach a maximum of 99.4 µg/L after 1 year and then steadily decrease thereafter to a concentration below the RGO at Year 70 (Table 5-3[e]). Both 2,4-DNT and 2,6-DNT are predicted to reach their maximum concentrations at 1 year (1054 and 243.2 µg/L, respectively) and gradually decrease to respective concentrations of 54.4 and 0.9 µg/L throughout the 150-year duration. These overburden/shale groundwater concentrations are based on leaching from very low soil concentrations. The residual soil concentrations do not exceed 3 mg/kg TNT, 6.5 mg/kg 2,4-DNT, and 1.5 mg/kg 2,6-DNT. The highest of these residual soil concentrations were collected at depths that are likely below the water table during the wet season. TNT from the overburden/shale is not predicted to affect the limestone bedrock groundwater. The current 2,4-DNT limestone plume is predicted to remain at about 19 µg/L throughout the 150-year simulation period. No effect on this plume from the overburden/shale groundwater is discernible. The current 0.43 µg/L 2,6-DNT plume is apparently affected by the overburden/shale groundwater contamination, but is predicted not to exceed the RGO of 0.5 µg/L over the 150-year simulation period.

5.4 Results of Simulation No. 4 – Completed Soil Removal, ISEB of the Overburden/Shale, and P&T

Simulation No. 4 presents the predicted concentrations of contaminants assuming that planned soil remedial efforts have been completed, the current overburden/shale groundwater plumes have been remediated (using ISEB), future plume migration downward in the WARWP is mitigated through P&T in the overburden/shale, and limestone bedrock groundwater contamination is being remediated in the WARWP and PRRWP Areas using P&T. The goal of this model simulation is to determine the effectiveness of P&T at remediating the PRRWP and WARWP plumes to drinking water quality, when coupled with soil remediation and ISEB. The results of Simulation No. 3, discussed in Section 5.3, predict that the implementation of soil remediation and ISEB alone will not result in reaching the RGO for 2,6-DNT at the WARWP Area and the RGOs for 2,4-DNT and 2,6-DNT at the PRRWP Area groundwater plumes.

Since the limestone bedrock DNT plumes exist in the PRRWP and WARWP Areas, Simulation No. 4 includes extraction wells only in these two areas. As mentioned, the objective is to remediate the groundwater within the limestone bedrock groundwater to RGOs. Therefore, placement of extraction wells is focused on the bedrock water-bearing unit. Some preliminary modeling indicated that extraction wells were also needed in the overburden/shale groundwater to mitigate against contaminants from migrating downward to the limestone bedrock at the WARWP Area. The number of wells and their respective pumping rates were determined by trial and error to avoid dewatering and still capture the plumes. The final "best" solution was to place three wells in the overburden in the WARWP Area, each at a pumping rate of 2 gallons per minute (gpm), at locations where soil leachate simulations exhibited high concentrations and three wells in the bedrock, each also at 2 gpm (see Figure 5-24). In the PRRWP area, four extraction wells were placed in the limestone bedrock groundwater only, each at a pumping rate of 2 gpm (Figure 5-25).

Simulation No. 4 is essentially the same in the TNT Areas as Simulation No. 3. It is noted that a comparison of Simulations Nos. 3 and 4 indicates some effect of the pumping wells on overburden/shale and limestone groundwater in the TNT Areas, especially with respect to 2,6-DNT. However, given the remoteness of the TNT Areas to the modeled extraction well locations and the low pumping rates, the model's predictions concerning these effects on the TNT Area are questionable. Therefore, the results of Simulation No. 4 for the TNT Areas are presented on Tables 5-4(b) through 5-4(d), but they are not discussed in this section. Instead, the results of Simulation No. 3, discussed in Section 5.3, are assumed to portray the effects of

Simulation No. 4 with respect to TNTA, TNTB, and TNTC. The results of Simulation No. 4 for the PRRWP and WARWP Areas are presented in Tables 5-4(e) and 5-4(f).

The results of Simulation No. 4 indicate that P&T in the overburden and in the bedrock is not effective at reducing 2,4-DNT in the bedrock to below its RGO (0.5 µg/L) at the WARWP Area, and P&T in the limestone bedrock groundwater is not effective at reducing 2,4-DNT concentrations for the PRRWP Area. However, the extent of the plumes are reduced and contained (Figures 5-24 and 5-25). TNT was not predicted to affect the limestone bedrock in either the PRRWP or WARWP Areas, so no plume figure is provided. Plume figures are not provided for 2,6-DNT because its extent and maximum limestone bedrock groundwater concentration are similar to those of 2,4-DNT in the PRRWP Area plume, and its maximum concentration in WARWP Area limestone bedrock groundwater was initially less than the RGO and is substantially less than for 2,4-DNT.

Results of Simulation No. 4 are described by area for the PRRWP and WARWP Areas in the following paragraphs. The results are also compared to those of Simulation No.3 to more specifically evaluate the effects of the P&T.

PRRWP Area. After 150 years, the P&T resulted in lower concentrations of TNT and 2,4-DNT in the overburden/shale when compared to soil remediation and ISEB only as was done in Simulation No. 3. The TNT overburden/shale concentration was reduced after 150 years to 12.7 µg/L using P&T as compared to 18.5 µg/L under Simulation No. 3. Similarly, the addition of P&T reduced the overburden/shale concentration to 114 µg/L after 150 years instead of 205.8 µg/L under Simulation No. 3. The predicted overburden/shale concentration of 2,6-DNT at 150 years was shown to increase by the addition of P&T from 6.6 µg/L under Simulation No. 3 to 35.1 µg/L under Simulation No. 4. The overburden/shale concentrations of TNT did not affect the current limestone concentration of 1.6 µg/L. The results of 2,4-DNT in the limestone were virtually identical to those under Simulation No. 3, resulting in a decrease from the current 1.5 to 1.3 µg/L in the limestone bedrock over the 150-year simulation period. The 2,6-DNT limestone plume was predicted to slightly decrease over the 150-year period, from 1.4 to 1.2 µg/L. Even though Alternative 3 showed concentrations up to 1.7 µg/L over the 150-year simulation period that were not predicted for Simulation No. 4, the concentration under Simulation No. 4 is slightly higher at year 150 than under Simulation No. 3 (1.3 and 1.2 µg/L, respectively). Overall, these model results show that the P&T is ineffective at reducing limestone groundwater concentrations to levels below the RGOs.

WARWP Area. The addition of P&T resulted in nearly identical results for TNT in overburden/shale groundwater; under Simulation No. 4 the TNT concentration reached and remained under the RGO at Year 70 instead of at Year 65 under Simulation No. 3. Simulation No. 4 resulted in an appreciably lower 2,4-DNT concentration (13.5 µg/L) after 150 years as compared to Alternative No. 3 (54.4 µg/L), but a higher 2,6-DNT concentration (13.3 µg/L versus 0.9 µg/L under Simulation No. 3). The overburden/shale concentrations of TNT did not affect the limestone bedrock groundwater. The Simulation No. 4 results of 2,4-DNT in the limestone show a very slight overall decrease from 19 to 18.1 µg/L at after 150 years; however, Simulation No. 4 reaches a predicted maximum 2,4-DNT concentration of 24.3 µg/L after 70 years. Although Simulation No. 3 predicts virtually no decrease, neither does it show this interim decrease predicted under Simulation No. 4. Under Simulation No. 4, the predicted 2,6-DNT concentration increased from a current concentration of 0.43 µg/L, which is less than the RGO (0.5 µg/L), to a high of 11.3 µg/L at Year 105 and remaining above the RGO at 7.6 µg/L after 150 years. Even with P&T in the overburden/shale groundwater, the model clearly portrays that P&T would draw the 2,6-DNT contamination downward to the limestone. In summary, the model predicts that Simulation No. 4 is ineffective at reducing 2,4-DNT below the RGOs and would increase 2,6-DNT to concentrations that exceed the RGO.

5.5 Results of Simulation No. 5 – Completed Soil Removal, ISEB of the Overburden/Shale, P&T, and Soil Removal at the Red Water Pond Areas

As described in Section 5.0, Simulation No. 5 does not reflect any of the FS remedial alternatives. Instead, Simulation No. 5 represents a refined examination of the P&T component of FS Alternatives GW-3 and G-4. Simulation No. 5 was developed after a comparison of the results of Simulations Nos. 3 and 4: Simulation No. 4 shows very little reduction in the 2,4-DNT plume concentrations over Simulation No. 3, and the predicted 2,6-DNT concentrations at the WARWP Area were shown to increase in the limestone bedrock groundwater under Simulation No. 4. This lack of the effectiveness of P&T under Simulation No. 4 might have been attributed to the continuous soil leachate from overlying soil. Therefore, Simulation No. 5 was run to gain a better understanding of the effectiveness of P&T at remediating the current limestone bedrock groundwater plumes under a hypothetical “best case” scenario in the absence of continuing sources, including groundwater contamination in the overburden/shale and with all potential leaching sources associated with soil contamination.

The P&T component of Simulation No. 5 differs slightly from Simulation No. 4. Two pumping schemes were developed under Simulation No. 5, which will be referred to as “5a” and “5b”. Simulation No. 5a includes five wells in the PRRWP Area limestone bedrock groundwater plume, each pumped at 2 to 2.5 gpm, and three limestone bedrock groundwater wells in the

WARWP Area, each pumped at 2 gpm (Figures 5-26 and 5-27). Simulation No. 5b includes seven limestone bedrock groundwater extraction wells in the WARWP Area, each pumped at 1.03 to 2 gpm and seven limestone bedrock extraction wells in the PRRWP Area, each pumped at 1.6 to 2 gpm (Figures 5-28 and 5-29). The differences in the performances of Simulation No. 5a as compared to 5b were minor in the PRRWP Area (Figures 5-25 and 5-27), but Simulation No. 5b resulted in lower concentrations at the WARWP. Note that it was unnecessary to place any wells in the overburden/shale because under this simulation all overburden/shale groundwater and associated soil was assumed to be remediated.

Simulation No. 5 is essentially the same in the TNT Areas as Simulation No. 3. It is noted that a comparison of Simulations Nos. 3 and 5 indicates some impact of the pumping wells on overburden/shale and limestone groundwater in the TNT Areas. However, given the remoteness of the TNT Areas to the modeled extraction well locations and the low pumping rates, the model's predictions concerning these effects on the TNT Area are questionable. Therefore, the results of Simulation No. 5 for the TNT Areas are included on Tables 5-5(a) through 5-5(d), but they are not discussed in this section. Instead, the results of Simulation No. 3, discussed in Section 5.3, are assumed to represent the effects of Simulation No. 5 with respect to TNTA, TNTB, and TNTC. The results of Simulation No. 5 for the Red Water Pond Areas are presented in Tables 5-5(e) and 5-5(f).

In general, Simulation No. 5 models that P&T is ineffective at reducing the concentrations of 2,4-DNT and 2,6-DNT in the PRRWP Area limestone bedrock groundwater to RGOs. Similarly, P&T is shown to be ineffective at reducing 2,4-DNT concentrations in WARWP limestone bedrock groundwater to RGOs. Results of Simulation No. 5b are described by area for the PRRWP and WARWP Areas in the following paragraphs. The results are also compared to those of Simulation No. 4 to more specifically evaluate the effects of the P&T scenario assumed under Simulation No. 5b.

PRRWP Area. The resulting concentrations of 2,4-DNT in the limestone were only marginally less after 150 years under Simulation No. 5b (1.1 µg/L) than under Simulation No. 4 (1.3 µg/L). The results for 2,6-DNT were identical under Simulations Nos. 4 and 5b, with a reduction to 1.2 µg/L after 150 years. Considering that the starting concentrations for 2,4-DNT and 2,6-DNT are 1.5 and 1.4 µg/L, respectively, these reductions in concentrations are negligible. However, as is observed by comparing Figures 5-27 and 5-29, the P&T under Simulation No. 5b would break the plume into smaller areas under Simulation No. 5b, thus reducing the total volume of contamination.

WARWP Area. The results of Simulation No. 5b show a much larger decrease of the maximum 2,4-DNT concentration in the limestone groundwater than do the results of Simulation No. 4. After 150 years, the plume is predicted to decrease from an initial 2,4-DNT concentration of 19 to 3.2 µg/L under Simulation No. 5b, whereas this plume is predicted at 18.1 µg/L under Alternative No. 4 after 150 years. It is possible that additional pumping beyond 150 years may further reduce the 2,4-DNT concentrations to the RGO. Note that the initial 0.43 µg/L 2,6-DNT plume would remain below the RGO under Simulation No. 5b due to a lack of continuing source.

6.0 Evaluation of Modeling Uncertainties

While modeling is an important tool that aids in understanding very complex vadose and saturated conditions at contaminated sites, the limitations of the data and assumptions that are made can bias results. In general, where data are limited or sometimes lacking, conservative estimates are used for model inputs based on literature values. For example, organic carbon data is frequently estimated based on soil types. A high organic content tends to limit contaminant leaching of certain types of compounds, including nitroaroamatics. In addition, the vadose zone is treated as if this media were homogeneous, meaning that surface water infiltration occurs uniformly across a site. In reality, soil fractures and textural changes in the soil generally result in preferential pathways for infiltration. Also, nitroaromatics in soil tend to be relatively heterogeneously distributed rather than homogeneous as assumed by the model. In addition, in areas where the concentrations of nitroaromatics in soils varied, the higher values were assumed for the leaching model, further biasing the results.

Even in the best characterized sites, input parameters for groundwater flow and fate and transport modeling are based on widely spaced monitoring wells and assumptions are made regarding input parameters such as porosity, groundwater elevation and hydraulic conductivity where measurements are not available. Porosity is typically based on literature values based on specific soil types. Bedrock porosity is more difficult to determine since it is driven by fracture networks. At PBOW, groundwater elevations tend to fluctuate, particularly in the overburden/shale. During periods of low precipitation, the overburden/shale groundwater is found in discrete pockets and is not interpreted to represent a continuous saturated unit across the site. During wetter periods, the overburden/shale may be saturated across the entire site. The transient nature of groundwater at PBOW leads to difficulties in modeling since the model is calibrated against one set of groundwater conditions. The groundwater elevation data chosen was based on a period of average precipitation resulting in the overburden/shale being completely saturated across the site. This in effect will result in increased groundwater

movement laterally through the overburden/shale, and also increased downward movement of groundwater into the limestone bedrock.. The end effect is that the plumes tend to get larger in the overburden/shale and more contamination is transported from the overburden/shale into the limestone bedrock. Hydraulic conductivity in the model is initially based on results of aquifer tests from single wells. These slug tests only determine hydraulic conductivity for a small area surrounding the well with the results extrapolated across the site. Some error is inherent in estimating the hydraulic conductivity in areas that are not adequately characterized, but model calibration is done to minimize the effect. The end result however, is that actual groundwater flow may be faster or slower than what is predicted.

Groundwater models such as MODFLOW applied to fractured bedrock assume that it behaves as an equivalent porous media. That is, the modeling is done assuming there is a dense network of fractures that result in the system behaving in a similar fashion to unconsolidated material. However, if the fracture flow system were to be dominated by a small number of widely spaced fractures, this accuracy of the flow model would decrease. In addition, data needed for fully characterizing fracture flow systems is difficult and costly to obtain. A key component of the site conceptual model includes natural attenuation. Because there is no data available, the groundwater model assumed no attenuation was occurring. This assumption introduces potentially a very strong bias that would result in an overestimate of the contaminant concentrations and aerial extent of plumes in groundwater.

An example of some of the uncertainties in the model is the relative location of contamination to the water table. It is noted that the site groundwater model is highly sensitive to low concentrations of COCs that are within 2 feet or less of the water column. In such instances, the model has predicted that a DNT concentration as low as 0.16 mg/kg (less than the detection limit) would result in overburden/shale groundwater concentrations that exceed the RGO by an order of magnitude. However, such soil concentrations were typically not found to correlate with such high concentrations based on the empirical results of collocated soil and groundwater samples. Again, the model does not predict that such low soil concentrations would at all impact the limestone bedrock aquifer. Similarly, small changes in groundwater flow gradients during the simulation of groundwater extraction at the WARWP and PRRWP caused increased leaching in the TNT areas. This seems unlikely given the distance to the TNT areas and likely causes another bias in the modeling results.

As previously stated, the groundwater model is a tool that must be interpreted using site-specific knowledge and best professional judgment. Most of the uncertainties identified above are

effectively managed through the model calibration process that reduces the errors associated with estimated input parameters and the extrapolation of sparse site-specific data. The two most critical areas that bias the model results are the leachability of contaminants in the vadose zone, and the lack of a natural attenuation component in simulating the limestone bedrock groundwater. The uncertainty associated with both of these components are likely to introduce bias that tends to overestimate rather than underestimate resulting groundwater concentrations.

7.0 Conclusion

Using groundwater modeling as a supportive tool provides a scientific platform for the evaluation and comparison of different remedial alternatives. In the current modeling effort, emphasis was placed in the cleaning up of contaminants in the overburden/shale and in the limestone bedrock. Vigorous modeling runs, however, conclude that the cleanup effort in the limestone is difficult even with the application of ISEB and soil excavation. Residual contaminants, especially 2,4-DNT and 2,6-DNT, will still exist above the RGOs after 150 years.

It can be noted that time-varying soil leachate is not the governing adverse factor in the cleanup process even though it was a major factor that generated contaminant plumes in the past. If soil leachate still exists, it will contribute to the contamination in the overburden and thereby may provide a threat to the limestone bedrock groundwater in the future.

Soil excavation, ISEB in the overburden, together with pump-and-treat in the bedrock could be a solution to the total cleanup of the limestone bedrock aquifer. However, it would take an extended period of time (i.e., >150 years) with very high cost.

Finally, the PBOW groundwater model includes simulations which assume that the groundwater plumes will be subject to natural attenuation with advection (dilution), dispersion, and adsorption (retardation); however, no biodegradation or abiotic degradation component was included in the model. As described in Section 2.7 of the FS text, the reducing conditions in the limestone bedrock groundwater are conducive to both biotic and abiotic degradation of nitroaromatics. A monitoring program may readily identify natural attenuation processes in the groundwater units, especially the limestone. If such processes are observed, this may obviate or reduce the need for further groundwater remedial efforts.

8.0 References

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TABLES

Table 5-1(a)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
Simulation No. 1 - No Action
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial	**32400**	**37600**	**10550**				**1.6**	**19**	**3.6**			
1	30818.2	29111.5	7244	2.8	3.5	66.7		16.2	3.54			
5	30675.1	28599.2	4571.3	39.5	76.9	70.8		16.2	3.5			
10	30497	27234.2	4001.5	39.6	106.6	123.8		16.2	5			
15	30320.8	25379.8	3540.5	37.3	105.2	109		16.2	10.8			
20	29800.4	24431.3	3198.7	57	103.6	114.4		16.2	17.4			
25	28144.9	23232	2945.8	56.9	101.7	93.3		16.1	31.3			
30	27667.1	21334.3	2681.5	56.8	99.6	87.2		16.1	37.8			
35	27472.6	19670.5	2447.3	56.7	89.1	138.8		17.1	43.5			
40	27279.4	18319.3	2244.9	56.6	87.1	132.6		22.1	45.4			3.03
45	24254	18818.5	1997.7	56.5	89.6	160.3		22.6	45			3.08
50	24085.2	18577.1	1789.5	56.4	99.3	100.6		23.2	44.3			3.1
55	23917.5	17795.8	1308.7	56.3	477.3	94.2	3.7	30.4	43.7			3.2
60	23750.9	17994.8	1308.9	56.3	473.4	67.8	5.1	31.4	43.4			4.3
65	23585.7	16976.3	967.1	56.2	469.1	71.5	6.4	32.4	43.1			6
70	23422	16300.8	919.1	56.1	464.5	64.1	6.5	33.6	46.4			8
75	23259.7	15443	817.5	56	420.7	99.9	8.8	40.8	46.5			9.4
80	23099.3	15792.9	688.7	55.9	416.1	96.4	8.9	41.9	44			10.1
85	22940.5	15173.7	554.8	55.9	411.5	95.6	10	49.2	43.7			10.9
90	22783.8	14969.6	430.4	193.8	407.1	96.6	10.1	50.3	42			14.5
95	22628.3	15266.7	354.2	213.8	402.8	106.7	11.2	51.6	40.5			15.9
100	22474.1	14720.8	341.5	214.4	369.2	112.7	11.3	52.8	39.6		0.67	16.1
105	22321.1	14676.1	275.6	214.8	364.3	141.2	11.3	54	42.9		0.68	27.2
110	22169	13771.8	257.7	214.9	388.4	122.2	11.4	59.2	56.5		0.69	29.3
115	22018	13969.2	248.2	214.7	347.9	99.8	12.5	60.6	62.3		0.71	29.2
120	21868.4	13322.6	230.7	214.4	333.9	95.5	12.6	63.6	68.6		1.03	29.2
125	20280.5	12830.5	193.4	214	327.2	94.3	12.7	65.1	69.6		1.06	29.15
130	20145	12358.8	182.1	213.6	320.6	73.3	12.7	66.6	65		1.09	29.1
135	20016.7	11796.1	161.2	213.2	289.5	70.4	12.8	75.1	62.8		1.11	25.1
140	18868	11550.3	141.9	212.6	312.5	94.8	12.9	81	62.2		1.14	24.4
145	18763.4	11162.2	136.2	212	310.7	90.7	13	86.5	60.3		1.2	24.3
150	18659.4	11391.8	125.5	211.4	308.3	84.4	13.1	87	56.3		1.4	24.2

All results are in units of micrograms per liter (μg/L).

---- concentration below 3.0 μg/L for TNT, 0.5 μg/L for 2,4-DNT and 2,6-DNT

ND ---- Non-detect

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Table 5-1(b)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
TNT Area A
Simulation No. 1 - No Action
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial	**32400**	**6900**	**6900**				**ND**	**0.49**	**3.6**			
1	30818.2	5801.2	5802.9	0.6	0.2	66.7			3.54			
5	30675.1	5660.1	4571.3	2.9	76.9	70.8			3.49			
10	30497	5589.5	4001.5	5.4	80.7	123.8			3.4			
15	30320.8	5507.9	3540.5	8.2	88.6	98.5			6			
20	29800.4	5423.2	3198.7	57	88.5	97.6			11.1			
25	28144.9	5339.9	2945.8	56.9	88.4	90.5			11.2			
30	27667.1	5252.1	2681.5	56.8	88.2	83.7			11.3			
35	27472.6	5160.9	2447.3	56.7	88	76.4			13			
40	27279.4	5114.3	2244.9	56.6	93.5	69.3			13.5			
45	24254	5039.1	1997.7	56.5	93.3	74.5		0.57	26.6			
50	24085.2	4956.1	1789.5	56.4	93	69.3		0.6	28.8			
55	23917.5	4889.7	1308.7	56.3	92.8	71.9		0.7	28.5			
60	23750.9	4783.5	1308.9	56.3	92.5	67.8		0.7	28			
65	23585.7	4545.3	967.1	56.2	92.3	71.5		3	24.2			
70	23422	4155.6	919.1	56.1	92	64.1		3	24			
75	23259.7	4137.7	817.5	56	107.5	99.9		3	25			
80	23099.3	3944.2	688.7	55.9	106.9	96.4		2.9	24.8			1.99
85	22940.5	3864.9	554.8	55.8	106.3	95.6		5.2	24.6			1.87
90	22783.8	3939.3	430.4	55.7	105.8	96.6		5.2	24.4			1.8
95	22628.3	3734.1	323.4	55.6	105.2	106.7	4.3	5.2	24.3			1.7
100	22474.1	3761	276.1	55.5	104.7	112.7	4.6	5.2	22.5			1.65
105	22321.1	3654.6	244.7	55.4	104.1	117	4.61	5.3	26.3			1.6
110	22169	3444.2	217.7	55.3	103.6	119.7	4.63	5.3	27.2			3.1
115	22018	3499.8	183.6	55.2	103	99.8	4.64	9.3	32.1			4.1
120	21868.4	3441.9	188.2	55.2	102.5	95.5	4.66	9.3	35			7.3
125	20280.5	3167.5	171.9	55.1	102.1	94.3	4.67	9.3	39.1			9.2
130	20145	3130.8	157.6	56.4	101.7	73.3	4.69	9.3	40.2			8.6
135	20016.7	3091.2	149.7	58.2	101.2	65.5	4.71	9.3	36			11.2
140	18868	3016.7	140.5	59.9	100.8	66.1	4.72	9.4	35.5			11.3
145	18763.4	2983.9	127.8	61.7	100.3	65.7	4.73	9.4	35.9			14.2
150	18659.4	2772.5	103	63.4	99.8	66.2	4.74	10.1	30			15.8

All results are in units of micrograms per liter (μg/L).

---- concentration below 3.0 μg/L for TNT and 0.5 μg/L for 2,4-DNT and 2,6-DNT

ND ---- Non-detect

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Table 5-1(c)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
TNT Area B
Simulation No. 1 - No Action
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial	**68**	**5.8**	**11**				**ND**	**ND**	**ND**			
1	49.6	3.8	7.9									
5	49.3	53.8	32			0.9						
10	49	841.7	45.4			1.8			0.5			
15	48.7	1572	33.4		0.8	1.6			0.9			
20	48.4	1606.6	25.1		1.4	1.4			1			
25	48.1	1274.8	102.7		1.9	1.35			1.1			
30	46.2	890.3	226.6		2.2	1.3			1.2			
35	44.5	578.7	348.5		2.4	1.3			1.2			
40	44.2	410.1	426.4		2.6	1			1.1			
45	44	327.9	447.4		2.69	1		0.5	1			
50	40.7	513.5	421.3		2.74	1.8		0.6	0.98			
55	39.4	669.9	379.9		2.77	2		0.68	0.95			
60	38.6	760.8	317.3		2.77	1.8		0.75	0.93			
65	38.4	776.1	259.2		2.77	1.9		0.8	0.93			
70	35.7	727.4	219.4		2.76	2.1		0.88	0.94			
75	34.7	698.1	188.3		2.75	2.2		0.93	0.92			
80	33.7	662.4	179.8		2.43	2.6		0.99	0.89			
85	33.6	598.6	159.7		2.42	2.5		1.04	0.9			
90	31.8	519.5	143.6		2.4	2.6		1.08	0.8			0.5
95	31.6	435.9	125.9		2.39	2.5		1.1	0.9			0.6
100	31.5	355.4	106.4		2.38	2.7		1.17	0.93			0.65
105	31.9	324.2	103.9		2.37	2.8		1.2	0.93			0.64
110	32	317.7	93.9		2.36	2.59		1.24	0.9			0.65
115	32.2	311	78.7		2.34	2.55		1.27	0.95			0.75
120	32	290.2	69.4		2.33	2.51		1.3	0.95			0.73
125	31.3	268.5	59.9		2.3	2.5		1.32	1			0.7
130	32	260.8	57.3		2.29	2.4		1.36	1.02			0.7
135	31.2	223	55.5		2.92	2.6		1.38	1			0.77
140	31.4	202	50.1		2.94	2.5		1.4	0.95			0.82
145	31.5	161.3	47		2.95	2.62		1.42	0.92			0.79
150	32	158	40.8		2.96	2.6		1.44	0.9			0.8

All results are in units of micrograms per liter (μg/L).

[ ] ---- concentration below 3.0 μg/L for TNT and 0.5 μg/L for 2,4-DNT and 2,6-DNT

ND ----- non-detect

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Note: Includes soil remediation performed to date.

Table 5-1(d)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
TNT Area C
Simulation No. 1 - No Action
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial	**20100**	**37600**	**10550**				**ND**	**0.1**	**0.7**			
1	16362.9	29111.5	7244	2.8	3.5	4.6			0.7			
5	16110	28599.2	4126.9	39.5	76.9	22.7			1.9			
10	15796	27234.2	3654.9	39.6	106.6	27.3		2.3	5			
15	15337.8	25379.8	2164.4	37.3	105.2	109		4.4	10.8			
20	14994.2	24431.3	1907.3	37.3	103.6	114.4		9.4	17.4			
25	14558.9	23232	1621	37.4	101.7	93.3		10.3	31.3			
30	13875.4	21334	1800.5	38.5	99.6	87.2		11.1	37.8			
35	13655.2	19670.5	1258.5	41.4	89.1	138.8		17.1	43.5			1.7
40	13303.7	18319.3	958.9	43.8	87.1	132.6		22.1	45.4			3.03
45	12933.7	18818.5	861.2	42.9	89.6	160.3		22.6	45			3.08
50	12148.9	18577.1	778.1	44.5	99.9	100.6		23.2	44.3			3.1
55	9949.4	17795.8	665.7	45.6	477.3	94.2	3.7	27.2	43.7			3.2
60	9755	17994.8	644.9	43.5	473.4	67.3	5.1	27.6	43.4			4.3
65	8851.5	16976.3	560.4	44.2	469.1	71.5	6.4	30.9	43.1			6
70	8105.6	16300.8	520.6	44.9	464.5	64.1	6.5	31.4	46.4			8
75	7420.7	15443	450.3	42.7	420.7	62.8	8.8	35.8	46.5			9.4
80	6697.8	15792.9	400.4	43.1	416.1	68	8.9	36.5	44			10.1
85	6517	15173.7	381.9	43.4	411.5	67.2	10	37.1	43.7			10.9
90	6401.2	14969.6	392.3	193.8	407.1	63.2	10.1	47.6	42			14.5
95	6087.8	15266.7	354.2	213.8	402.8	66.6	11.2	48.7	40.5			15.9
100	5707.9	14720.8	341.5	214.4	369.2	83.5	11.3	49.9	39.6		0.67	16.1
105	5430.6	14676.1	275.6	214.8	364.3	141.2	11.3	51.2	42.9		0.68	27.2
110	5340.1	13771.8	257.7	214.9	388.4	122.2	11.4	59.2	56.5		0.69	29.3
115	5323	13969.2	248.2	214.7	347.9	87.2	12.5	60.6	62.3		0.71	29.2
120	5234.4	13322.6	230.7	214.4	333.9	73.1	12.6	63.6	68.6		1.04	29.2
125	5119.7	12830.5	193.4	214	327.2	69	12.7	65.1	69.6		1.06	29.15
130	5128.2	12358.8	182.1	213.6	320.6	70.7	12.7	66.6	65		1.09	29.1
135	5126	11796.1	161.2	213.2	289.5	70.4	12.8	75.1	62.8		1.11	25.1
140	5641.7	11550.3	141.9	212.6	312.5	94.8	12.9	81	62.2		1.14	24.4
145	5411.9	11162.2	136.2	212	310.7	90.7	13	86.5	60.3		1.4	24.3
150	4702.8	11391.8	125.5	211.4	308.3	84.4	13.1	87	56.3		1.42	24.2

All results are in units of micrograms per liter (μg/L).

---- concentration below 3.0 μg/L for TNT and 0.5 μg/L for 2,4-DNT and 2,6-DNT

ND ----- non-detect

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Table 5-1(e)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
Pentolite Road Red Water Pond Area
Simulation No. 1 - No Action
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial	**160**	**9200**	**550**				**1.6**	**1.5**	**1.4**			
1	28.8	8069.3	418.1					1.5	1.38			
5	28.2	7903.3	313.8		1.2	8.5		1.49	1.32			
10	67.1	7219.7	309.5		2.5	11.5		1.47	1.3			
15	121.5	6193.8	304		3.8	9.7		1.48	1.2			
20	138.9	6041.9	321		5	11.3		1.47	1.2			
25	128.6	5892.7	279.8		6.3	11		1.46	1.2			
30	105.7	5748.1	200.5		7.7	20.5		1.45	1.3			
35	80.7	4608.6	130		8.9	19.8		1.45	1.5			
40	58.6	4437.3	100.1		17.6	19.2		1.44	1.5			
45	41.2	4414.3	82.2		17.9	18.7		1.43	1.5			
50	30.7	4292.3	77.8		17.5	18.2		1.43	1.9			
55	32.2	4325	70.7		17.7	21.2		1.42	1.8			
60	44	4495.9	66.6		18.8	20.7		1.41	1.9			
65	54.4	4261.6	58.5		19	16.9		1.4	2.7			
70	62.1	4140.5	54.2		18.5	16.6		1.4	4.3			
75	66.5	3875.1	49		19.5	18.7		1.4	4.6			
80	67.4	3765.7	44.1		19.8	18.2		1.4	4.7			
85	65.4	3412.4	39.2		19.9	17.2		1.39	5.1			
90	61.2	3226.2	35.5		20.1	15.5		1.38	5.2			
95	55.4	2952.9	31.1		20.3	15.2		1.4	5.6			
100	48.9	2769.5	26.8		207.4	15		1.6	5.68			
105	42.1	2649	23.3		207.3	14.8		1.9	5.76			
110	35.6	2479.6	20.5		221.9	14.6		2.8	5.8			
115	29.5	2256.1	17.5		239	16.6		3.7	6.1			
120	24.1	2193	14.5		259.2	16.3		4.5	6.16			
125	23.3	2076.1	13.5		258.7	14.5		4.9	6.2			
130	23	1996.8	12		258.1	14.1		5.2	6.2			
135	22.8	1859.8	11		257.5	14		5.6	6.06			
140	22.5	1807.6	10.8		281.9	13.4		6.3	6.1			
145	22.3	1745.6	8.9		281.1	14.3		6.7	6.8			
150	22	1695.5	7.4		280.3	13.8		7.2	7.2			

All results are in units of micrograms per liter (μg/L).

---- concentration below 3.0 μg/L for TNT and 0.5 μg/L for 2,4-DNT and 2,6-DNT

ND -----non-detect

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Note: Includes remediation of soil hot spot.

Table 5-1(f)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
West Area Red Water Ponds Area
Simulation No. 1 - No Action
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial	**34**	**950**	**63**				**0.081**	**19**	**0.43**			
1	99.4	1054	243.2		2.1			16.2				
5	81.4	828.3	199		2.1	1.7		16.19				
10	63.4	813.7	146.1		3.5	2.2		16.18				
15	49.4	783.9	91.8		3.4	2.8		16.17				
20	38.4	764.4	68.8		3.4	2.6		16.15				
25	30.7	728	78.3		3.38	2.7		16.14				
30	30.4	710.5	62.8		3.35	2.5		16.13				
35	30.2	706.9	47.5		3.3	2.3		16.12				
40	29.8	698.4	44.9		3.3	2.2		16.1				
45	29.5	690	39.4		3.3	1.94		16.09				
50	29.2	681.7	29.5		3.1	1.57		16.08				
55	29	661.3	24.9		3.3	1.49		16.07				
60	28.8	651.8	20.2		3.6	1.4		16.06				
65	28.3	640	18.8		3.9	1.9		16.04				
70	28	632.1	16.7		17.5	1.89		16.03				
75	27.8	625.8	14.2		18.6	1.85		16				
80	27.4	619.7	13.1		17.62	1.83		16				
85	27	611.7	11.5		17.62	1.81		16				
90	26.8	605	10.5		17.61	1.78		16				
95	26.4	598.2	10.3		17.61	1.76		16				
100	26	590.5	9.2		17.61	1.74		16				
105	25.7	587.5	9.9		17.6	1.72		16				
110	25.5	578.6	9.1		16.76	1.73		16				
115	25.1	573	8		16.76	1.7		16				
120	24.8	563.9	7.2		16.76	1.7		16				
125	24.6	577.1	6.3		16	1.12		16				
130	24.3	567.7	5.5		16	1.1		16				
135	24.7	558.8	5.2		16	1.09		16				
140	24.5	548.8	4.1		15.31	1.02		16				
145	24.6	539	3.7		15.32	1		16				
150	24.3	511.6	2.8		15.3	1		16				

All results are in units of micrograms per liter (μg/L).

---- concentration below 3.0 μg/L for TNT and 0.5 μg/L for 2,4-DNT and 2,6-DNT

ND ----- Non-detect

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Table 5-2(a)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
Simulation No. 2 - Target Soil Excavation
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial	**32400**	**37600**	**10550**				**1.6**	**19**	**3.6**			
1	30818.2	28948.3	6096.41		3.27	6.58		18.96	3.54			
5	30675	27856.3	4942.74	39.45	15.78	126.15		18.95	3.55			
10	30496.9	25914.4	3928.77	39.55	102.84	113.85		18.95	32.63			
15	30320.7	23717.2	3423.59	37.21	100.69	104.32		18.95	48.44			
20	29800.4	22079.6	3163.19	57	98.43	98.17		18.94	58.28			
25	28144.1	21044.4	2897.28	56.92	95.96	194.42		18.94	64.63			0.59
30	27667.1	19040.8	2654.6	56.84	93.43	227.2		18.94	66.05			0.62
35	27472.6	17877.2	2441.96	56.76	83.22	136.4		20.02	66.5			2.23
40	27279.4	16542.7	2233.82	56.68	81.07	97.54		21.17	66.92			2.29
45	24254	16811.6	2051.21	56.6	79.04	91.04		25.9	68.5			2.36
50	24085.2	16554.3	1849.26	56.51	80.69	74.86		26.85	66.33			2.43
55	23917.5	15564.3	1647.07	56.42	464.89	73.94		30.56	65.56			2.64
60	23750.9	15545.2	1471	56.34	457.22	73.39	3.57	31.35	61.89			3.38
65	23585.7	14425.2	1256.19	56.25	449.56	76.23	4.91	34.33	62.59			4.25
70	23422	14341.2	972.44	56.16	441.97	91.61	6.22	35	62.31			10.16
75	23259.6	13270.2	858.18	56.08	434.66	86.12	6.29	37.42	55.75		0.81	12.62
80	23099.3	14031.7	704.39	55.99	389.63	115	7.47	37.98	56.11		1.5	15.6
85	22940.5	13134.6	647.69	55.91	382.91	132.82	8.55	40.61	56.04		1.53	21.25
90	22783.8	12593.3	628.9	189.71	376.24	83.95	9.58	45.71	53.64		1.56	23.34
95	22628.2	12571.7	603.69	190.48	369.49	101.76	9.64	50.63	54.41		1.59	23.32
100	22474	11930.9	551.67	191.02	363.1	81.17	9.69	55.38	56.4		1.63	26.37
105	22321	11600.4	484.74	210.37	329.42	74.91	10.71	59.79	56.39		1.67	27.58
110	22169	10947.9	418.45	210.47	323.39	79.83	10.77	63.78	59.27		1.7	27.58
115	22017.9	10357	377.68	210.25	533.69	90.85	10.83	67.69	55.33		1.75	27.36
120	21868.4	11765.5	346.15	209.92	517.65	90.15	10.89	71.12	51.88		1.79	27
125	20280.4	9139.17	309.6	209.56	557.24	89.36	11.92	74.25	55.72		1.84	26.69
130	20144.9	9110.77	283.65	209.18	542.3	88.53	11.98	77.18	45.58		1.89	28.45
135	20010.6	8562.19	261.74	208.78	426.95	95.15	12.05	79.99	43.37		1.93	28.46
140	18866.7	8700.28	241.54	208.21	411.74	85.91	12.11	82.49	38.32		1.98	29.94
145	18762.2	8016.68	215.28	207.62	401.69	85.01	12.18	84.73	36		2.03	30.59
150	18658.2	8259.74	193.37	207.03	391.71	87.88	12.24	86.79	34.67		2.08	31.72

All results are in units of micrograms per liter (μg/L).

---- concentration below 3.0 μg/L (TNT), 0.5 μg/L (2,4-DNT and 2,6-DNT)

ND ---- Non-detect

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Table 5-2(b)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
TNT Area A
Simulation No. 2 - Targeted Soil Excavation
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial	**32400**	**6900**	**6900**				**ND**	**0.49**	**3.6**			
1	30818.2	5793.55	5793.12			6.58			3.54			
5	30675	5626.01	4573.71		76.64	8.57			3.49			
10	30496.9	5519.38	3928.77	4.95	78.7	27.29			3.42			
15	30320.7	5398.33	3423.59	7.53	86.25	35.75			3.35			
20	29800.4	5273.24	3163.19	57	85.86	37.33			3.31			
25	28144.1	5153.68	2897.28	56.92	85.45	72.15			3.29			
30	27667.1	5018.77	2654.6	56.84	85.18	63.7			3.73			
35	27472.6	4889.9	2441.96	56.76	84.61	63.95			3.75			
40	27279.4	4757.5	2233.82	56.68	84.17	70.64		0.52	5.01			
45	24254	4660.49	2051.21	56.6	83.7	79.79		0.61	5.91			
50	24085.2	4547.12	1849.26	56.51	83.24	72.23		0.7	6.24			
55	23917.5	4338.67	1647.07	56.42	82.78	61.89		0.79	7.53			
60	23750.9	4224.55	1471	56.34	82.32	60.61		0.88	7.19			
65	23585.7	3990.18	1256.19	56.25	82.18	59.07		3.18	7.72			
70	23422	3740.65	972.44	56.16	87.8	53.16		3.2	8.11			
75	23259.6	3666.94	858.18	56.08	81.01	66.25		3.39	11.41			
80	23099.3	3617.55	704.39	55.99	80.72	62.45		3.41	11.95			
85	22940.5	3566.71	647.69	55.91	80.19	72.35		3.43	12.53			
90	22783.8	3552.74	628.9	55.82	79.77	83.95		3.45	12.63			
95	22628.2	3496.21	603.69	55.74	78.62	101.76		5.96	12.74			
100	22474	3425.59	551.67	55.65	78.1	81.17		5.9	12.91			
105	22321	3344.74	484.74	55.57	77.58	74.91	4.34	5.91	12.62			
110	22169	3299.12	418.45	55.49	77.07	79.83	4.36	5.92	12.72			
115	22017.9	3210.73	377.68	55.41	76.57	90.85	4.37	5.92	12.72			
120	21868.4	3307.66	346.15	55.33	76.09	90.15	4.39	7.96	12.95			
125	20280.4	2990.92	309.6	55.25	75.62	89.36	4.4	7.97	14.26			
130	20144.9	2855.73	283.65	55.17	75.2	88.53	4.41	8	14.3			
135	20010.6	2724.46	261.74	55.1	74.82	95.15	4.43	8.02	15.17			
140	18866.7	2615.92	241.54	55.02	74.4	85.91	4.44	8.05	15.39			
145	18762.2	2525.06	215.28	56.3	73.98	85.01	4.45	8.06	16.35			0.65
150	18658.2	2660.93	193.37	57.91	73.55	87.88	4.47	8.08	16.88			0.53

All results are in units of micrograms per liter (μg/L).

---- concentration below 3.0 μg/L (TNT), 0.5 μg/L (2,4-DNT and 2,6-DNT)

ND ---- Non-detect

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Table 5-2(c)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
TNT Area B
Simulation No. 2 - Targeted Soil Excavation
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial	68	5.8	11				ND	ND	ND			
1	49.58	3.79	7.83									
5	49.32	3.51	31.98									
10	49	12.07	45.43									
15	48.7	48.36	33.35									
20	48.4	108.06	25.09			1.33						
25	48.1	216.61	102.66			1.2						
30	46.16	289.18	226.56			1.12			0.67			
35	44.5	306.12	348.49			1.06			0.79			
40	44.24	280.6	426.43			1.03			0.85			
45	43.99	233.89	447.4			1.02			0.88			
50	40.95	200.6	421.34		1.08	7.91			0.9			
55	39.42	176.9	366.78		1.07	6.72			0.91			
60	38.58	151.4	320.96		1.43	4.59			0.96			
65	38.39	174.4	275.11		1.61	4.32			1			
70	34.71	176.82	209.22		1.69	4.1			1.01			
75	34.05	185.08	178.42		1.7	3.45		0.53	1.02			
80	33.01	179.22	150.68		1.68	3.07		0.61	1.04			
85	32.88	162.75	133.59		1.64	3.12		0.68	1.14			
90	31.77	140.09	112.76		1.59	3.17		0.74	1.42			
95	31.63	115.29	97.28		1.54	3.11		0.79	1.48			0.66
100	31.5	105.75	83.95		1.48	3.22		0.83	1.46			0.64
105	31.94	100.48	86.9		1.42	4.42		0.87	1.43			0.81
110	32.04	97.85	80.87		1.37	4.35		0.9	1.44			0.92
115	32.15	102.13	62.74		1.31	4.27		0.92	1.38			1.04
120	32.01	94.58	56.12		1.36	4.19		0.94	1.33			1.09
125	31.27	87.07	47.81		1.4	4.11		0.96	1.3			1.08
130	31.96	83.95	44.71		1.44	4.03		0.97	1.3			1.11
135	31.25	80.85	40.55		1.47	3.59		0.97	1.13			1.11
140	31.37	69.95	38.04		1.5	3.89		0.98	1.16			1.06
145	31.5	60.16	35.66		1.52	3.83		0.98	1.22			1.06
150	32.01	55.4	32.95		1.54	3.77		0.97	1.28			1.06

All results are in units of micrograms per liter (μg/L).

---- concentration below 3.0 μg/L (TNT), 0.5 μg/L (2,4-DNT and 2,6-DNT)

ND ----- non-detect

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Table 5-2(d)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
TNT Area C
Simulation No. 2 - Targeted Soil Excavation
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial	20100	37600	10550				ND	0.1	0.7			
1	16362.5	28948.3	6096.41		3.27	4.22						
5	16108.2	27856.3	4942.74	39.45	15.78	126.15			3.55			
10	15792.9	25914.4	3024	39.55	102.84	113.85		2.36	32.63			
15	15334	23717.2	2159.75	37.21	100.69	104.32		4.66	48.44			
20	14989.7	22079.6	1814.87	37.27	98.43	98.17		10.98	58.28			
25	14554.3	21044.4	1568.43	37.3	95.96	194.42		12.6	64.63			0.59
30	13871.1	19040.8	1557.62	37.3	93.43	227.2		14.13	66.05			0.62
35	13650.8	17877.2	1255.75	37.3	83.22	136.4		20.02	66.5			2.23
40	13299.5	16542.7	1020.91	39.15	81.07	97.54		21.17	66.92			2.29
45	12929.8	16811.6	896.07	40.73	79.04	91.04		25.9	68.5			2.36
50	12145.8	16554.3	1023.67	39.52	80.69	74.86		26.85	66.33			2.43
55	9946.54	15564.3	851.85	40.69	464.89	73.94		30.56	65.56			2.64
60	9751.93	15545.2	837.24	41.66	457.22	73.39	3.57	31.35	61.89			3.38
65	8369.48	14425.2	671.97	39.92	449.56	76.23	4.91	34.33	62.59			4.25
70	7671.46	14341.2	580.24	40.66	441.97	91.61	6.22	35	62.31			10.16
75	7032.16	13270.2	501.79	41.26	434.66	86.12	6.29	37.42	55.75		0.81	12.62
80	6294.29	14031.7	412.29	39.05	389.63	115	7.47	37.98	56.11		1.5	15.6
85	6118.3	13134.6	388.24	39.16	382.91	132.82	8.55	40.61	56.04		1.53	21.25
90	6051.55	12593.3	367.06	189.71	376.24	76.09	9.58	45.71	53.64		1.56	22.34
95	5755.17	12571.7	373.24	190.48	369.49	73.31	9.64	50.63	54.41		1.59	23.32
100	5637.57	11930.9	340.02	191.02	363.1	50.37	9.69	55.38	56.4		1.63	26.37
105	5333.43	11600.4	277.76	210.37	329.42	45.4	10.71	59.79	56.39		1.67	27.58
110	5239.41	10947.9	280.99	210.47	323.39	55.28	10.77	63.78	59.27		1.7	27.58
115	5143.53	10357	245.21	210.25	533.69	53.68	10.83	67.69	55.33		1.75	27.36
120	5166.89	11765.5	209.42	209.92	517.65	67.85	10.89	71.12	51.88		1.79	27
125	5088.05	9139.17	200.51	209.56	557.24	73.18	11.92	74.25	55.72		1.84	26.69
130	5102.94	9110.77	157.21	209.18	542.3	54.11	11.98	77.18	45.58		1.89	28.45
135	5111.53	8562.19	154.85	208.78	426.95	55.15	12.05	79.99	43.37		1.93	28.46
140	5630.36	8700.28	138.6	208.21	411.74	54.69	12.11	82.49	38.32		1.98	29.94
145	5383.15	8016.68	130.15	207.62	401.69	55.39	12.18	84.73	36		2.03	30.59
150	4681.7	8259.74	119.83	207.03	391.71	49.31	12.24	86.79	34.67		2.08	31.72

All results are in units of micrograms per liter (µg/L).

---- concentration below 3.0 µg/L (TNT), 0.5 µg/L (2,4-DNT and 2,6-DNT)

ND ----- non-detect

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Table 5-2(e)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
Pentolite Road Red Water Pond Area
Simulation No. 2 - Targeted Soil Excavation
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial	160	9200	550				1.6	1.5	1.4			
1	28.83	8042.15	428.54					1.49	1.38			
5	28.2	7771.61	372.84		0.89	8.97		1.49	1.35			
10	67.09	6983.39	374.85		1.84	8.63		1.48	1.3			
15	121.49	5900.61	284.83		2.68	8.85		1.47	1.26			
20	138.94	5667.28	229.2		3.56	9.44		1.46	1.21			
25	128.59	5440.64	180.43		4.47	12.86		1.46	1.17			
30	105.67	5224.82	223.4		5.38	12.71		1.45	1.14			
35	80.66	4144.37	123.98		6.19	12.29		1.44	1.73			
40	58.64	3858.24	95.14		18.75	11.95		1.43	2.07			
45	41.23	3846.31	86.58		18.9	11.65		1.43	2.26			
50	34.1	3681.56	72.55		19.03	11.36		1.42	2.37			
55	33.44	3550.73	74.64		18.31	11.09		1.41	2.48			
60	44.02	3750.9	66.44		18.39	10.84		1.41	2.59			
65	54.43	3489.46	60.01		19.31	12.79		1.4	2.68			
70	62.14	3325.31	53.58		18.49	12.44		1.39	2.98			
75	66.48	3061.26	48.52		19.38	11.18		1.38	3.04			
80	67.43	2918.42	43.53		19.37	14.56		1.38	3.48			
85	65.43	2746.28	39.02		19.32	14.19		1.37	3.54			
90	61.18	2406.65	34.72		19.27	12.74		1.36	3.57			
95	55.43	2103.37	27.59		19.2	12.43		1.36	3.22			
100	48.88	1924.91	25.06		151.24	12.12		1.35	3.37			
105	42.13	1835.24	21.74		150.77	11.52		1.63	3.23			
110	35.58	1676.37	19.28		150.26	10.06		1.97	3.22			
115	33.48	1540.21	16.47		160.75	9.81		2.64	2.96			
120	31.25	1442.06	15.88		173	9.41		3.3	2.82			
125	29.07	1360.25	12.85		187.59	8.37		3.96	2.95			
130	28.75	1349.22	12.83		186.8	8.2		4.38	2.88			
135	28.43	1246.99	10.03		185.98	8.56		4.81	2.86			
140	28.12	1176.22	8.58		185.16	7.17		5.23	2.86			
145	27.82	1122.51	7.8		202.87	6.63		5.76	2.88			
150	25.79	1069.11	6.99		201.9	8.09		6.22	2.99			

All results are in units of micrograms per liter (µg/L).

---- concentration below 3.0 µg/L (TNT), 0.5 µg/L (2,4-DNT and 2,6-DNT)

ND -----non-detect

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Table 5-2(f)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
West Area Red Water Ponds Area
Simulation No. 2 - Targeted Soil Excavation
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial	34	950	63				0.081	19	0.43			
1	99.38	1054	243.22		2.1	0.54		18.96				
5	81.37	862.6	198.97		2.09	1.24		18.95				
10	63.37	809.21	146.11		3.48	2.27		18.95				
15	49.35	776.38	91.83		3.46	2.87		18.95				
20	38.44	754.49	64.33		3.44	3.18		18.94				
25	30.69	724.57	62.37		3.43	2.42		18.94				
30	30.44	716.06	57.67		3.41	3.35		18.94				
35	30.18	707.37	47.12		3.4	2.22		18.93				
40	29.79	698.82	38.92		3.38	1.88		18.93				
45	29.54	690.04	34.67		3.36	1.79		18.93				
50	29.21	681.36	33.3		3.35	1.8		18.93				
55	28.93	655.32	23.23		3.53	1.79		18.93				
60	28.68	644.52	19.82		3.78	1.34		18.93				
65	28.36	633.17	18.21		4.03	1.54		18.93				
70	28.04	622.87	17.81		17.64	1.5		18.92				
75	27.66	614.95	16.8		16.56	1.57		18.92				
80	27.2	610.01	14.27		17.58	1.49		18.91				
85	26.66	600.14	12.66		14.95	1.64		18.92				
90	26.45	594.26	11.58		14.94	1.44		18.92			1.02	
95	25.98	583.92	10.42		14.93	1.42		18.92			1.02	
100	25.6	573.64	8.94		14.92	1.55		18.92			1.02	
105	25.36	562.97	7.57		14.91	1.31		18.91			1.01	
110	24.89	563.52	6.77		14.89	1.21		18.91			1.01	
115	24.7	555.91	5.06		14.14	1.21		18.91			1.01	
120	24.5	563	4.56		14.13	1.2		18.91			1.00	
125	23.94	570.84	3.97		14.12	1.11		18.91			1.00	
130	23.44	560.24	3.64		24.67	1.09		18.91			1.00	
135	23.3	548.3	3.24		24.66	0.98		18.91			1.00	
140	23.16	525.06	2.84		24.65	0.88		18.91			0.99	
145	22.91	511.03	2.58		24.64	0.88		18.9			0.99	
150	22.83	493.74	2.38		24.63	0.87		18.9			0.99	

All results are in units of micrograms per liter (µg/L).

---- concentration below 3.0 µg/L (TNT), 0.5 µg/L (2,4-DNT and 2,6-DNT)

ND ----- Non-detect

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Table 5-3 (a)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
Simulation No. 3 - Soil Excavation and ISEB
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial							**1.6**	**19**	**3.6**			
1	500.2	4215.9	324.3		1.3			19.0	3.6			
5	409.5	3433.4	1079.5		1.3	1.2		19.0	3.6			
10	316.8	2510.0	1588.2		1.4	3.2		19.0	3.6			
15	238.0	1758.9	991.0		1.5	5.1		19.0	3.6		0.7	
20	172.9	1221.0	607.9		2.0	5.5		19.0	3.6		0.7	
25	137.7	849.5	362.9		3.0	4.0		19.0	3.5		0.7	
30	129.4	594.9	226.6		3.0	7.6		19.0	3.5		0.7	
35	142.6	583.1	348.5		3.1	7.3		19.0	3.5		0.7	
40	137.5	560.0	426.4		3.2	7.7		18.9	3.5		0.7	
45	123.9	510.9	447.4		3.3	7.6		18.9	3.5		0.7	
50	105.1	490.9	411.7		3.3	7.7		18.9	3.5		0.7	
55	95.5	433.4	366.8		3.9	6.9		18.9	3.5		0.7	
60	84.2	417.9	326.4	1.1	4.0	6.5		18.9	3.5		0.7	
65	65.7	372.1	268.7	1.1	3.9	6.6		18.9	3.5		0.7	
70	62.1	350.5	238.9	1.2	4.0	6.9		18.9	3.5		0.7	
75	66.5	340.1	201.5	1.2	4.1	10.1		18.9	3.5		0.7	
80	67.5	273.6	170.1	1.2	4.1	9.9		18.9	3.5		0.7	
85	65.4	304.7	169.0	1.7	4.2	9.7		18.9	3.5		0.7	
90	61.7	316.5	152.6	1.7	4.2	10.0		18.9	3.5		0.7	
95	55.4	347.8	126.0	1.7	4.2	10.6		18.9	3.5		0.7	
100	52.7	410.7	109.6	1.7	4.3	10.4		18.9	3.5		0.7	
105	55.4	410.7	100.0	1.7	4.3	11.1		18.9	3.5		0.7	
110	49.9	389.9	91.0	1.7	4.4	9.1		18.9	3.5		0.7	
115	52.4	370.4	81.8	1.7	4.4	9.6		18.9	3.5		0.7	
120	56.2	375.0	73.0	1.7	4.8	8.2		18.9	3.5		0.7	
125	49.1	354.8	66.0	1.7	4.8	7.6		18.9	3.5		0.7	
130	42.6	320.2	56.0	1.7	4.8	7.4		18.9	3.5		0.7	
135	41.7	307.2	54.1	1.7	4.9	7.3		18.9	3.5		0.7	
140	40.8	243.8	49.1	1.8	4.9	7.2		18.9	3.5		0.7	
145	40.9	231.3	43.1	1.8	5.1	6.4		18.9	3.5		0.7	
150	42.7	205.8	39.4	1.7	5.1	6.0		18.9	3.5		0.7	

All results are in units of micrograms per liter (μg/L).

---- concentration below 3.0 μg/L (TNT), 0.5 μg/L (2,4-DNT and 2,6-DNT)

ND ---- Non-detect

ISEB = In situ enhanced bioremediation

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Table 5-3(b)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
TNT Area A
Simulation No. 3 - Soil Excavation and ISEB
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial							**ND**	**0.49**	**3.6**			
1	9.9		23.8					0.5	3.6			
5	8.1		19.4					0.5	3.6			
10	6.3		13.2					0.5	3.6			
15	4.9	4.5	7.9					0.5	3.6			
20	3.8	9.7	16.5					0.5	3.6			
25	3.2	10.9	21.3					0.5	3.5			
30	3.4	8.4	20.5					0.5	3.5			
35	3.1	5.5	17.4					0.5	3.5			
40	2.8	4.0	16.2					0.5	3.5			
45	2.7	3.8	12.5			0.9		0.5	3.5			
50	2.6	3.6	10.4			1.6		0.5	3.5			
55	2.5	3.0	6.8			1.0		0.5	3.5			
60	3.1	3.3	4.9			1.3		0.5	3.5			
65	3.4	3.3	3.6			0.9		0.5	3.5			
70	3.0	3.1	2.4			0.8		0.5	3.5			
75		2.7	2.3			0.8		0.5	3.5			
80		2.5	2.6			0.8		0.5	3.5			
85		3.1	3.2			0.7		0.5	3.5			
90		3.5	3.7			0.7		0.5	3.5			
95		3.8	4.0			0.6		0.5	3.5			
100		3.9	4.0			0.5		0.5	3.5			
105		3.7	3.9			0.5		0.5	3.5			
110		3.5	3.6					0.5	3.5			
115		3.1	3.3			0.5		0.5	3.5			
120		2.7	2.8			0.5		0.5	3.5			
125		2.3	2.4			0.5		0.5	3.5			
130		1.9	2.0					0.5	3.5			
135		1.5	1.6					0.5	3.5			
140		1.2	1.3					0.5	3.5			
145		1.0	1.2					0.5	3.5			
150		0.8	0.9					0.5	3.5			

All results are in units of micrograms per liter (μg/L).

---- concentration below 3.0 μg/L (TNT), 0.5 μg/L (2,4-DNT and 2,6-DNT)

ND ---- Non-detect

ISEB = In situ enhanced bioremediation

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Table 5-3 (c)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
TNT Area B
Simulation No. 3 - Soil Excavation and ISEB
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial							ND	ND	ND			
1	9.3											
5	7.6		32.0									
10	5.9	12.1	45.4									
15	4.5	48.4	33.4									
20	6.0	108.1	25.1									
25	15.9	216.6	102.7		1.2							
30	27.4	289.2	226.6		1.2							
35	36.8	306.1	348.5		1.2							
40	42.1	280.6	426.4		1.2							
45	43.2	233.9	447.4		1.1							
50	41.0	182.6	411.7		1.1	1.1						
55	36.7	136.0	366.8		1.5	1.4						
60	31.5	126.2	326.4		1.4	5.0						
65	26.2	130.0	268.7		1.4	5.4						
70	21.2	125.0	238.9		1.4	5.8						
75	16.8	120.5	201.5		1.4	5.7						
80	15.8	129.8	170.1		1.4	5.6						
85	15.6	135.5	169.0		1.4	8.3						
90	15.1	122.7	152.6		1.4	8.1						
95	14.1	115.9	126.0		1.4	8.0						
100	13.9	99.6	109.6		1.4	7.9						
105	13.7	84.7	100.0		1.4	7.6						
110	12.4	71.4	91.0		1.5	7.4			1.4			
115	12.2	60.6	81.8		1.5	7.3			1.4			
120	12.1	49.4	73.0		1.4	7.1			1.4			
125	11.3	47.7	66.0		1.3	7.0			1.4			
130	11.1	46.4	56.0		1.2	6.4			1.5			
135	10.4	44.9	54.1		1.2	6.2			1.9			
140	10.3	43.3	49.1		1.2	5.5			2.1			
145	8.8	37.9	43.1		1.2	5.3			2.1			
150	8.2	33.5	39.4		1.2	6.0			2.5			

All results are in units of micrograms per liter (μg/L).

---- concentration below 3.0 μg/L (TNT), 0.5 μg/L (2,4-DNT and 2,6-DNT)

ND ----- non-detect

ISEB = In situ enhanced bioremediation

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Table 5-3(d)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
TNT Area C
Simulation No. 3 - Soil Excavation and ISEB
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial							ND	0.1	0.7			
1	500.2	11.8	11.8									
5	409.5	1079.5	1079.5			0.9						
10	316.8	1388.2	1588.2			3.2						
15	238.0	991.0	991.0			5.1						
20	172.9	607.9	607.9			5.5						
25	137.7	353.5	353.5			4.0						
30	129.4	236.0	239.6			7.6						
35	142.6	291.8	183.3			7.3						
40	137.5	229.8	140.4			7.7						
45	123.9	168.3	124.7			7.6						
50	105.1	417.4	82.6			7.7			1.1			
55	95.5	132.7	64.1			6.9			1.1			
60	84.2	114.2	50.5	1.1	1.3	6.5			1.1			
65	65.7	102.3	46.7	1.1	1.2	6.3			1.2			
70	57.1	80.5	42.8	1.2	1.2	5.3			1.2			
75	61.3	68.6	28.7	1.2	1.1	5.1			1.2			
80	67.5	64.4	24.6	1.2	1.1	5.5			1.2			
85	62.3	58.1	19.5	1.7	1.0	4.5			1.2			
90	61.7	58.6	18.3	1.7	1.0	4.8			1.3			
95	53.7	61.6	14.7	1.7	1.7	5.8			1.6			
100	52.7	51.9	12.2	1.7	1.7	5.1			1.6			
105	53.4	48.5	9.5	1.7	1.7	5.1			1.4			
110	49.9	47.4	7.4	1.7	1.8	4.3			1.5			
115	52.4	43.5	6.8	1.7	1.8	4.4			1.6			
120	56.2	41.8	5.6	1.7	1.8	4.5			1.6			
125	49.1	40.7	4.8	1.7	1.7	3.0			1.6			
130	42.6	40.1	3.7	1.7	1.7	3.8			1.6			
135	41.7	38.7	2.8	1.7	2.3	3.9			1.6			
140	40.8	37.3	2.5	1.8	1.9	3.5			1.6			
145	40.9	36.7	2.2	1.8	1.9	2.9			1.7			
150	42.7	34.6	1.7	1.7	1.9	3.3			1.7			

All results are in units of micrograms per liter (μg/L).

---- concentration below 3.0 μg/L (TNT), 0.5 μg/L (2,4-DNT and 2,6-DNT)

ND ----- non-detect

ISEB = In situ enhanced bioremediation

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Table 5-3 (e)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
Pentolite Road Red Water Pond Area
Simulation No. 3 - Soil Excavation and ISEB
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial							**1.6**	**1.5**	**1.4**			
1	12.6	4215.9	324.3					1.5	1.4			
5	10.3	3433.4	265.5		0.6	0.7		1.5	1.4			
10	67.1	2510.0	212.7		1.0	1.2		1.5	1.3			
15	121.5	1758.9	189.8		1.3	1.5		1.5	1.2			
20	138.9	1221.0	168.7		1.6	1.6		1.5	1.2			
25	128.6	849.5	136.1		1.7	1.5		1.5	1.2			
30	105.7	594.9	121.6		1.8	2.3		1.5	1.1			
35	80.7	583.1	111.6		1.9	2.1		1.5	1.1			
40	58.6	560.0	106.9		1.8	2.1		1.5	1.0			
45	41.2	510.9	90.0		1.8	2.2		1.4	1.0			
50	28.3	490.9	79.9		1.9	2.2		1.4	1.0			
55	32.2	433.4	71.5		1.9	2.3		1.4	1.0			
60	44.0	417.9	63.1		1.9	6.1		1.4	1.0			
65	54.4	372.1	57.0		1.8	6.6		1.4	0.9			
70	62.1	350.5	51.0		1.8	6.9		1.4	0.9			
75	66.5	340.1	46.3		1.8	10.1		1.4	0.9			
80	67.4	273.6	44.2		1.7	9.9		1.4	0.9			
85	65.4	304.7	38.9		1.7	9.7		1.4	0.9			
90	61.2	316.5	38.4		1.6	10.0		1.4	0.9			
95	55.4	347.8	33.9		1.5	10.6		1.4	1.0			
100	48.9	410.7	27.7		1.5	10.4		1.4	1.3			
105	42.1	410.7	25.4		1.5	11.1		1.4	1.4			
110	35.6	389.9	21.2		1.5	9.1		1.4	1.4			
115	29.5	370.4	16.8		1.6	9.6		1.4	1.6			
120	24.1	375.0	15.8		1.6	8.2		1.3	1.6			
125	21.6	354.8	13.5		1.6	7.6		1.3	1.6			
130	20.3	320.2	12.0		1.6	7.4		1.3	1.7			
135	20.1	307.2	11.0		1.7	7.3		1.3	1.7			
140	19.8	243.8	9.0		1.7	7.2		1.3	1.7			
145	18.7	231.3	7.6		1.7	6.4		1.3	1.7			
150	18.5	205.8	6.6		1.7	5.9		1.3	1.2			

All results are in units of micrograms per liter (μg/L).

---- concentration below 3.0 μg/L (TNT), 0.5 μg/L (2,4-DNT and 2,6-DNT)

ND -----non-detect

ISEB = In situ enhanced bioremediation

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Table 5-3 (f)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
West Area Red Water Ponds Area
Simulation No. 3 - Soil Excavation and ISEB
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial							**0.081**	**19**	**0.43**			
1	99.4	1054.0	243.2		1.3			19.0		ND		
5	81.4	862.6	199.0		1.3	1.2		19.0				
10	63.4	668.6	146.1		1.4	1.9		19.0				
15	49.4	513.3	91.8		1.5	2.3		19.0			0.7	
20	38.4	383.5	51.1		2.0	2.2		19.0			0.7	
25	29.9	291.9	52.6		3.0	2.1		19.0			0.7	
30	23.3	271.1	50.5		3.0	2.0		19.0			0.7	
35	18.2	243.9	35.5		3.1	1.7		19.0			0.7	
40	14.1	212.3	24.2		3.2	1.6		18.9			0.7	
45	11.0	202.4	19.7		3.3	1.2		18.9			0.7	
50	6.6	176.9	15.8		3.3	1.3		18.9			0.7	
55	5.1	161.9	14.1		3.9	0.9		18.9			0.7	
60	3.9	141.1	9.9		4.0	0.8		18.9			0.7	
65	3.0	134.9	8.8		3.9	0.8		18.9			0.7	
70		108.7	7.8		4.0	0.8		18.9			0.7	
75		104.4	6.8		4.1	0.7		18.9	0.5		0.7	
80		97.7	5.8		4.1	0.7		18.9	0.5		0.7	
85		98.9	4.9		4.2	0.7		18.9	0.5		0.7	
90		94.2	4.3		4.2	0.6		18.9	0.5		0.7	
95		89.9	3.4		4.2	0.6		18.9	0.5		0.7	
100		87.4	3.1		4.3	0.6		18.9	0.5		0.7	
105		83.3	2.8		4.3	0.6		18.9	0.5		0.7	
110		80.9	2.5		4.4	0.6		18.9	0.5		0.7	
115		78.7	2.3		4.4	0.5		18.9	0.5		0.7	
120		76.5	2.1		4.8	0.5		18.9	0.5		0.7	
125		72.6	1.7		4.8	0.5		18.9	0.5		0.7	
130		68.5	1.5		4.8	0.5		18.9	0.5		0.7	
135		65.5	1.3		4.9	0.5		18.9	0.5		0.7	
140		63.8	1.1		4.9	0.5		18.9	0.5		0.7	
145		59.2	1.0		5.1	0.5		18.9	0.5		0.7	
150		54.4	0.9		5.1	0.5		18.9	0.5		0.7	

All results are in units of micrograms per liter (μg/L).

---- concentration below 3.0 μg/L (TNT), 0.5 μg/L (2,4-DNT and 2,6-DNT)

ND ----- Non-detect

ISEB = In situ enhanced bioremediation

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Table 5-4(a)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
Simulation No. 4 - Soil Excavation, ISEB, Pump-and-Treat (10-Well Option)
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial							1.6	19	3.6			
1	500.2	4215.9	324.3	69	140.7	60.7		18.9				
5	409.5	3433.4	1079.5	69	158.2	60		18.6			1.3	
10	316.8	2510	1388.2	69	157.9	75.2		18.1	2.2		1.9	
15	238	1758.9	991	68.9	210.5	76.5		17.8	5.4		2.3	
20	172.9	1221	607.9	68.9	236.7	63.7		17.7	5.3		2.4	
25	128.6	849.5	353.5	64.8	233.8	53.8		17.1	4.5		2.7	
30	105.7	594.9	302.7	58	230.7	49.2		16.6	4		3.1	
35	80.7	419.4	348.5	57.9	225.2	48.1		16.5	5.3		3.2	
40	58.6	259.3	426.4	57.9	221.9	47.1		15.3	6.8		3.4	
45	48.3	250.5	447.4	57.8	221.3	38.1		14.9	6.7		3.5	
50	47.6	257.4	421.3	57.8	219.5	35.2		14.8	7.7		3.6	
55	46.9	253.8	366.8	57.7	217.9	40.7		14.5	7.7		3.7	
60	46.2	239.2	295.1	57.6	214.5	38.1		14.4	7.7		3.6	
65	54.4	250.2	272.8	57.6	211	37		14.4	7.7		3.6	
70	62.1	246.1	228.7	57.5	207.6	25.3		14.4	11		3.7	
75	66.5	241.9	192.2	57.4	204.2	23.7		13.8	10.1		3.7	
80	67.4	237.8	171.1	57.4	155.3	22.4		13.6	10.4		3.8	
85	65.4	233.8	143.5	57.3	152.8	22.1		13.6	10.1		3.8	
90	61.2	213	112.7	57.3	117	20.1		13.5	9.4		4.2	
95	55.4	208.2	104.2	57.2	114.7	21.4		13.4	8.6		4.1	
100	48.9	203.2	104.5	57.1	112.9	21		13.4	9.5		3.7	
105	42.1	169.7	103.3	57.1	107	18.5		13.3	11.3		3.7	
110	35.6	167.2	87.8	57	101.6	18.1		13.2	11		3.7	
115	29.5	153	89.3	56.9	100	16.1		13.2	10.8		3.6	
120	24.1	150.8	76.7	56.9	98.4	16.4		13.1	9.5		3.8	
125	19.5	148.7	80.4	56.8	96.8	17.5		12.4	9.7		4	
130	16.6	146.5	68.1	56.8	95.3	14.8		12	9.2		3.7	
135	16.4	134.1	65.9	56.7	93.8	14.6		12	9.2		4.1	
140	17.8	132.2	62.8	56.6	92.2	14.2		12.6	9.2		3.1	
145	19.5	130.3	59.4	56.6	82.7	14		12.5	9.1		3.2	
150	21.2	114	58.2	56.5	81.4	13.5		12.5	9.1		3.5	1.3

All results are in units of micrograms per liter (μg/L).

---- concentration below 3.0 μg/L (TNT), 0.5 μg/L (2,4-DNT and 2,6-DNT)

ND ---- Non-detect

ISEB = In situ enhanced bioremediation

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Table 5-4(b)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
TNT Area A
Simulation No. 4 - Soil Excavation, ISEB, Pump-and-Treat (10-well Option)
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial							**ND**	**0.49**	**3.6**			
1	9.9		23.8						3.6			
5	8.1		19.3						3.6			
10	6.3		13.2						3.6			
15	4.9	4.5	11.1						3.6			
20	3.8	9.7	16.5						3.6			
25	3	10.9	21.2						3.6			
30	3.4	8.4	20.5						3.6			
35	3.1	5.5	15.2						3.6			
40		3.8	14.9						3.6			
45		2.8	12.4						3.6			
50		2.9	10.4						3.6			
55		2.9	10.4						3.6			
60	3.1	3.3	10.1						3.6			
65	3.4	3.3	11.2						3.6			
70	3	3.1	8.4						3.6			
75		2.7	11.3						3.6			
80		2	9.3						3.6			
85		3.1	7.7						3.6			
90		3.5	7.5						3.6			
95		3.8	7.2						3.6			
100		3.9	6.7						3.6			
105		3.7	5.9						3.6			
110		3.5	6.2						3.6			
115		3.1	5.1						3.6			
120		2.7	5.3						3.6			
125		2.3	4.9						3.5			
130		1.9	4.8						3.5			
135		1.5	4.6						3.5			
140		1.2	4.2						3.5			
145			3.8						3.6			
150			3.7						3.6			

All results are in units of micrograms per liter (µg/L).

---- concentration below 3.0 µg/L (TNT), 0.5 µg/L (2,4-DNT and 2,6-DNT)

ND ---- Non-detect

ISEB = In situ enhanced bioremediation

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Table 5-4(c)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
TNT Area B
Simulation No. 4 - Soil Excavation, ISEB, Pump-and-Treat (10-well Option)
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4- DNT	2,6-DNT
Initial												
1	9.3											
5	7.6		32									
10	5.9	12.1	45.4									
15	4.5	48.4	33.4			1.8						
20	6	108.1	25.1			2						
25	15.9	216.6	102.7			1.5						
30	27.4	289.2	226.6			1.1						
35	36.8	306.1	348.5			1.2						
40	42.1	280.6	426.4			1.8						
45	43.2	212.8	447.4			4.5						
50	41	200.6	421.3		4.3	8.7			1.2			
55	36.7	176.9	366.8		3.9	17.9			1.2			
60	31.5	151.4	295.1		3.9	18.9			1.2			
65	26.2	174.4	272.8		3.9	23.4			1.2			
70	21.2	176.8	228.7		3.8	21.4			1.2			
75	16.8	185.1	192.2		3.8	21.1			1.2			
80	20.1	179.2	171.1		3.8	19.4			1.6			
85	20.3	162.8	123.2		3.8	19.4			1.5			
90	23.5	140.1	87.8		3.7	22.5			1.5			
95	21.7	115.3	70.9		3.7	23			1.5			
100	19	105	52.2		3.7	22.7			1.5			
105	14.1	91.2	37.6		3.7	22.6			3.2			
110	12.7	87	21.7		3.7	23.1			3.4			
115	12.2	81.8	13.6		3.6	22.7			3.6			
120	9.8	64.5	12.5		3.6	21			5.4			
125	9.6	78.1	8.3		3.6	21.2			5.7			
130	11.5	81.2	6		3.3	20.7			6.1			
135	11.5	63	3		2.8	20.2			6.4			
140	15.3	61.2	2.7		2.8	19.8			6.4			
145	15.8	58.5	2.6		2.8	19.5			6.8			
150	21.2	55.4	1.9		2.8	18.7			6.4			

All results are in units of micrograms per liter (μg/L).

---- concentration below 3.0 μg/L (TNT), 0.5 μg/L (2,4-DNT and 2,6-DNT)

ND ----- non-detect

ISEB = In situ enhanced bioremediation

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Table 5-4(d)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
TNT Area C
Simulation No. 4 - Soil Excavation, ISEB, Pump-and-Treat (10-well Option)
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial							ND	0.1	0.7			
1	500.2	11.7	11.8	69								
5	409.5	1079.5	1079.5	69								
10	316.8	1388.2	1388.2	69		1.4						
15	238	991	991	68.9		8.5						
20	172.9	607.9	607.9	68.9		34.1						
25	122.5	353.5	353.5	64.8		53.8						
30	85.4	233	302.7	58		49.2						
35	59	175.6	297.9	57.9		48.1			3.3			
40	49	150.3	244.9	57.9		47.1			4.7			
45	48.3	136.1	229.9	57.8		38.1			5.9			
50	47.6	122.8	205.7	57.8		34.5			7.7			
55	46.9	116.9	172.7	57.7		32.4			7.7			
60	46.2	103.8	147.3	57.6	1.4	28.6			7.7			
65	36.8	91.6	141.4	57.6	1.5	24.1			7.7			
70	29.5	84.6	137.2	57.5	1.5	22.1			7.6			
75	22.8	86.1	149.6	57.4	1.5	21.5			8.8			
80	20.7	82.7	120.1	57.4	1.5	21.2			8.4			
85	18.6	72.2	143.5	57.3	1.5	22.1			9.3			
90	18.3	71.7	112.7	57.3	1.5	20.1			9.3			
95	18.2	75.3	104.2	57.2	1.5	21.4			9.3			
100	18.9	69.7	104.5	57.1	1.4	21			9.3			
105	20	70.9	103.3	57.1	1.4	18.5			9.5			
110	20.1	68.9	87.8	57	1.4	18.1			9.5			
115	18.5	58.9	89.3	56.9	1.7	16.1			9.1			
120	17	51.1	76.7	56.9	1.6	16.4			9.4			
125	16.8	42.1	80.4	56.8	1.5	17.5			9.4			
130	16.6	44.9	68.1	56.8	1.5	14.8			9.2			
135	16.4	50.9	65.9	56.7	1.5	14.6			9.2			
140	17.8	56.8	62.8	56.6	1.5	14.2			9.2			
145	19.5	53.1	59.4	56.6	1.4	14			9.1			
150	19.3	60.1	58.2	56.5	1.4	13.5			9.1			

All results are in units of micrograms per liter (μg/L).

---- concentration below 3.0 μg/L (TNT), 0.5 μg/L (2,4-DNT and 2,6-DNT)

ND ----- non-detect

ISEB = In situ enhanced bioremediation

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Table 5-4(e)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
Pentolite Road Red Water Pond Area
Simulation No. 4 - Soil Excavation, ISEB, Pump-and-Treat (10-well Option)
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial							1.6	1.5	1.4			
1	12.6	4215.9	324.3					1.5	1.4			
5	10.3	3433.4	265.5					1.5	1.4			
10	67.1	2510	206.8			15.7		1.5	1.4			
15	121.5	1758.9	189.7		1.9	14.8		1.5	1.4			
20	138.9	1221	168.7		1.9	14.7		1.5	1.4			
25	128.6	849.5	131.8		1.9	14.7		1.5	1.4			
30	105.7	594.9	99.4		1.9	14.7		1.4	1.4			
35	80.7	419.4	85.3		1.9	14.7		1.4	1.4			
40	58.6	259.3	83.6		1.9	13.9		1.4	1.4			
45	41.2	250.5	70.9		1.8	13.9		1.4	1.4			
50	28.3	257.4	68.4		1.8	13.9		1.4	1.4			
55	32.2	253.8	65.8		1.8	13.8		1.4	1.4			
60	44	239.2	69.3		1.8	13.8		1.4	1.4			
65	54.4	250.2	67.2		1.8	13.8		1.4	1.4			
70	62.1	246.1	53.3		1.8	13.1		1.4	1.4			
75	66.5	241.9	52.1		4.2	13		1.4	1.4			
80	67.4	237.8	52.1		4.2	13		1.4	1.4			
85	65.4	233.8	58.2		4.2	13		1.4	1.4			
90	61.2	213	48.9		4.2	13		1.4	1.4			
95	55.4	208.2	52.1		4.2	13		1.4	1.4			
100	48.9	203.2	51.9		4.2	13		1.4	1.4			
105	42.1	169.7	52.2		4.4	13		1.3	1.4			
110	35.6	167.2	44		4.4	13		1.3	1.3			
115	29.5	153	44.4		4.4	13		1.3	1.3			
120	24.1	150.8	40.2		4.4	13		1.3	1.3			
125	19.5	148.7	41.2		4.4	12.9		1.3	1.3			
130	15.5	146.5	41.3		4.4	12.9		1.3	1.3			
135	14.9	134.1	36.6		4.4	12.9		1.3	1.2			
140	12.8	132.2	32.3		4.4	12.9		1.3	1.2			
145	12.8	130.3	35		4.4	12.9		1.3	1.2			
150	12.7	114	35.1		4.4	12.9		1.3	1.2			

All results are in units of micrograms per liter (µg/L).

---- concentration below 3.0 µg/L for TNT; 0.5 µg/L for 2,4-DNT and 2,6-DNT

ND -----non-detect

ISEB = In situ enhanced bioremediation

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Table 5-4(f)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
West Area Red Water Ponds Area
Simulation No. 4 - Soil Excavation, ISEB, Pump-and-Treat (10-well Option)
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial							0.081	19	0.43			
1	99.4	1054	243.2	3.3	247.8	60.7		18.9				
5	81.4	862.6	199	3.3	247	60		18.6			1.3	
10	63.4	668.6	146.1	3.3	310.3	75.2		18.1	2.2		1.9	
15	49.4	513.3	91.8	3.3	340.2	76.5		17.8	5.4		2.3	
20	38.4	383.5	51.2	3.3	342.3	63.7		17.7	5.3		2.4	
25	29.9	275.5	52.6	3.3	337.9	53.8		17.3	4.5		2.7	
30	23.3	190.5	50.5	3.3	322	49		19.1	4		3.1	
35	18.2	127.8	43.5	3.3	317.4	42.9		18.1	5.3		3.2	
40	14.1	83.7	43.1	2.9	295	38.3		18.9	6.8		3.4	
45	11	53.9	32.3	2.9	290.6	37.7		19.8	6.7		3.5	
50	8.5	46.4	32	2.9	284	35.2		19.9	6.8		3.6	
55	6.6	44.3	30.3	2.9	279.5	40.7		20.5	7		3.7	
60	5.1	39.9	26.8	2.9	273.7	38.1		21.3	6.1		3.6	
65	3.9	34.8	27.1	2.9	269.4	37		23.1	7		3.6	
70	3	33.9	25.5	2.9	243	25.3		24.3	11		3.7	
75	2.3	31.9	22.7	2.9	219	23.7		22.3	10.1		3.7	
80	1.7	31.2	27.6	2.8	194	22.4		23	10.4		3.8	
85	1.3	30.3	21.8	2.8	190.9	18.3		26	10.1		3.8	
90	1.2	28.8	22.5	2.8	187.9	16.4		24	9.4		4.2	
95	1.2	28.6	19.9	2.7	172	15.1		21.6	8.6		4.1	
100	1.2	27.9	14.3	2.7	158.2	12.6		21.3	9.5		3.7	
105	1.2	24.8	24.4	2.6	155.7	12.2		20.1	11.3		3.7	
110	1.2	24.3	21.5	2.6	153.3	12.1		19.3	11		3.7	
115	1.1	23.7	17.3	2.5	150.8	12		19	10.8		3.6	
120	1.1	23.2	13	2.5	148.4	11.2		20	9.5		3.8	
125	1.1	19.4	23.6	2.5	146	11.1		19.5	9.7		4	
130	1.1	17.9	20.5	2.5	143.7	9.5		19	9.2		3.7	
135		17.6	16.3	2.5	141.4	9.4		19.3	9		4.1	
140		16.7	18.4	2.5	135.6	9.7		18.7	8.7		3.1	
145		14.5	16.9	2.5	133.4	9		18.8	8.3		3.2	
150		13.5	13.3	2.5	123.1	8.8		18.1	7.6		3.5	1.3

All results are in units of micrograms per liter (μg/L).

---- concentration below 3.0 μg/L for TNT, 0.5 μg/L for 2,4-DNT and 2,6-DNT

ND ----- Non-detect

Soil in WARWP area is assumed excavated at hot spots

ISEB = In situ enhanced bioremediation

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Table 5-5(a)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
Simulation No. 5 - Soil Excavation, ISEB, Pump-and-Treat (14-well Option)
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial							**1.6**	**19**	**3.6**			
1	500.2	11.7	11.8	69				16	3.6			
5	409.5	1079.5	1079.5	69				14.9	3.6			
10	316.8	1388.2	1388	69				14.6	3.6			
15	238	991	991	68.9				13.4	3.6			
20	172.9	607.9	607.9	68.9	1.8	1.3		12.7	3.6			
25	122.5	353.5	353.5	64.8	1.5	2.1		12.2	3.6			
30	85.4	289.2	280.8	58	2.1	1.9		11.9	3.6			
35	59	306.1	348.5	57.9	3.9	4.3		11.6	3.6			
40	45.9	280.6	426.4	57.9	3.7	4		11.4	3.6			
45	45.3	233.9	447.4	57.8	2.9	7.2		11.1	3.6			
50	44.6	188.2	421.3	57.8	2.8	14.2		10.5	3.6			
55	44	192.8	366.8	57.7	2.4	16.5		9.8	3.6			
60	43.4	165.7	301	57.6	1.97	14		9.2	3.6			
65	42.8	153.5	236.4	57.6	1.7	11.8		8.6	3.6			
70	38.6	176.8	276.1	57.5	1.7	10.7		8.1	3.6			
75	30.8	185.1	167.2	57.4	1.5	9.4		7.8	3.6			
80	26.9	179.2	135.5	57.4	1.4	9.9		7.7	3.6			
85	24.6	162.8	122.2	57.3	1.3	13		7.3	3.6			
90	20.4	140.1	107	57.3	1.1	12.7		6.7	3.6			
95	22	115.3	108.1	57.2		10.9		6.2	3.6			
100	22.5	100.7	99.7	57.1		12.6		5.8	3.6			
105	24.1	87.5	99.4	57.1		22.7		5.6	3.6			
110	19.6	81.4	96.4	57		29.3		5.1	3.6			
115	15.6	66.3	102.3	56.9		28.7		4.8	3.6			
120	15.6	59.8	84.8	56.9		28.9		4.5	3.6			
125	15.7	60	82	56.8	0.6	28.4		4.1	3.6			
130	15.2	56.2	84.2	56.8	0.6	25.7		3.7	3.6			
135	14.5	48	85.2	56.7	0.6	26.1		3.4	3.6			
140	14.7	45.4	72.6	56.6	0.6	20.3		3.3	3.6			
145	14.2	37.4	67.2	56.6	0.6	21.9		3.3	3.6			
150	14.1	39.2	75.3	56.5	0.6	30.4		3.2	3.6			

All results are in units of micrograms per liter (µg/L).

---- concentration below 3.0 µg/L (TNT), 0.5 µg/L (2,4-DNT and 2,6-DNT)

ND ---- Non-detect

Soil in WARWP and PRRWP areas is assumed excavated

ISEB = In situ enhanced bioremediation

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Table 5-5(b)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
TNT Area A
Simulation No. 5 - Soil Excavation, ISEB, Pump-and-Treat (14-well Option)
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial							**ND**	**0.49**	**3.6**			
1	9.9		23.8						3.6			
5	8.1		19.3						3.6			
10	6.3		13.2						3.6			
15	4.9	4.5	11.4						3.6			
20	3.8	9.7	16.5						3.6			
25	3	10.9	21.2						3.6			
30	3.4	8.4	20.5						3.6			
35	3.1	5.5	16.5						3.6			
40		3.8	15.2						3.6			
45		2.8	13.2						3.6			
50		2.9	12.1						3.6			
55		2.9	11.2						3.6			
60	3.1	3.3	11.1						3.6			
65	3.4	3.3	9.6						3.6			
70	3	3.1	8.8						3.6			
75		2.7	8.5						3.6			
80		2	7						3.6			
85		3.1	7.3						3.6			
90		3.5	7.1						3.6			
95		3.8	6.9						3.6			
100		3.9	6						3.6			
105		3.7	5.6						3.6			
110		3.5	5.6						3.6			
115		3.1	5.2						3.6			
120		2.7	4.7						3.6			
125		2.3	4.7						3.6			
130		1.9	4.4						3.6			
135		1.5	4.2						3.6			
140		1.2	3.9						3.6			
145			3.8						3.6			
150			3.7						3.6			

All results are in units of micrograms per liter (µg/L).

---- concentration below 3.0 µg/L (TNT), 0.5 µg/L (2,4-DNT and 2,6-DNT)

ND ---- Non-detect

ISEB = In situ enhanced bioremediation

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Table 5-5(c)

Maximum Simulated Concentrations of -TNT, 2,4-DNT, and 2,6-DNT
TNT Area B
Simulation No. 5 - Soil Excavation, ISEB, Pump-and-Treat (14-well Option)
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial												
1	9.3											
5	7.6		32									
10	5.9	12.1	45.4									
15	4.5	48.4	33.4									
20	6	108.1	25.1		1.8	1.3						
25	15.9	216.6	102.7		1.5	2.1						
30	27.4	289.2	226.6		2.1	1.9						
35	36.8	306.1	348.5		3.9	4.3						
40	42.1	280.6	426.4		3.7	4						
45	43.2	233.9	447.4		2.9	7.2						
50	41	188.2	421.3		2.8	14.2						
55	36.7	192.8	366.8		2.4	16.5						
60	31.5	165.7	301		1.97	14						
65	26.2	153.5	236.4		1.7	11.8						
70	21.9	176.8	276.1		1.7	10.7						
75	18.8	185.1	167.2		1.5	9.4						
80	18.3	179.2	114.4		1.4	9.9						
85	18.3	162.8	81.8		1.3	13						
90	16.4	140.1	68.6		1.1	12.7						
95	16.8	115.3	49.1			10.9						
100	15.4	100.7	31.8			9.8						
105	15.8	87.5	22.7			9.2						
110	15.3	81.4	16.6			6.9						
115	15	66.3	9.5			11.5						
120	15.1	59.8	6.9			9.4						
125	14.8	60	6.2			9.6						
130	14.7	56.2	5.6			9						
135	13.2	48	5.2			8.6						
140	10.7	45.4	5			8.2						
145	7.9	37.4	4			8.1						
150	6.6	39.2	4			7.7						

All results are in units of micrograms per liter (µg/L).

---- concentration below 3.0 µg/L (TNT), 0.5 µg/L (2,4-DNT and 2,6-DNT)

ND ----- non-detect

ISEB = In situ enhanced bioremediation

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Table 5-5(d)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
TNT Area C
Simulation No. 5 - Soil Excavation, ISEB, Pump-and-Treat (14-well Option)
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial							ND	0.1	0.7			
1	500.2	11.7	11.8	69								
5	409.5	1079.5	1079.5	69								
10	316.8	1388.2	1388	69								
15	238	991	991	68.9								
20	172.9	607.9	607.9	68.9								
25	122.5	353.5	353.5	64.8								
30	85.4	201.3	280.8	58		1.4						
35	59	126	315.5	57.9		1.8						
40	45.9	107.6	203.2	57.9		1.6						
45	45.3	102.9	220.4	57.8		1.6						
50	44.6	93.2	182.4	57.8		1.6						
55	44	88.6	190.6	57.7		4.3						
60	43.4	80.7	146.6	57.6		4.5						
65	42.8	67	159.3	57.6		4.6						
70	38.6	47	161.9	57.5		4.2						
75	30.8	45.8	130	57.4		4						
80	26.9	37.4	135.5	57.4		8.7						
85	24.6	35.3	122.2	57.3		8.3						
90	20.4	55.6	107	57.3		11						
95	22	50.8	108.1	57.2		7.5						
100	22.5	45.3	99.7	57.1		12.6						
105	24.1	40.6	99.4	57.1		22.7						
110	19.6	43.5	96.4	57		29.3						
115	15.6	42.2	102.3	56.9		28.7						
120	15.6	39.9	84.8	56.9		28.9						
125	15.7	39.4	82	56.8	0.6	28.4						
130	15.2	41.8	84.2	56.8	0.6	25.7						
135	14.5	41.8	85.2	56.7	0.6	26.1						
140	14.7	37	72.6	56.6	0.6	20.3						
145	14.2	35.2	67.2	56.6	0.6	21.9						
150	14.1	28.6	75.3	56.5	0.6	30.4						

All results are in units of micrograms per liter (μg/L).

---- concentration below 3.0 μg/L (TNT), 0.5 μg/L (2,4-DNT and 2,6-DNT)

ND ----- non-detect

ISEB = In situ enhanced bioremediation

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Table 5-5(e)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
Pentolite Road Red Water Pond Area
Simulation No. 5 - Soil Excavation, ISEB, Pump-and-Treat (14-well Option)
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial							1.6	1.5	1.4			
1								1.5	1.4			
5								1.5	1.4			
10								1.5	1.4			
15								1.5	1.3			
20								1.5	1.3			
25								1.4	1.3			
30								1.4	1.3			
35								1.4	1.3			
40								1.4	1.3			
45								1.4	1.3			
50								1.4	1.3			
55								1.4	1.3			
60								1.4	1.3			
65								1.4	1.3			
70								1.4	1.3			
75								1.4	1.3			
80								1.4	1.3			
85								1.3	1.3			
90								1.3	1.3			
95								1.3	1.3			
100								1.3	1.3			
105								1.2	1.3			
110								1.2	1.3			
115								1.2	1.3			
120								1.2	1.3			
125								1.2	1.3			
130								1.2	1.3			
135								1.2	1.2			
140								1.2	1.2			
145								1.2	1.2			
150								1.1	1.2			

All results are in units of micrograms per liter (µg/L).

---- concentration below 3.0 µg/L for TNT; 0.5 µg/L for 2,4-DNT and 2,6-DNT

ND -----non-detect

Soil in PRRWP area is assumed excavated

ISEB = In situ enhanced bioremediation

TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

Table 5-5(f)

Maximum Simulated Concentrations of TNT, 2,4-DNT, and 2,6-DNT
West Area Red Water Ponds Area
Simulation No. 5 - Soil Excavation, ISEB, Pump-and-Treat (14-well Option)
Former Plum Brook Ordnance Works, Sandusky, Ohio

Year	Layer 1			Layer 2			Layer 3			Layer 4		
	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT	TNT	2,4-DNT	2,6-DNT
Initial							0.081	19	0.43			
1								16				
5								14.9				
10								14.6				
15								13.4				
20								12.7				
25								12.2				
30								11.9				
35								11.6				
40								11.4				
45								11.1				
50								10.5				
55								9.8				
60								9.2				
65								8.6				
70								8.1				
75								7.8				
80								7.7				
85								7.3				
90								6.7				
95								6.2				
100								5.8				
105								5.6				
110								5.1				
115								4.8				
120								4.5				
125								4.1				
130								3.7				
135								3.4				
140								3.3				
145								3.3				
150								3.2				

All results are in units of micrograms per liter (µg/L).

---- concentration below 3.0 µg/L for TNT, 0.5 µg/L for 2,4-DNT and 2,6-DNT

ND ----- Non-detect

Soil in WARWP area is assumed excavated

ISEB = In situ enhanced bioremediation

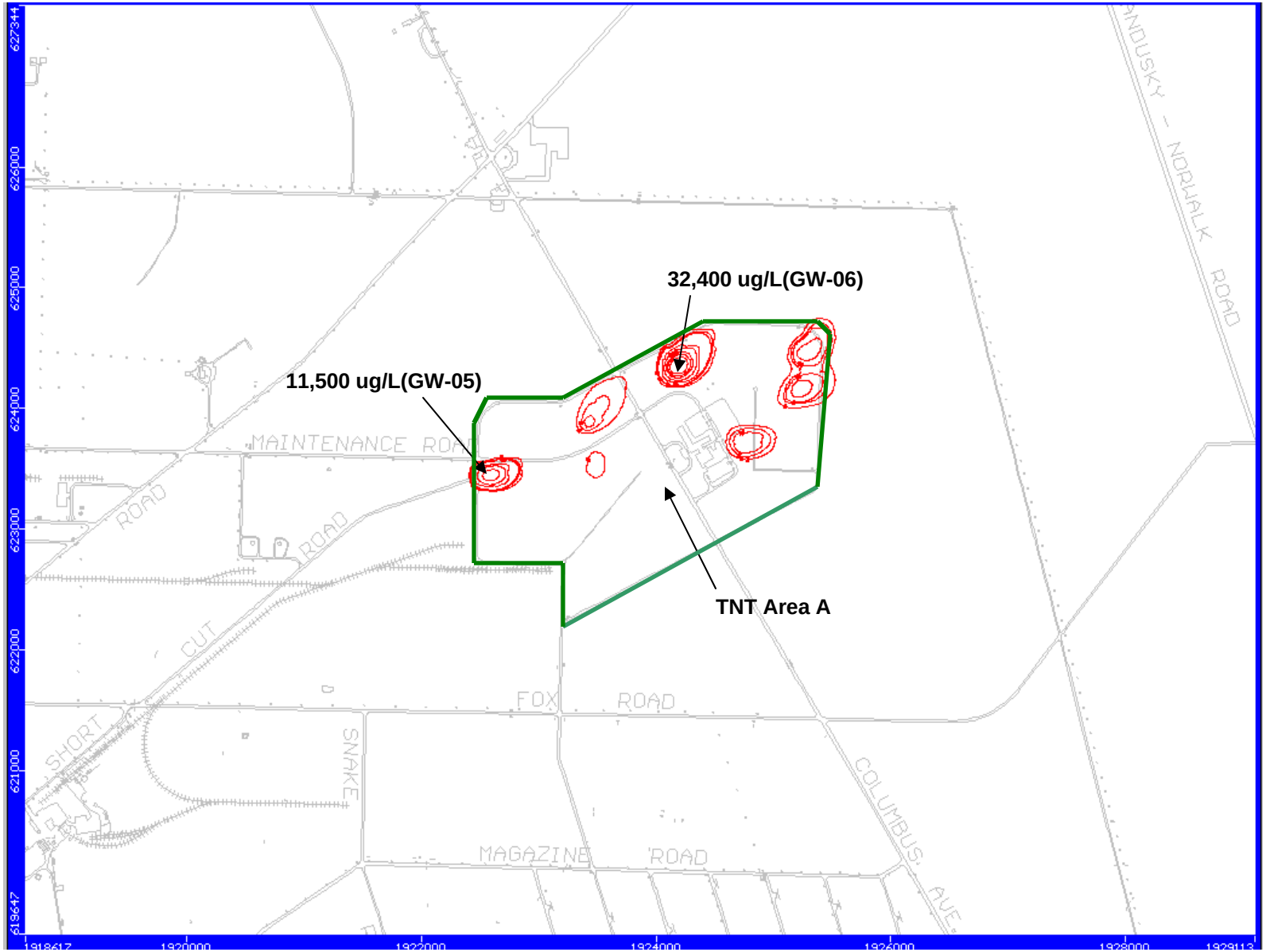
TNT = trinitrotoluene

2,4-DNT = 2,4-dinitrotoluene

2,6-DNT = 2,6-dinitrotoluene

FIGURES

Figure 3-1
TNT Plumes in the Overburden/Shale Water Bearing Zone
TNT Area A
Former Plum Brook Ordnance Works, Sandusky, Ohio



KN8\PBOW\TNT-RWP\FS\Final\APA\Figs\Fig3-1.ppt

Figure 3-2
TNT Plumes in the Overburden/Shale Water Bearing Zone
TNT Area B
Former Plum Brook Ordnance Works, Sandusky, Ohio

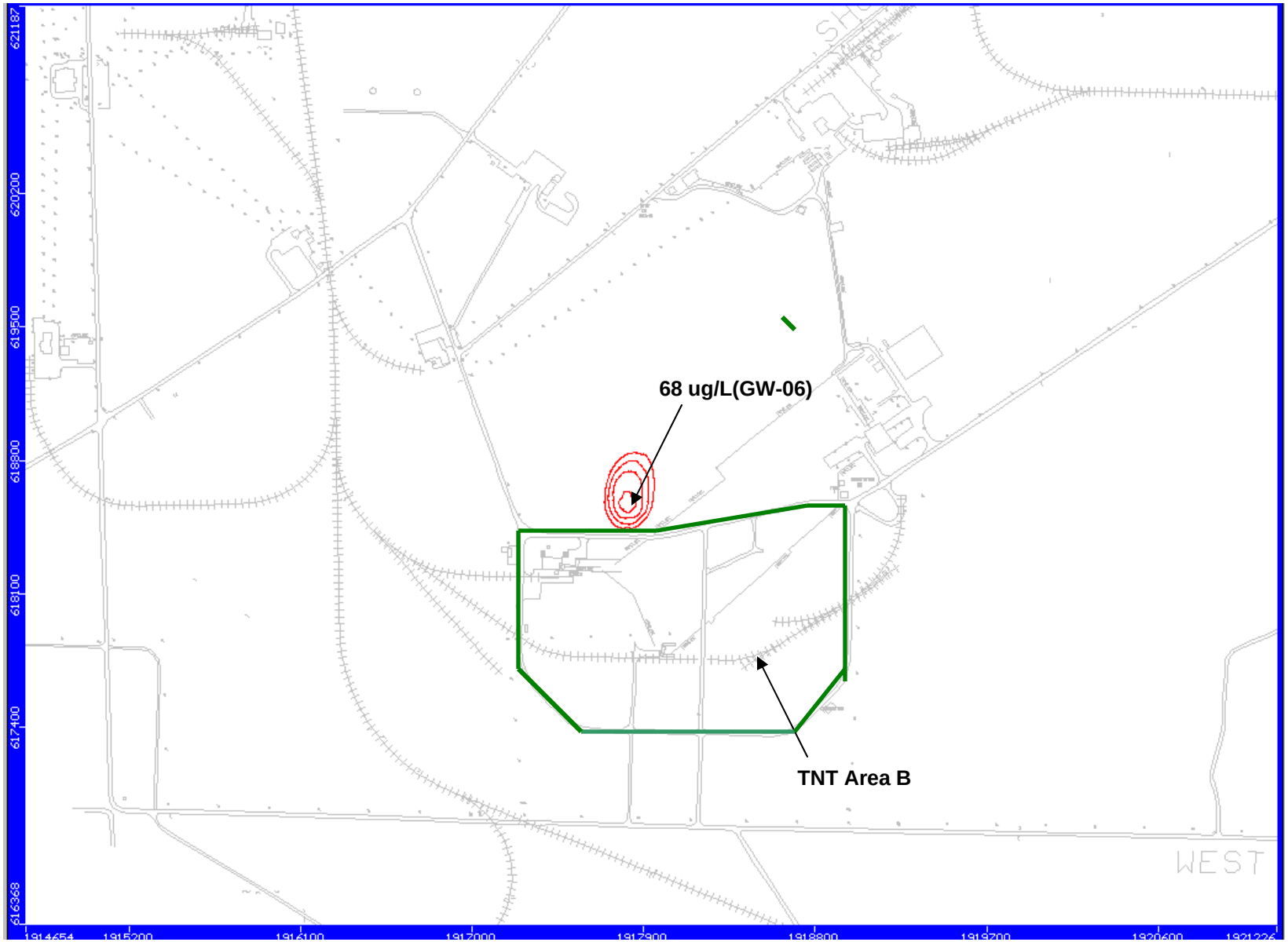


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Figure 3-3
TNT Plumes in the Overburden/Shale Water Bearing Zone
TNT Area C
Former Plum Brook Ordnance Works, Sandusky, Ohio

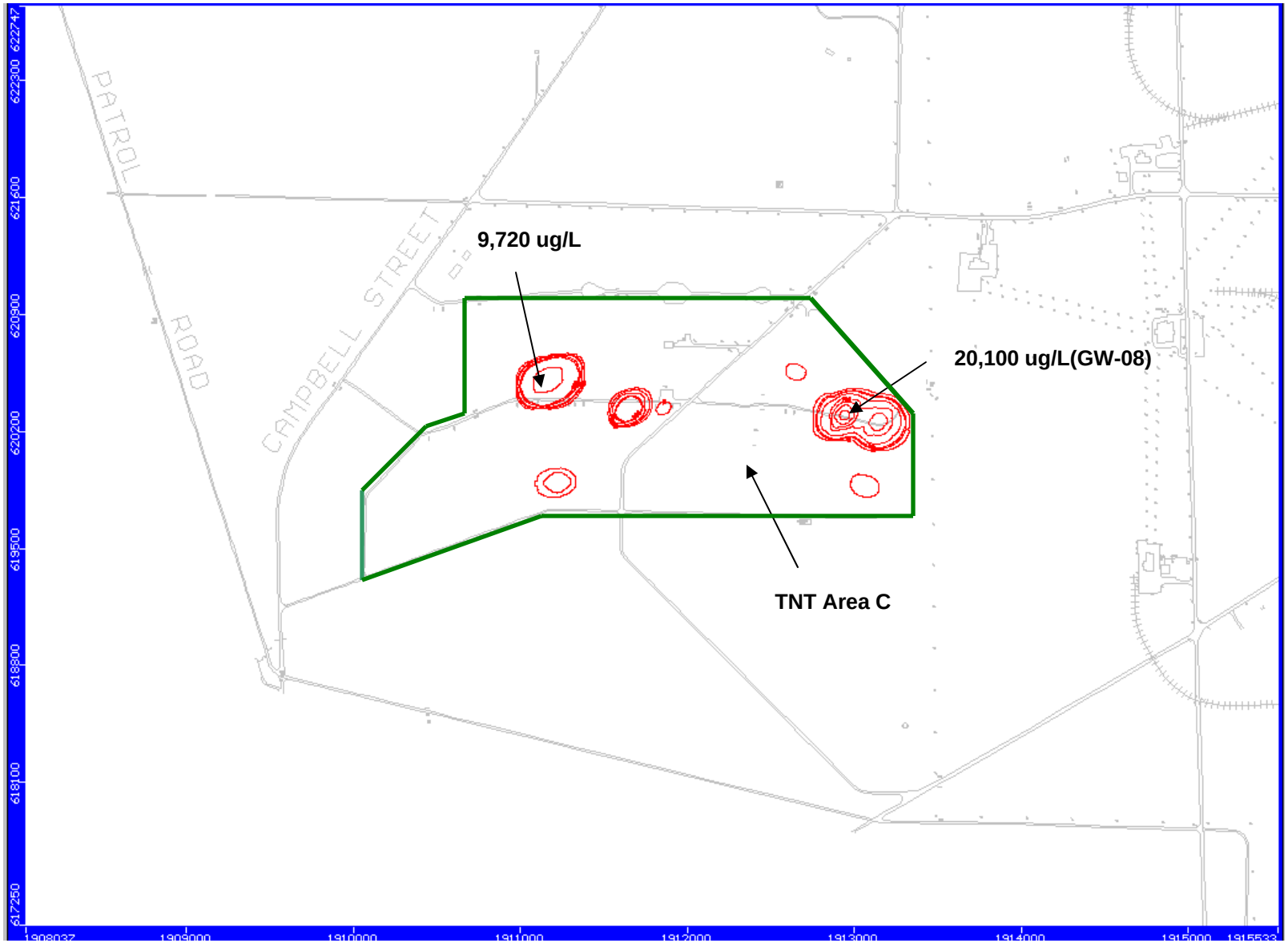

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Figure 3-4
TNT Plumes in the Overburden/Shale Water Bearing Zone
Pentolite Road Red Water Pond Area
Former Plum Brook Ordnance Works, Sandusky, Ohio

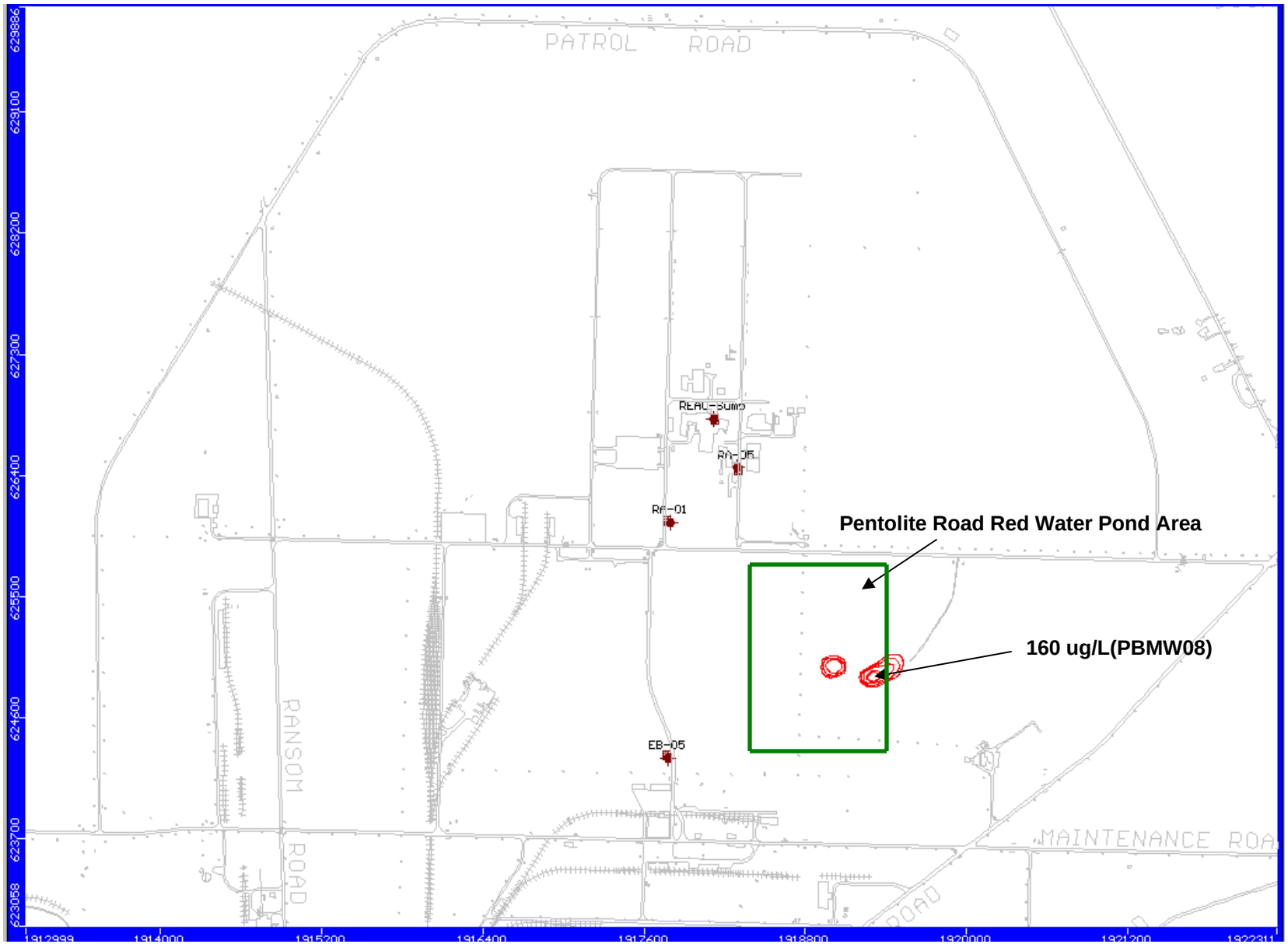

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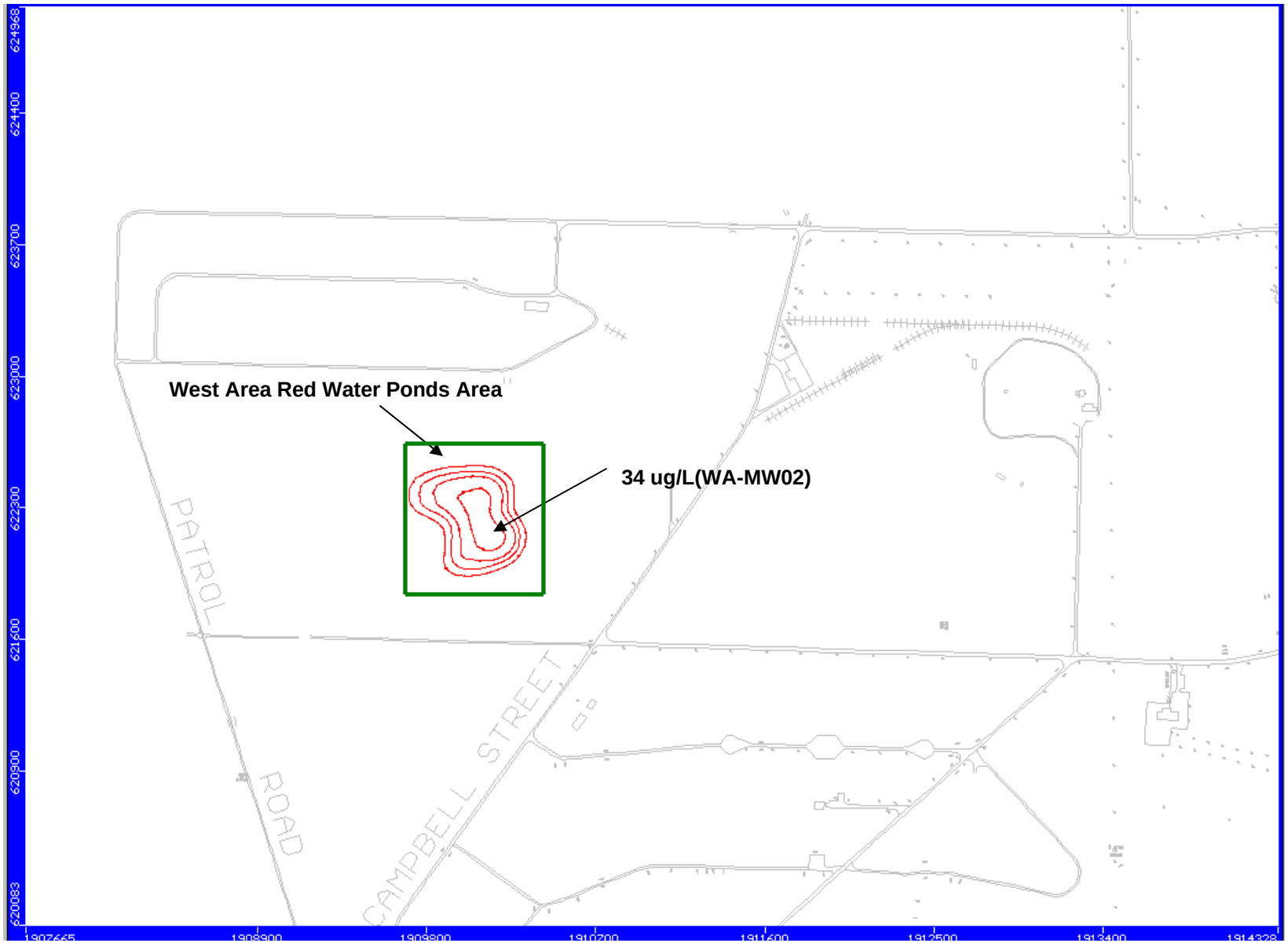
Figure 3-5
TNT Plumes in the Overburden/Shale Water Bearing Zone
West Area Red Water Ponds Area
Former Plum Brook Ordnance Works, Sandusky, Ohio



KN8\PBOW\TNT-RWP\FS\Final\APA\Figs\Fig3-5.ppt

Figure 3-6
2,4-DNT Plumes in the Overburden/Shale Water Bearing Zone
TNT Area A
Former Plum Brook Ordnance Works, Sandusky, Ohio

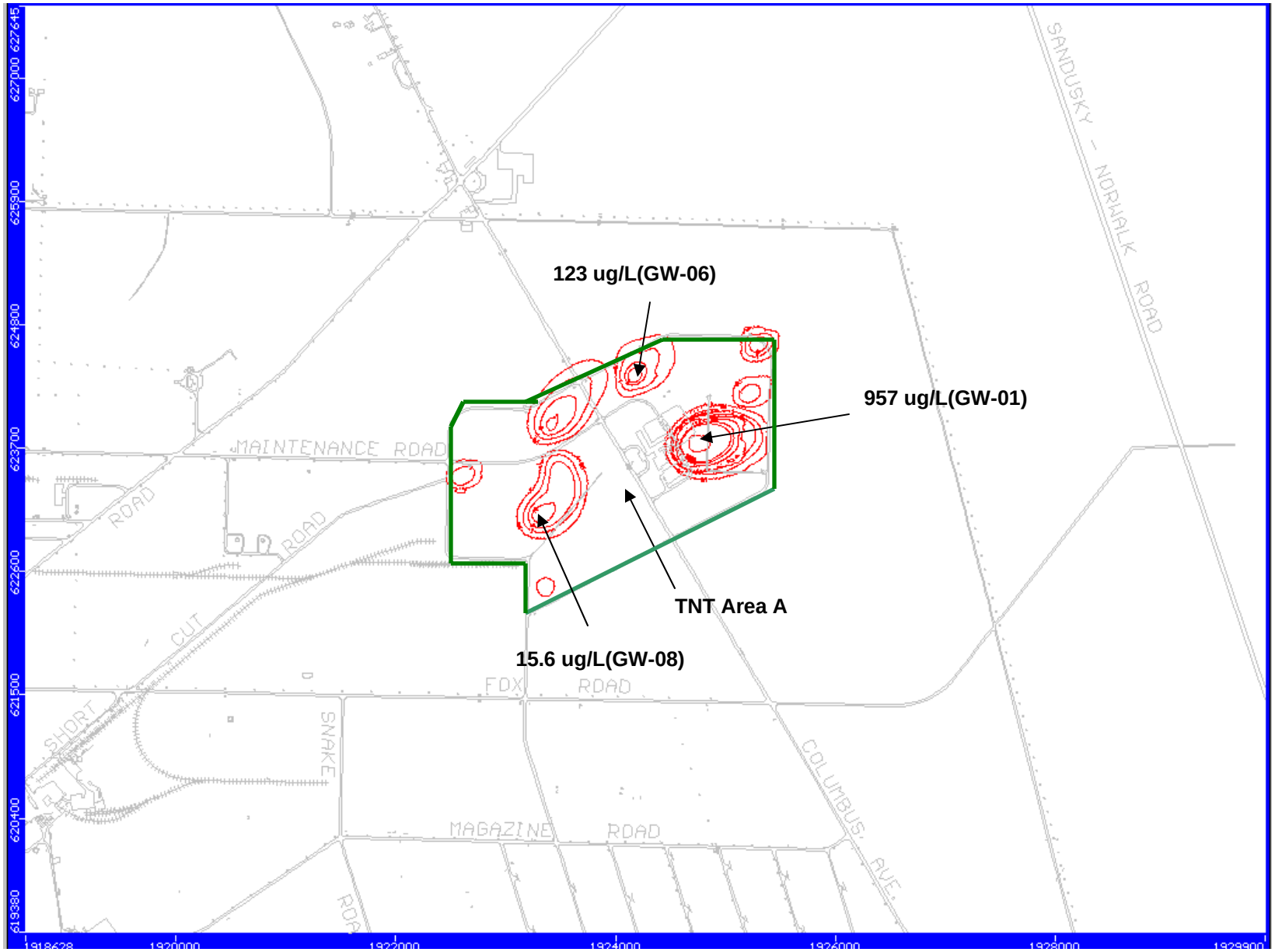


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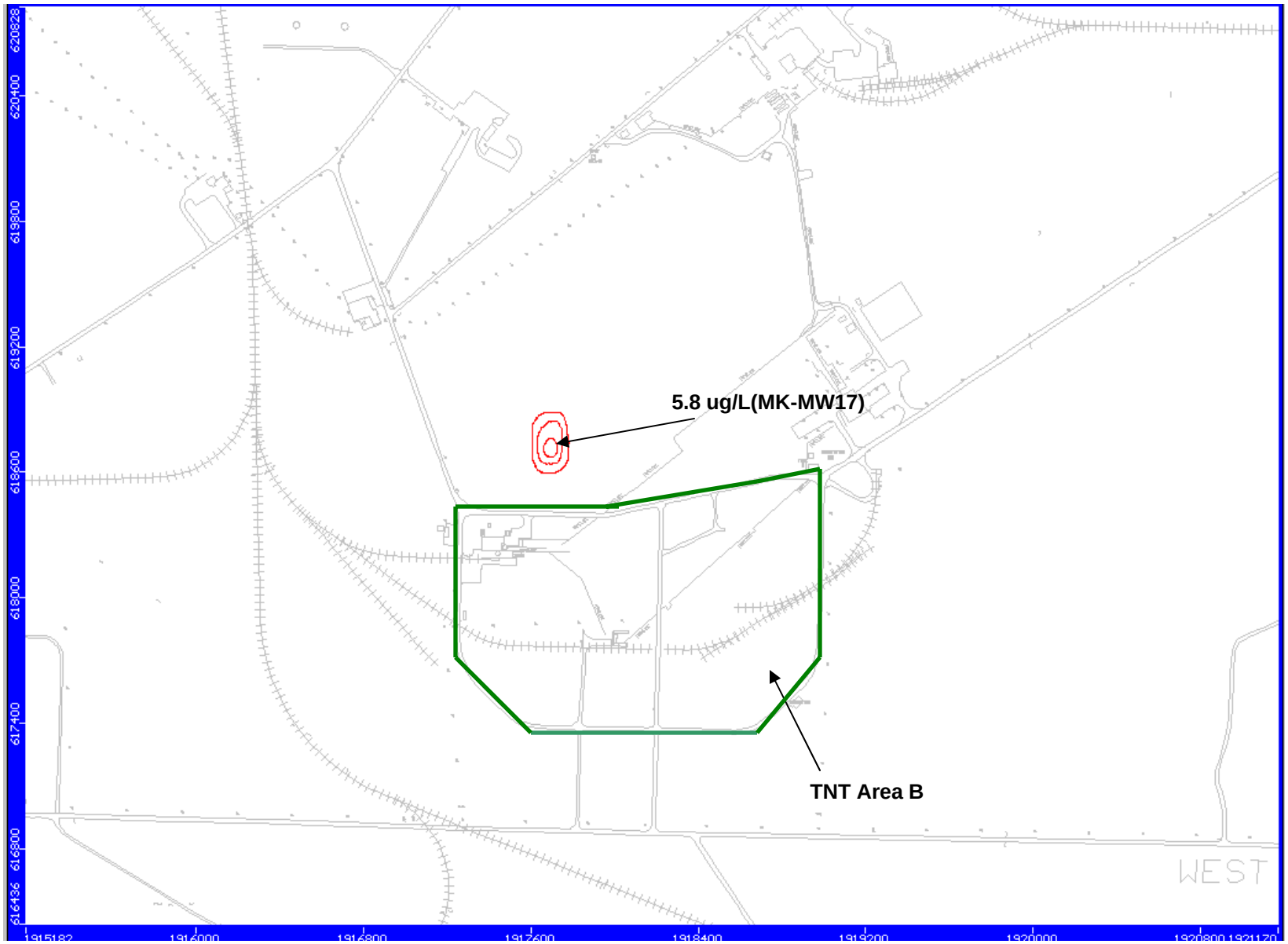
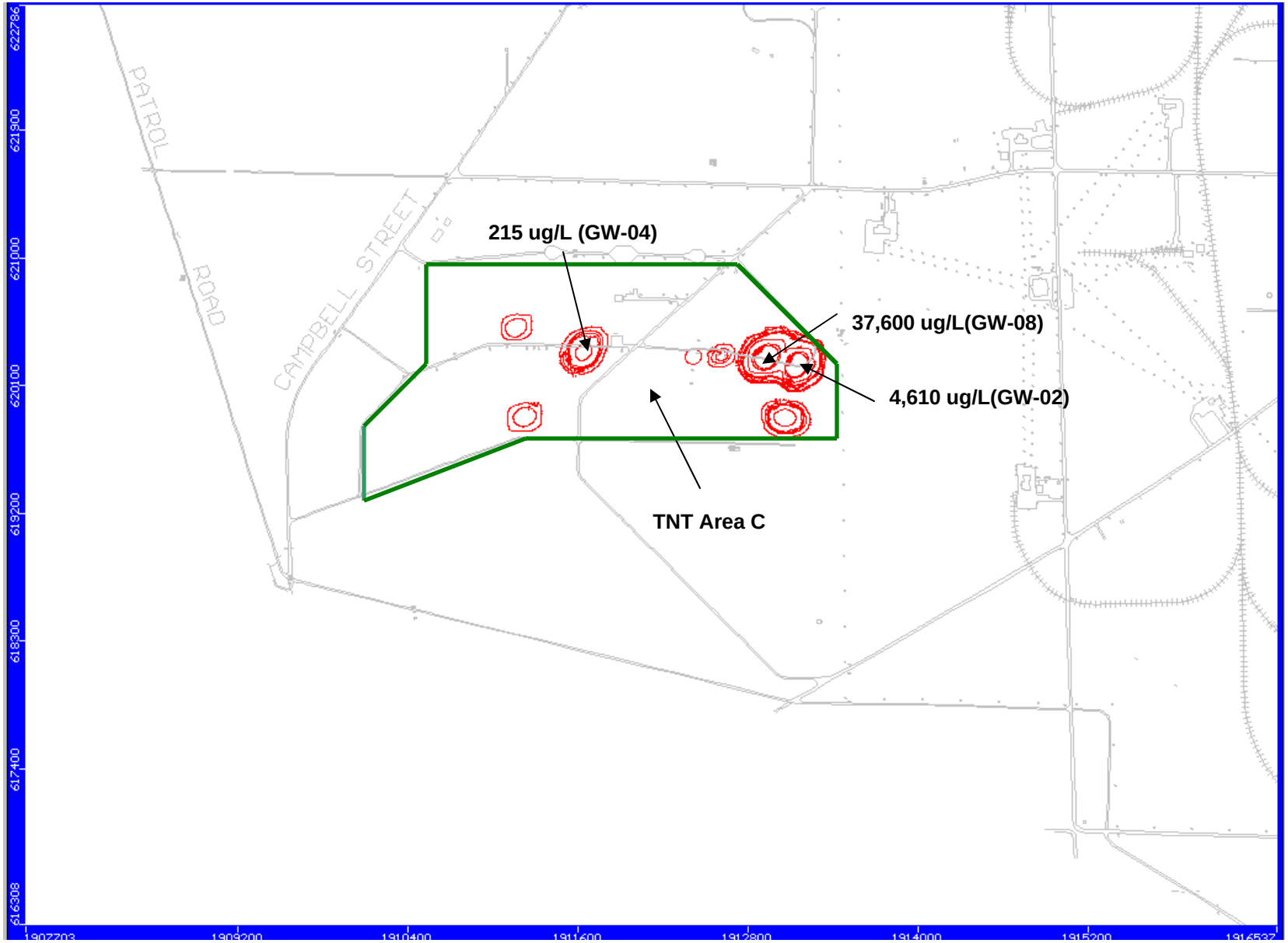
Figure 3-7
2,4-DNT Plumes in the Overburden/Shale Water Bearing Zone
TNT Area B
Former Plum Brook Ordnance Works, Sandusky, Ohio



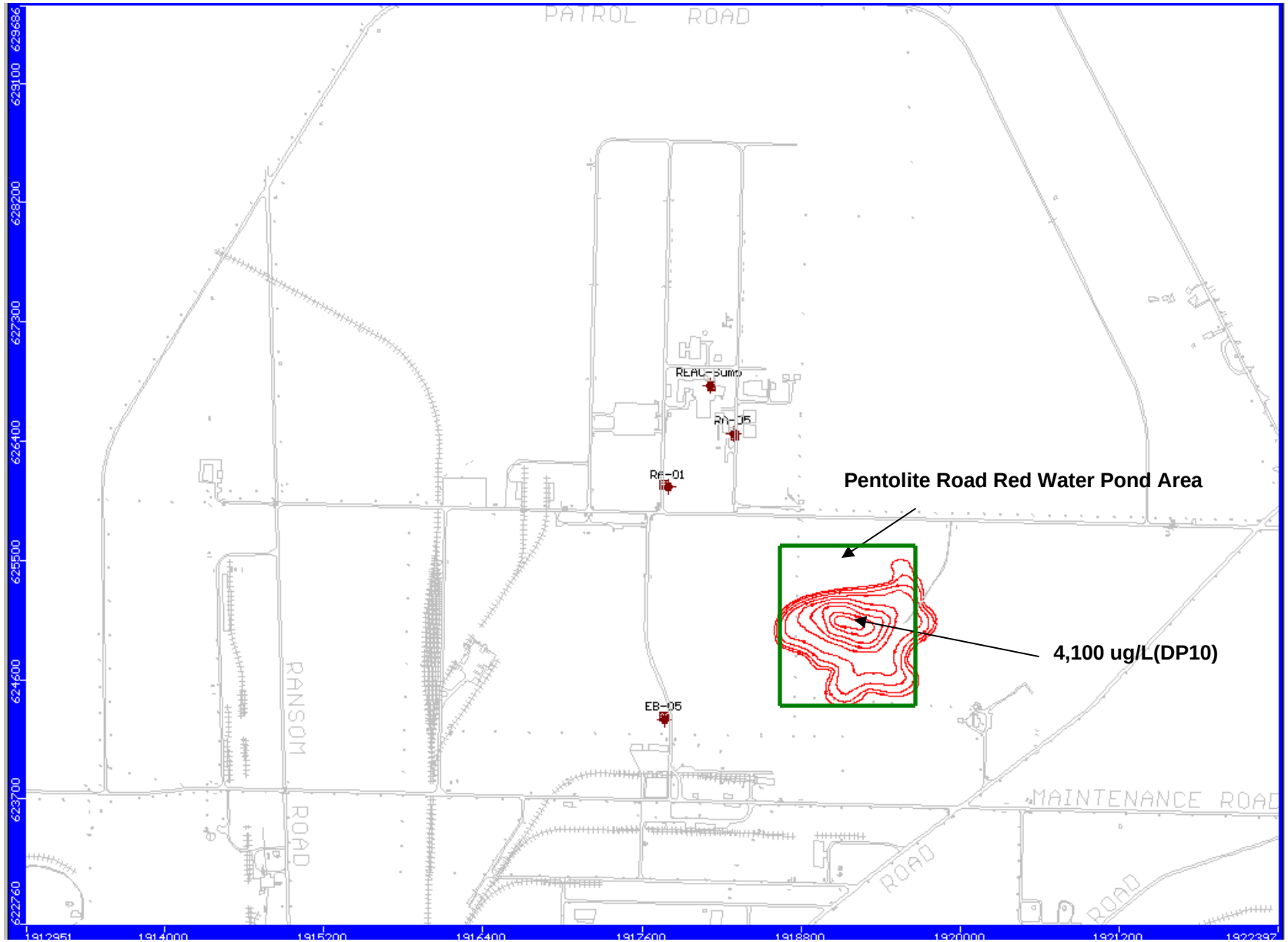
KN8\PBOW\TNT-RWP\FS\Final\APA\Figs\Fig3-7.ppt

Figure 3-8
2,4-DNT Plumes in the Overburden/Shale Water Bearing Zone
TNT Area C
Former Plum Brook Ordnance Works, Sandusky, Ohio



KN8\PBOW\TNT-RWP\FS\Final\APA\Figs\Fig3-8.ppt

Figure 3-9
2,4-DNT Plumes in the Overburden/Shale Water Bearing Zone
in the Pentolite Road Red Water Pond Area
Former Plum Brook Ordnance Works, Sandusky, Ohio



KN8\PBOW\TNT-RWP\FS\Final\APA\Figs\Fig3-9.ppt

Figure 3-10
2,4-DNT Plume in the Overburden/Shale Water Bearing Zone
West Area Red Water Ponds Area
Former Plum Brook Ordnance Works, Sandusky, Ohio

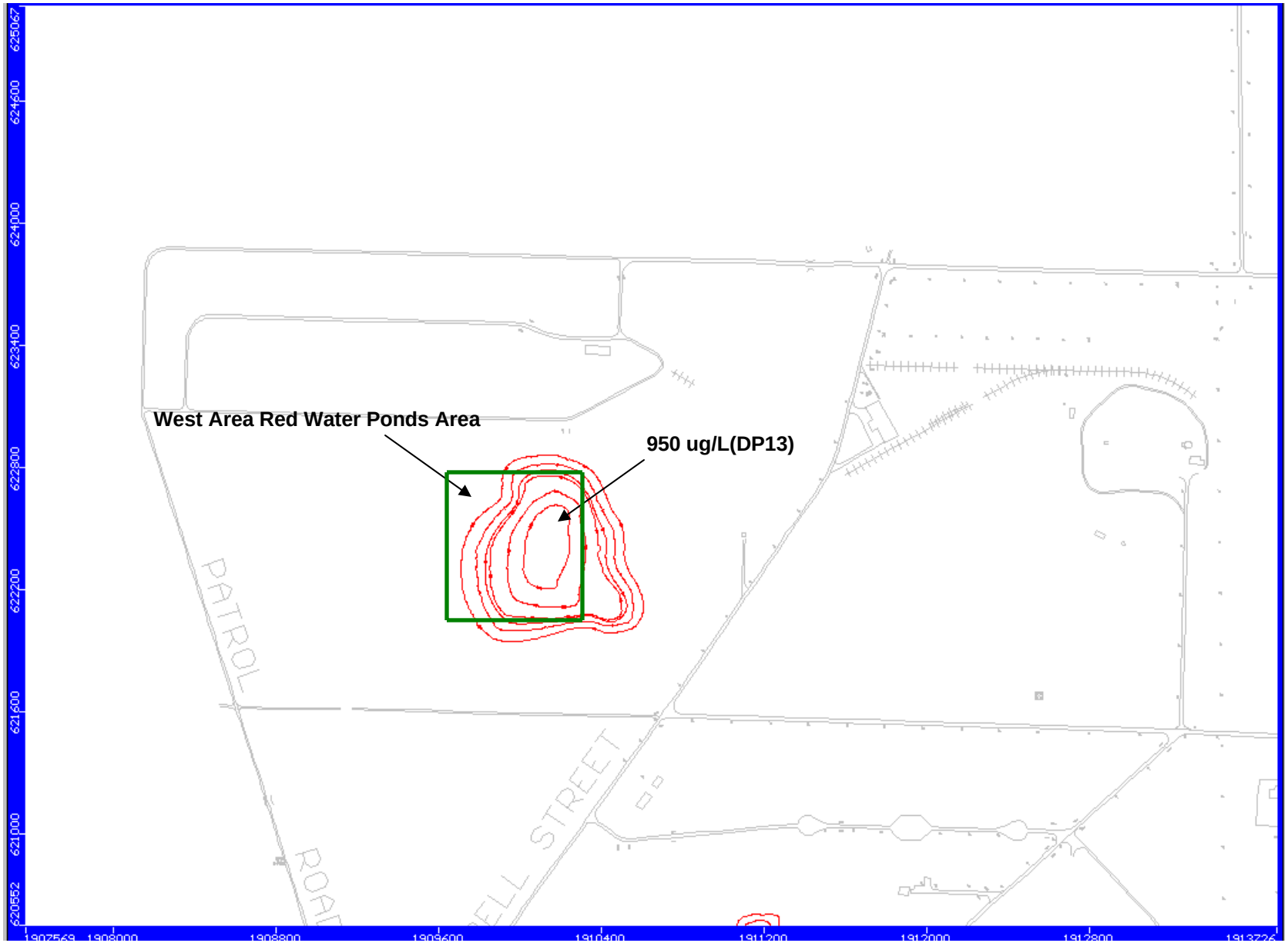


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Figure 3-11
2,4-DNT Plumes in the Delaware Limestone Bedrock Water Bearing Zone
TNT Area A, Pentolite Road Red Water Pond Area,
and West Area Red Water Ponds Area
Former Plum Brook Ordnance Works, Sandusky, Ohio

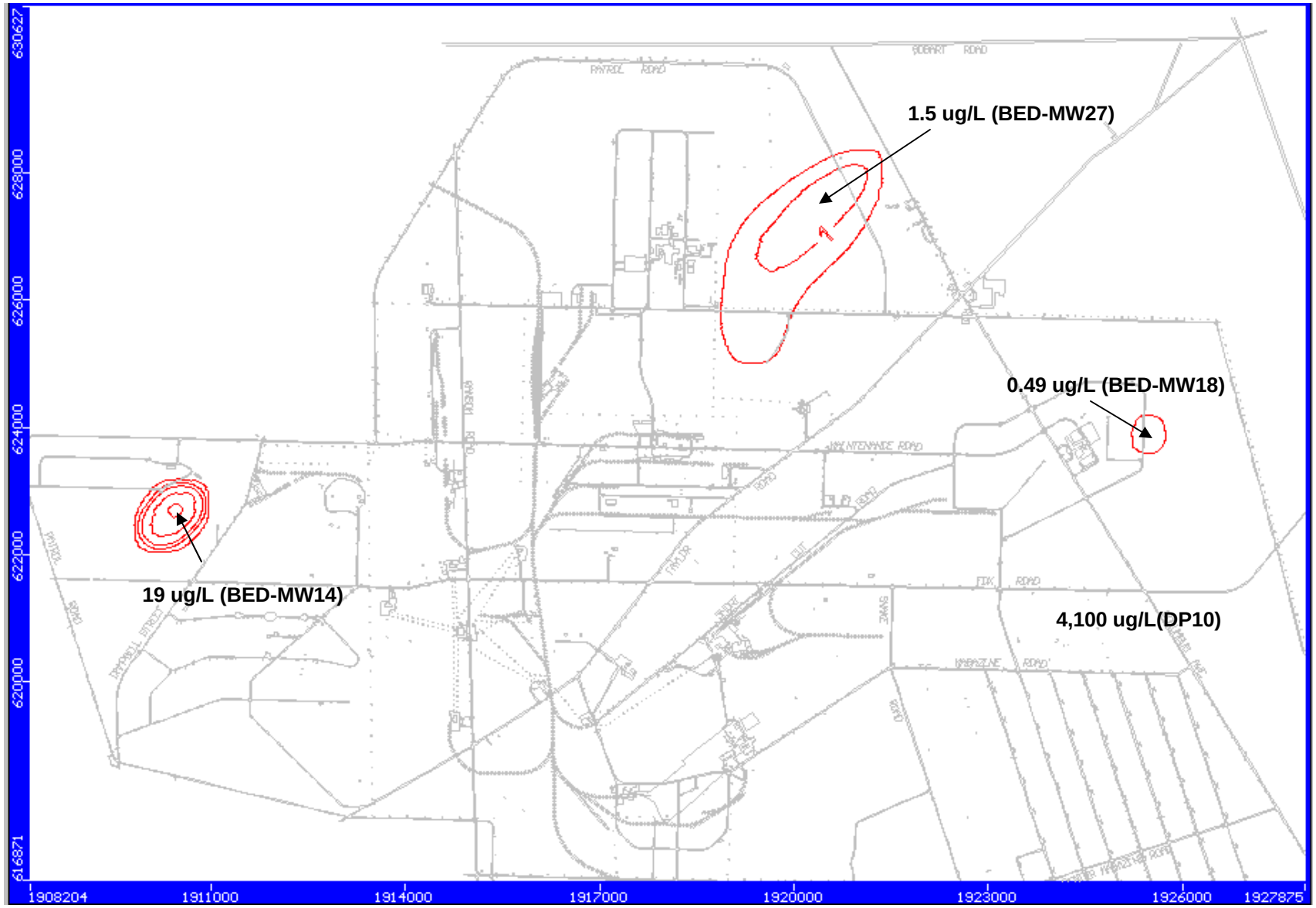

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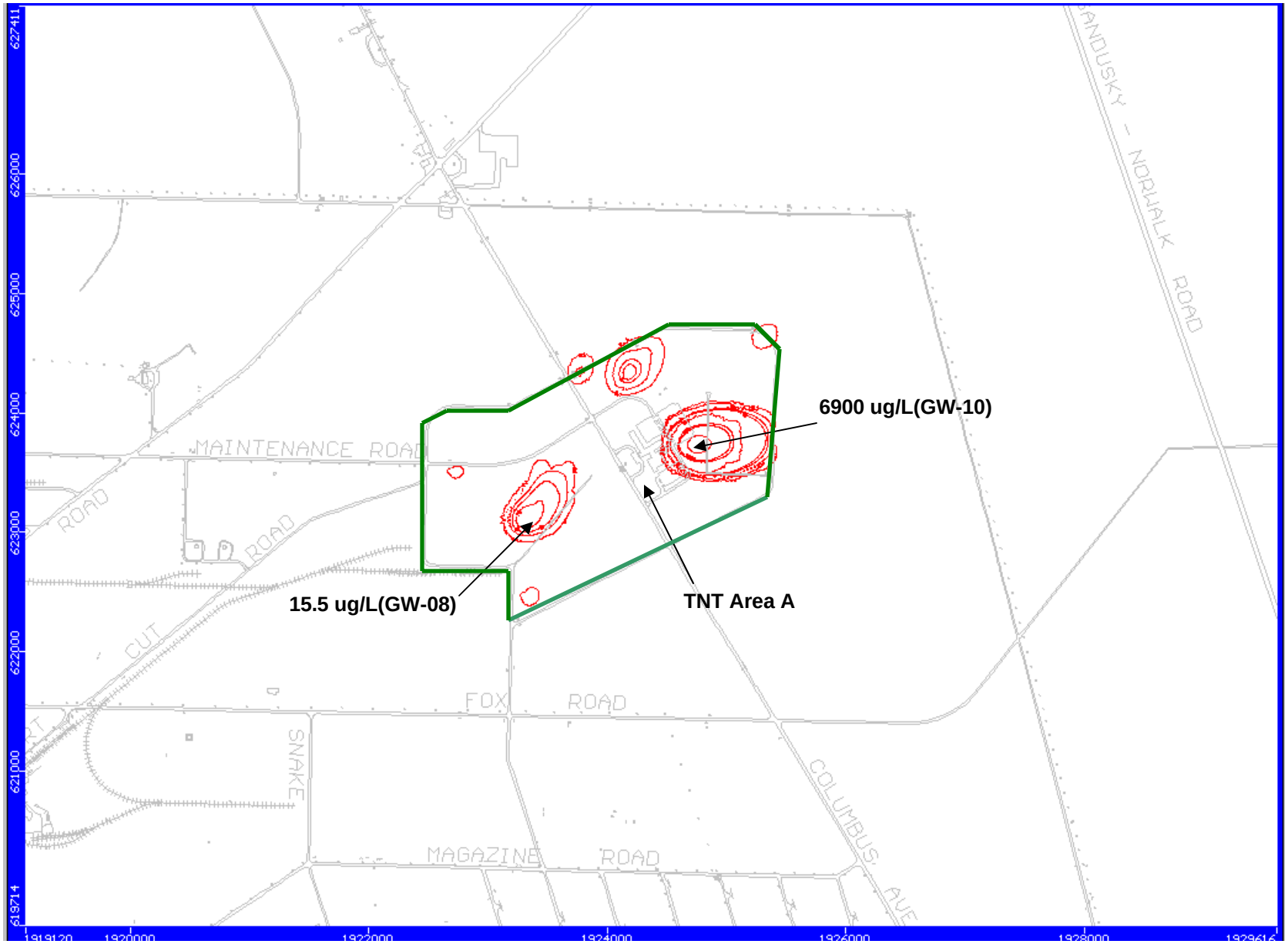
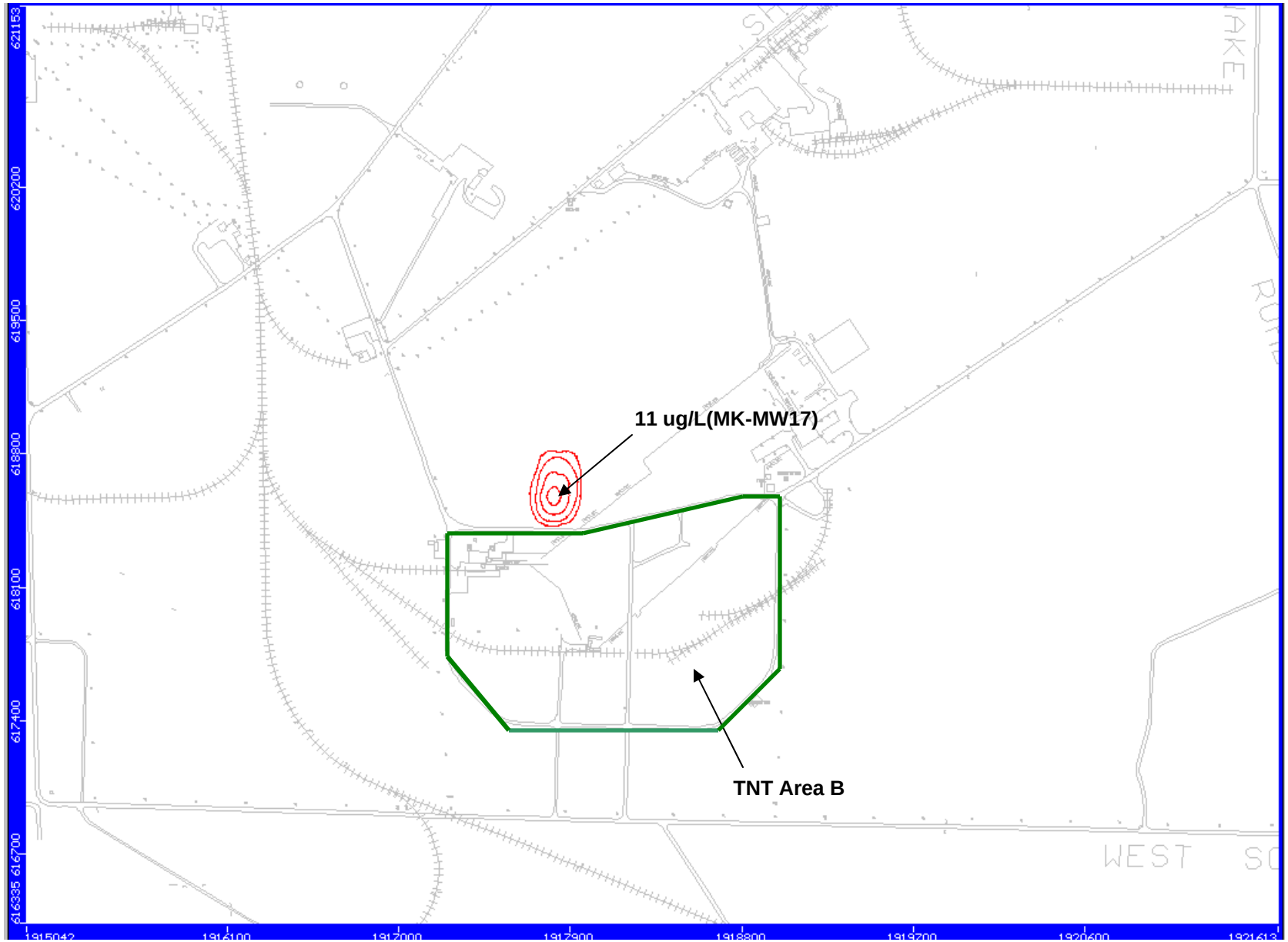
Figure 3-12
2,6-DNT Plumes in the Overburden/Shale Water Bearing Zone
TNT Area A
Former Plum Brook Ordnance Works, Sandusky, Ohio



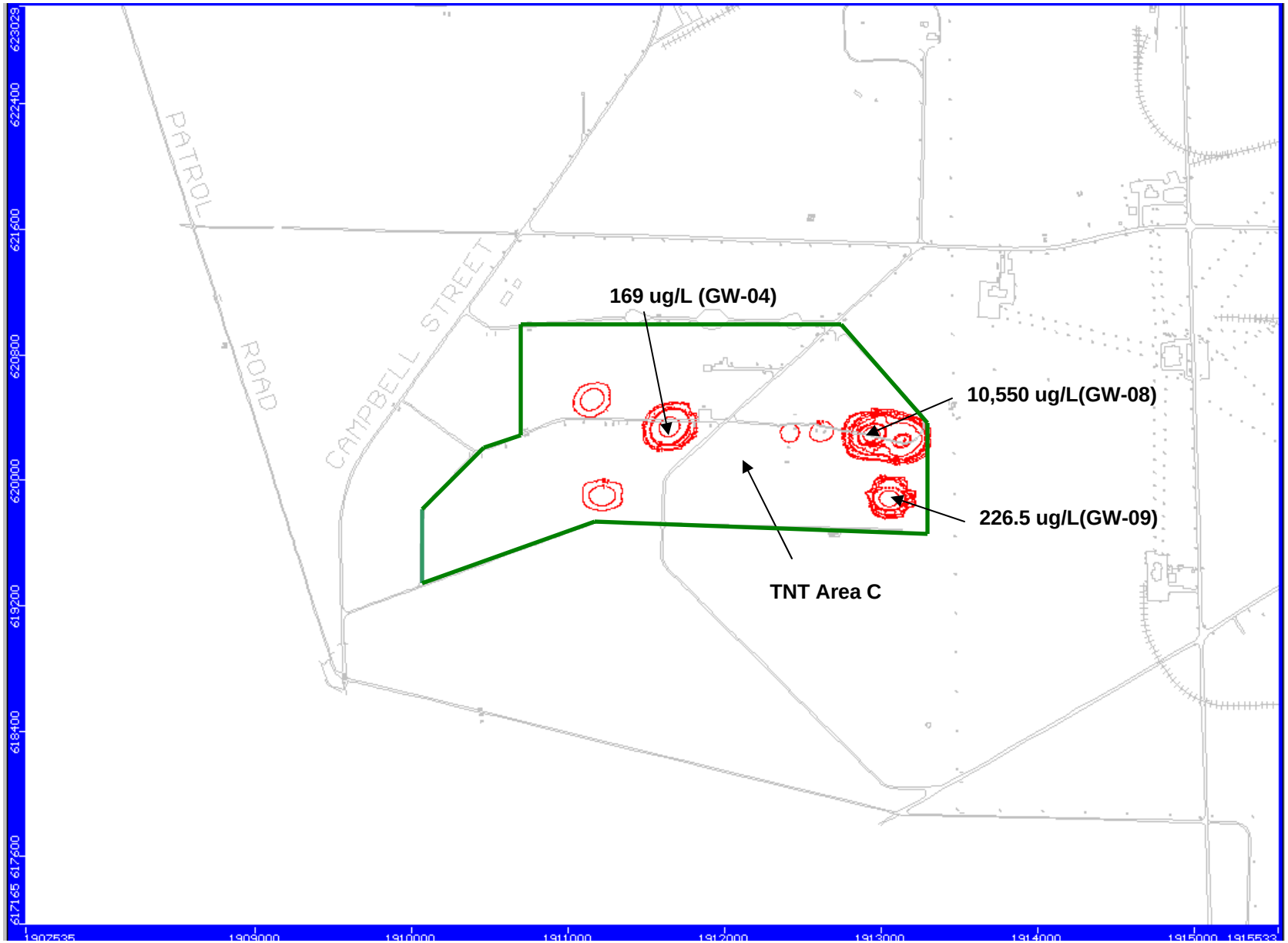
KN8\PBOW\TNT-RWP\FS\Final\APA\Figs\Fig3-12.ppt

Figure 3-13
2,6-DNT Plumes in the Overburden/Shale Water Bearing Zone
TNT Area B
Former Plum Brook Ordnance Works, Sandusky, Ohio



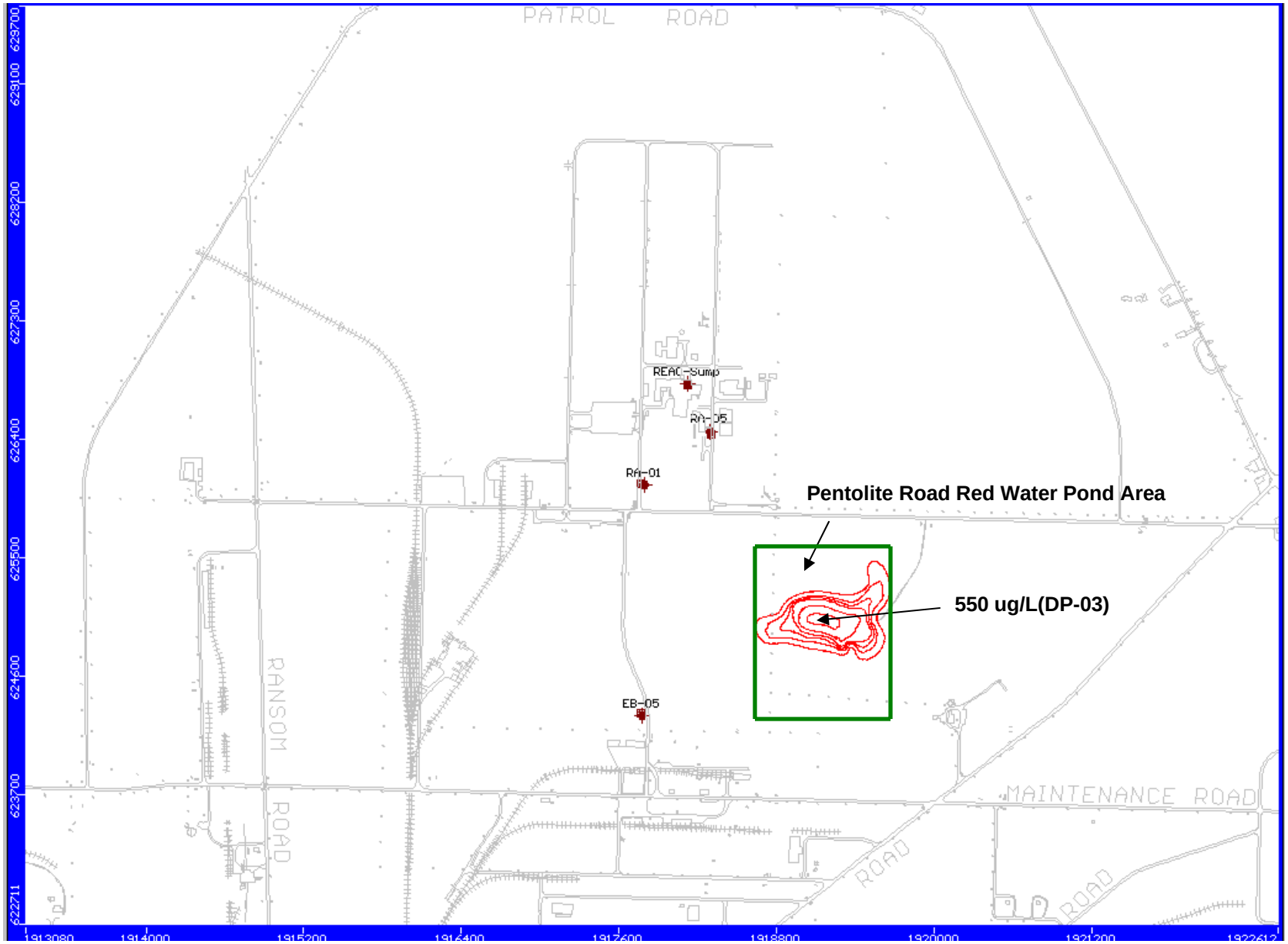
KN8\PBOW\TNT-RWP\FS\FinalAPA\Figs\Fig3-13.ppt

Figure 3-14
2,6-DNT Plumes in the Overburden/Shale Water Bearing Zone
TNT Area C
Former Plum Brook Ordnance Works, Sandusky, Ohio



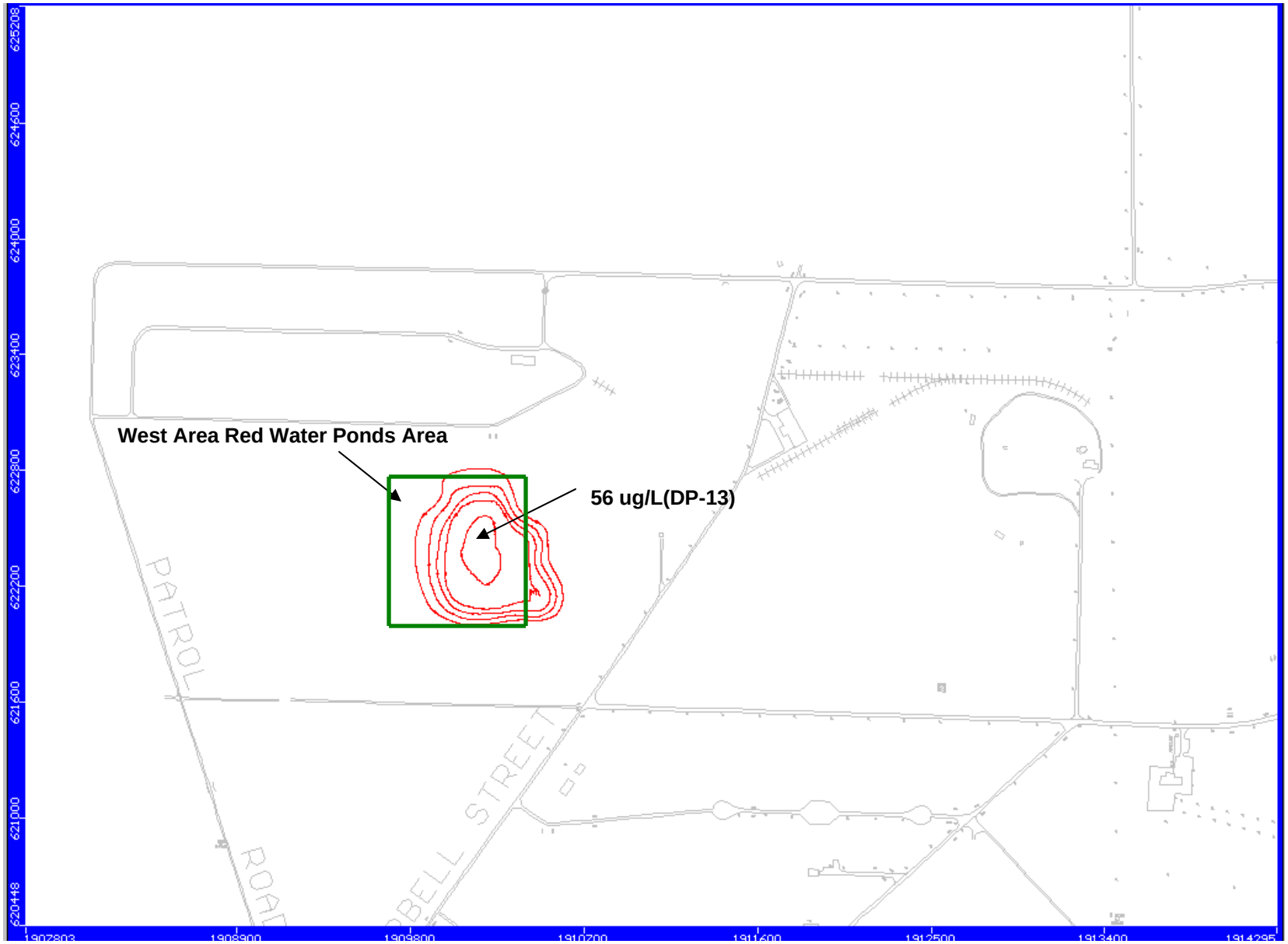
KN8\PBOW\TNT-RWP\FS\Final\APA\Figs\Fig3-14.ppt

Figure 3-15
2,6-DNT Plumes in the Overburden/Shale Water Bearing Zone
Pentolite Road Red Water Pond Area
Former Plum Brook Ordnance Works, Sandusky, Ohio



KN8\PBOW\TNT-RWP\FS\Final\APA\Figs\Fig3-15.ppt

Figure 3-16
2,6-DNT Plumes in the Overburden/Shale Water Bearing Zone
West Area Red Water Ponds Area
Former Plum Brook Ordnance Works, Sandusky, Ohio



KN8\PBOW\TNT-RWP\FS\Final\APA\Figs\Fig3-16.ppt

Figure 3-17
2,6-DNT Plumes in the Delaware Limestone Bedrock Water Bearing Zone
In TNT Area A, Pentolite Road Red Water Pond Area,
and West Area Red Water Ponds Area
Former Plum Brook Ordnance Works, Sandusky, Ohio

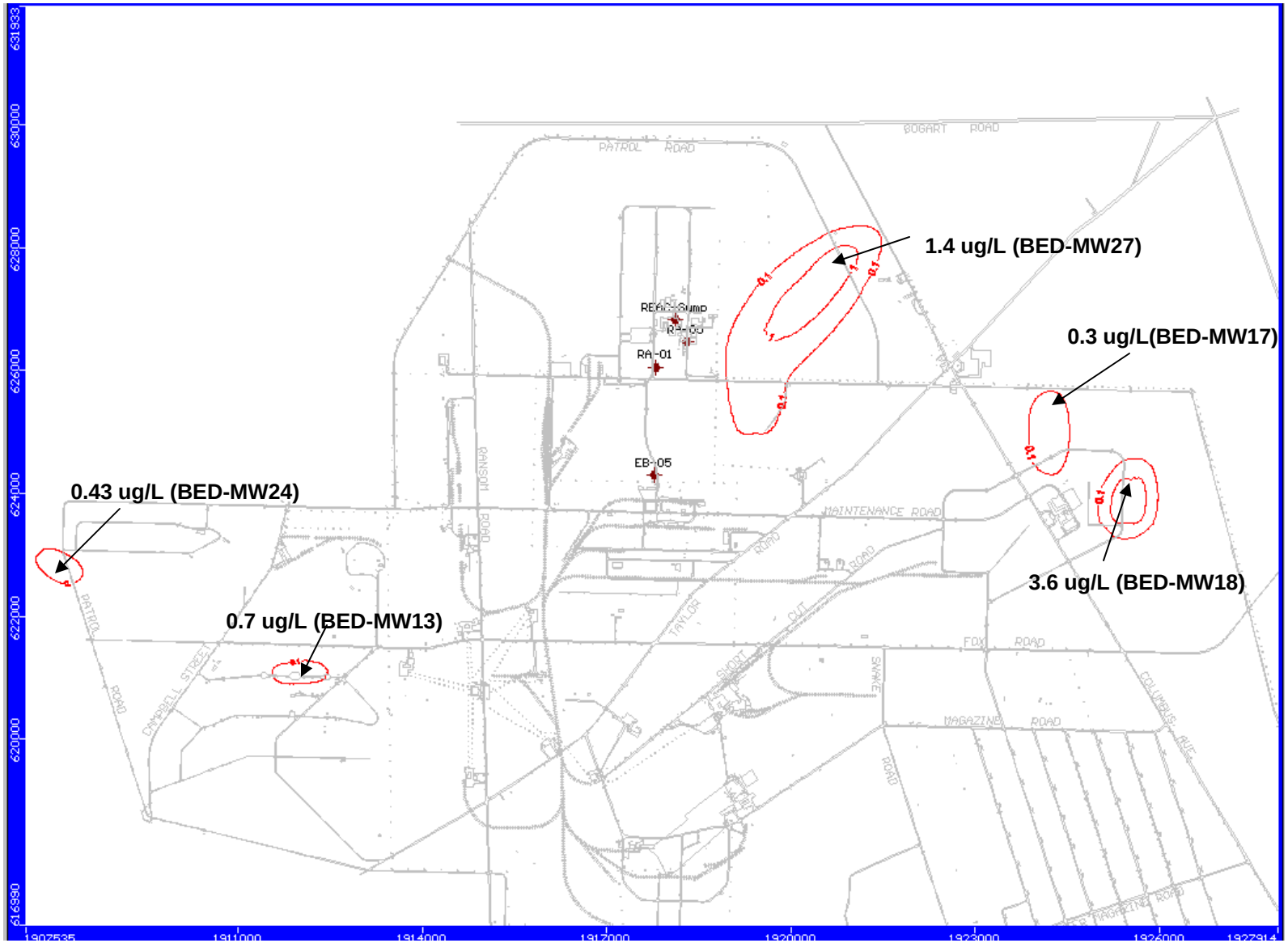


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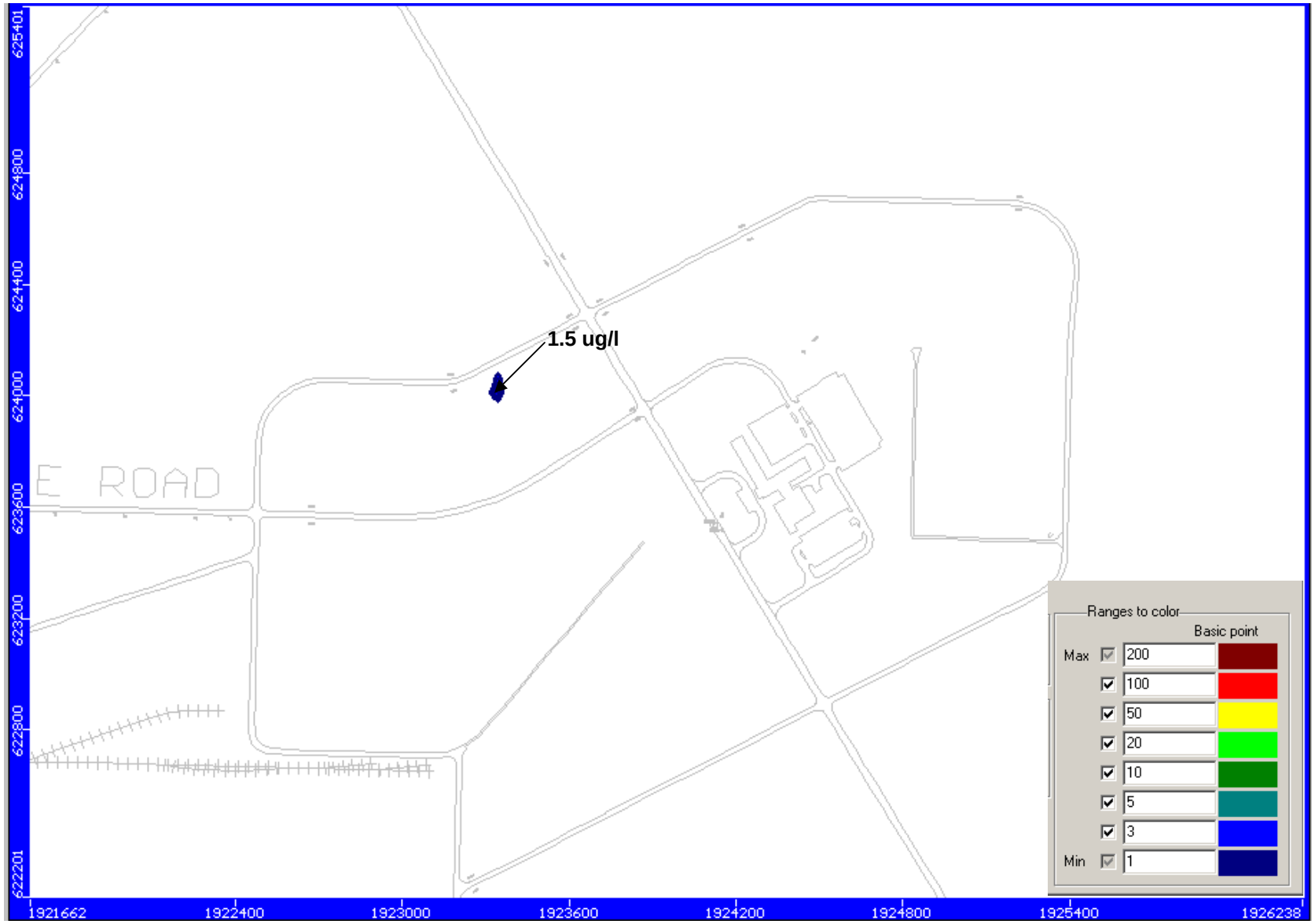
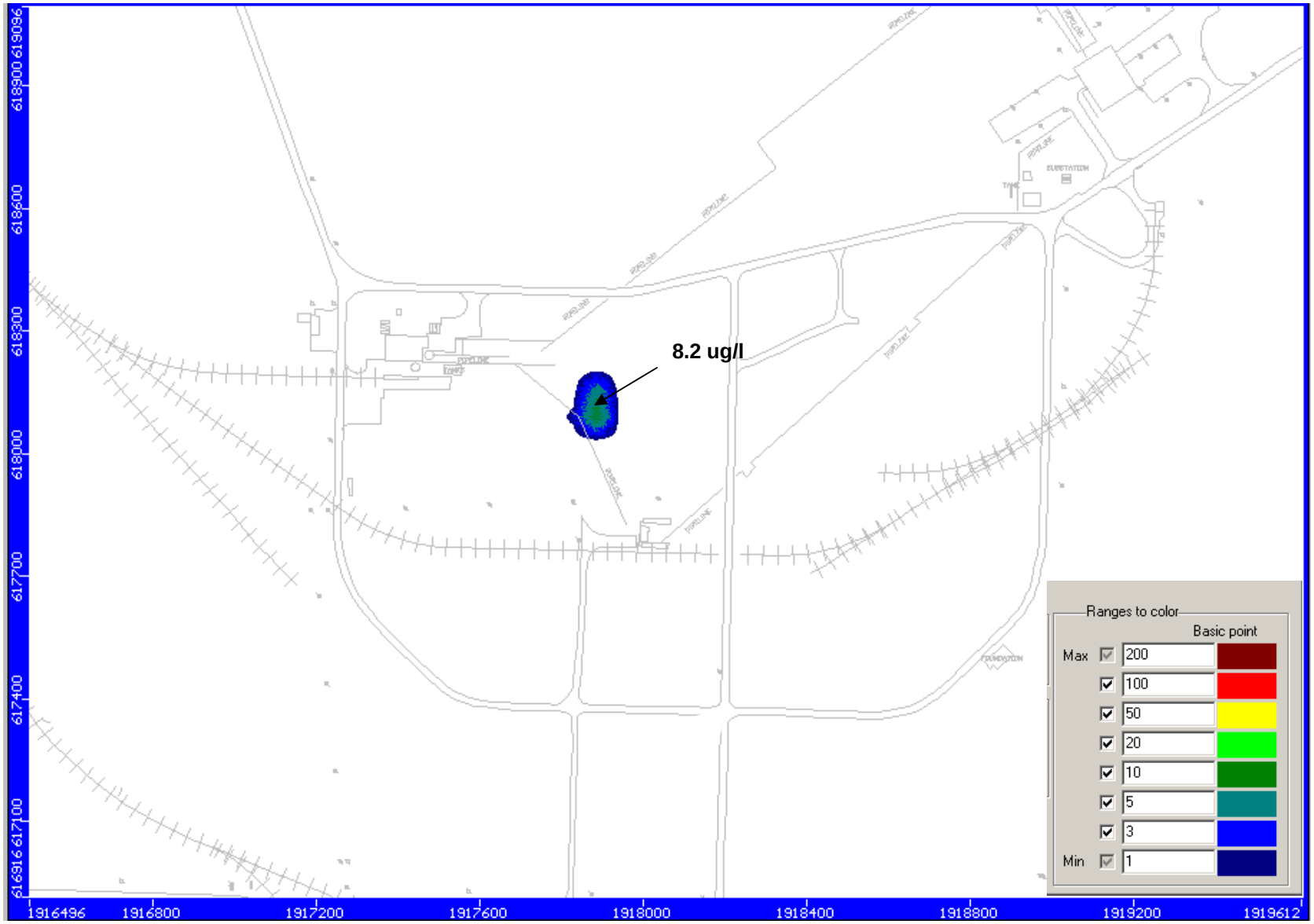
Figure 5-1
Simulated TNT Plumes in TNT Area A After 150 Years
In the Overburden – Layer 1
Simulation No. 3: Soil Excavation and In Situ Enhanced Bioremediation in the Overburden
Former Plum Brook Ordnance Works, Sandusky, Ohio



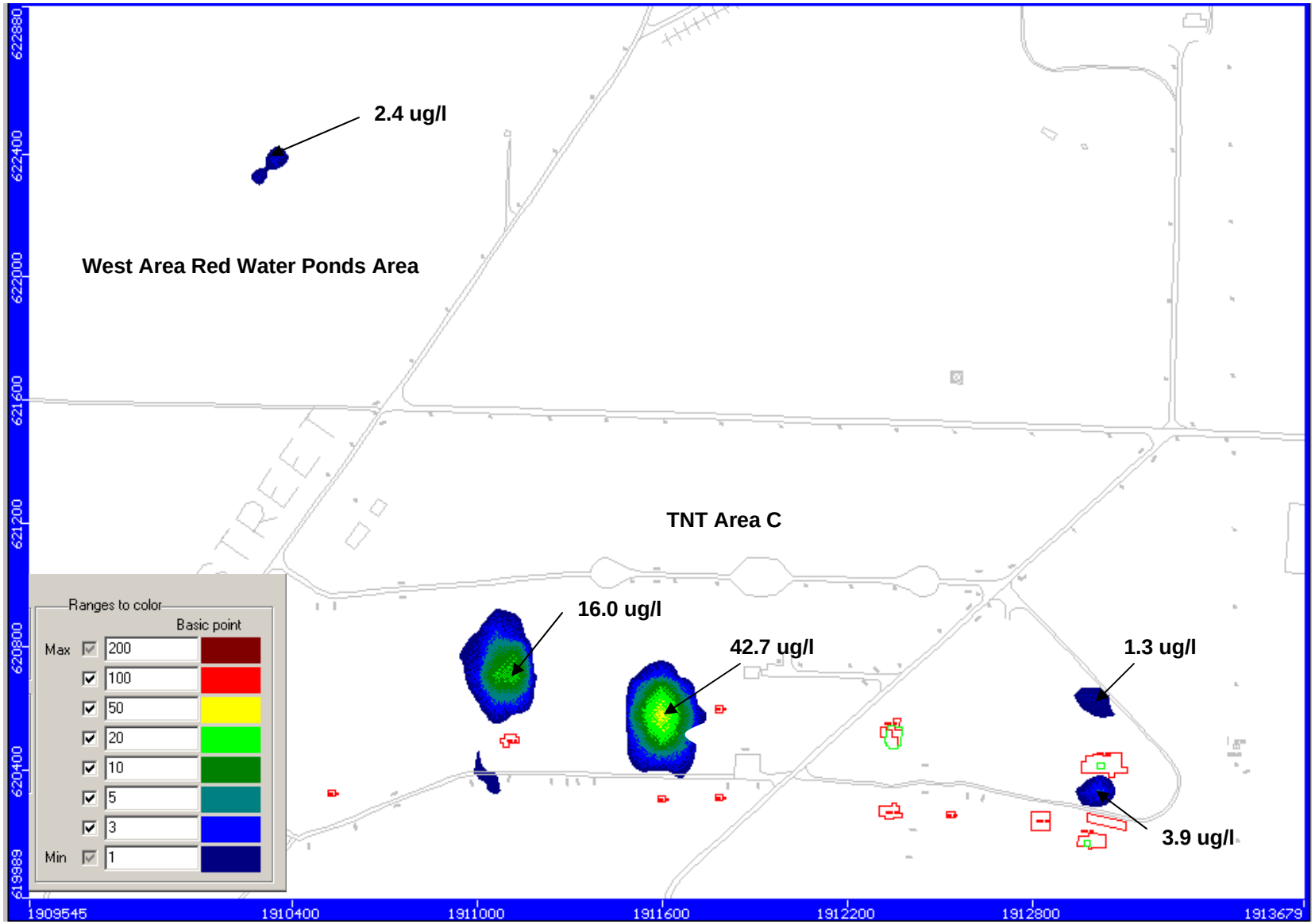
KN7\PBOW\TNT-RWP\FS\Draft\Figs\Fig5-1.ppt

Figure 5-2
Simulated TNT Plumes in TNT Area B After 150 Years
In the Overburden – Layer 1
Simulation No. 3: Soil Excavation and In Situ Enhanced Bioremediation in the Overburden
Former Plum Brook Ordnance Works, Sandusky, Ohio



KN7\PBOW\TNT-RWP\FS\Draft\Figs\Fig5-2.ppt

Figure 5-3
Simulated TNT Plumes in TNT Area C and West Area Red Water Ponds Area After 150 Years
In the Overburden – Layer 1
Simulation No. 3: Soil Excavation and In Situ Enhanced Bioremediation in the Overburden
Former Plum Brook Ordnance Works, Sandusky, Ohio



KN8\PBOW\TNT-RWP\FS\Final\APA\Figs\Fig5-3.ppt

Figure 5-4
Simulated TNT Plumes in the Pentolite Red Water Pond Area After 150 Years
In the Overburden – Layer 1
Simulation No. 3: Soil Excavation and In Situ Enhanced Bioremediation in the Overburden
Former Plum Brook Ordnance Works, Sandusky, Ohio

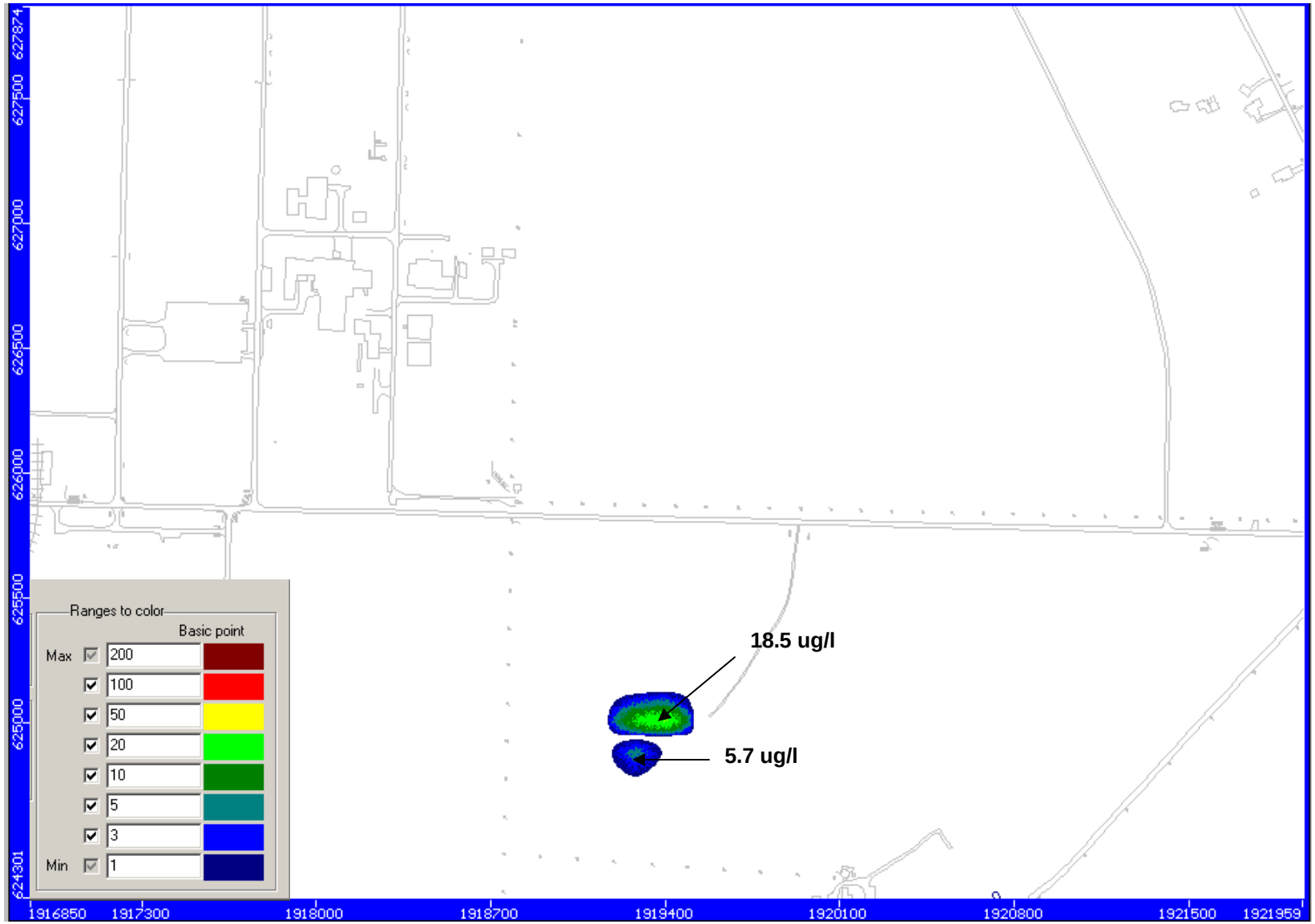


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Figure 5-5
Simulated 2,4-DNT Plumes in the TNT Area A After 27 Years (Maximum Concentration Occurs)
In the Overburden – Layer 1
Simulation No. 3: Soil Excavation and In Situ Enhanced Bioremediation in the Overburden
Former Plum Brook Ordnance Works, Sandusky, Ohio

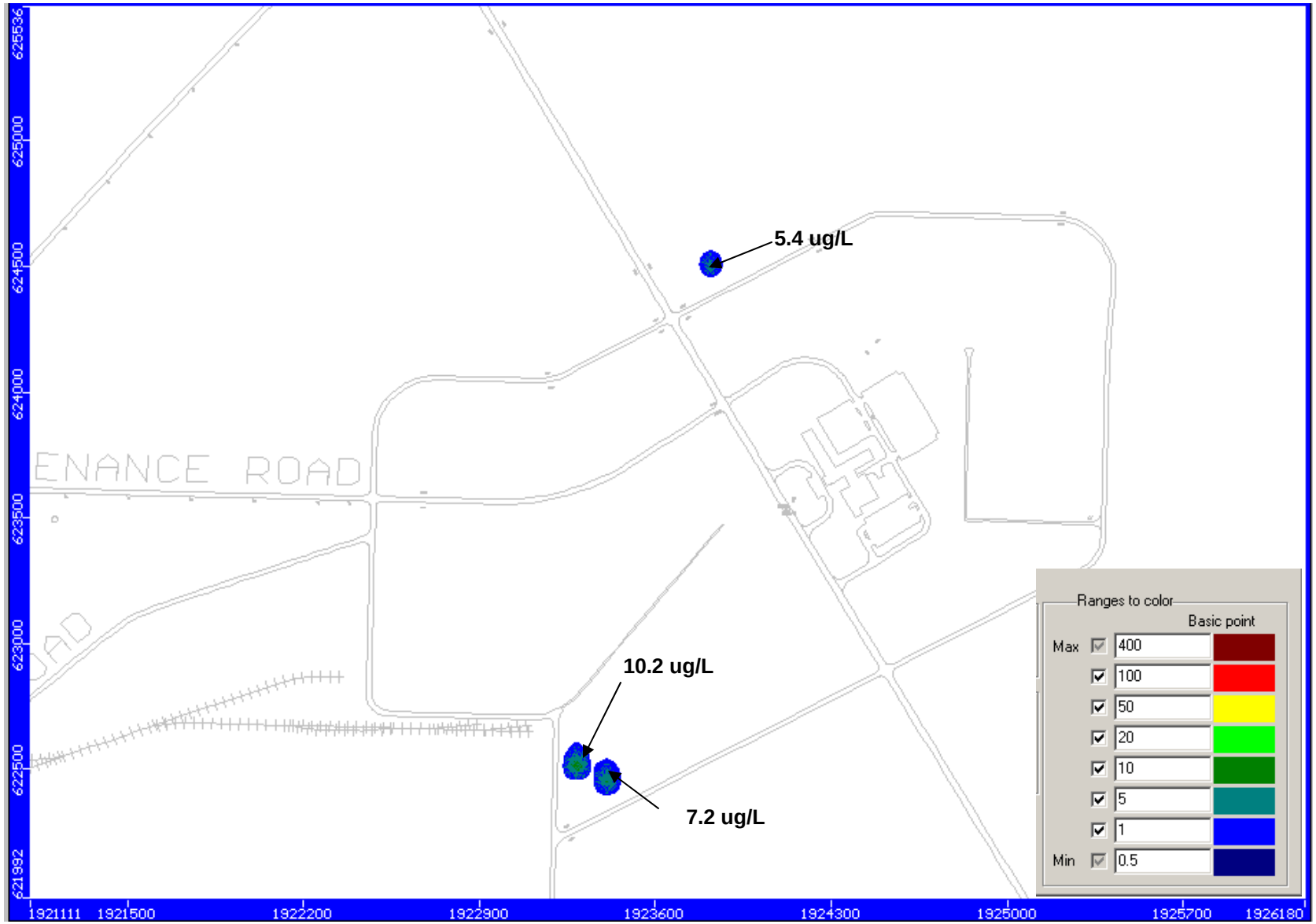

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Figure 5-6
Simulated 2,4-DNT Plumes in TNT Area B After 65 Years (Maximum Concentration Occurs)
In the Overburden – Layer 1
Simulation No. 3: Soil Excavation and In Situ Enhanced Bioremediation in the Overburden
Former Plum Brook Ordnance Works, Sandusky, Ohio

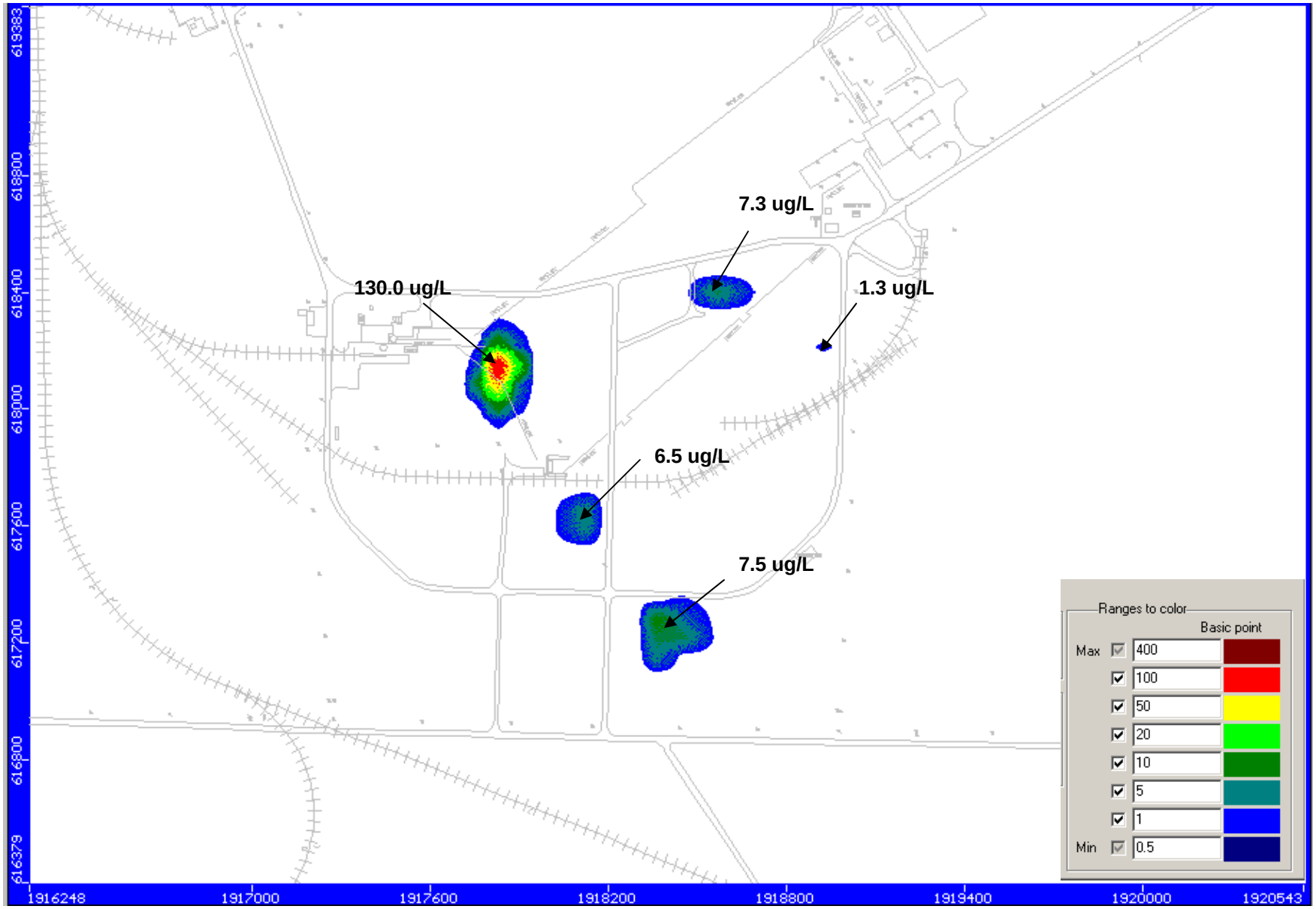

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Figure 5-7
Simulated 2,4-DNT Plumes in TNT Area B After 150 Years
In the Overburden – Layer 1
Simulation No. 3: Soil Excavation and In Situ Enhanced Bioremediation in the Overburden
Former Plum Brook Ordnance Works, Sandusky, Ohio

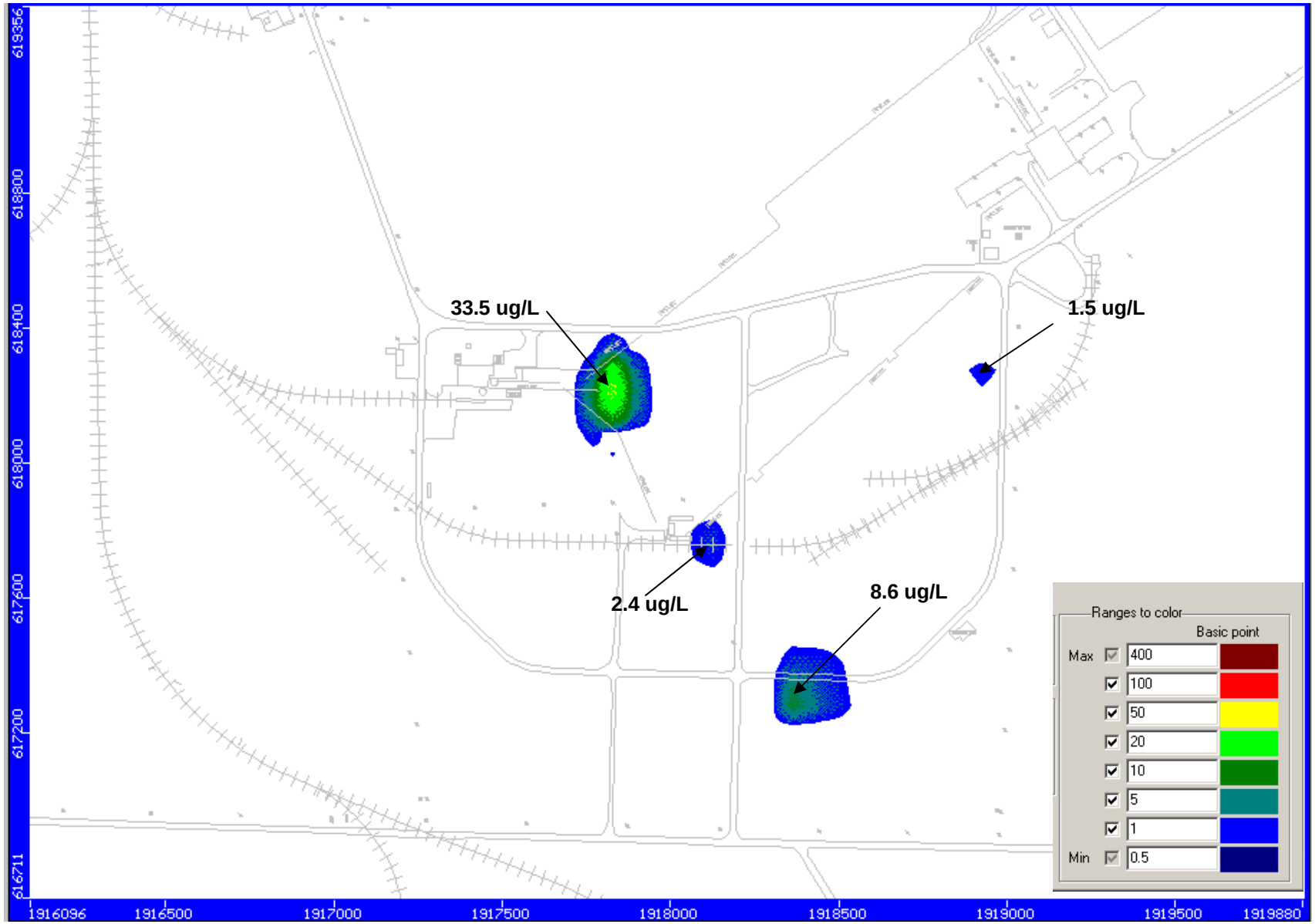

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Figure 5-8
Simulated 2,4-DNT Plumes in TNT Area C (Max. Concentration Appears) and West Area Red Water Ponds Area After 8 Years In the Overburden – Layer 1
Simulation No. 3: Soil Excavation and In Situ Enhanced Bioremediation in the Overburden
Former Plum Brook Ordnance Works, Sandusky, Ohio

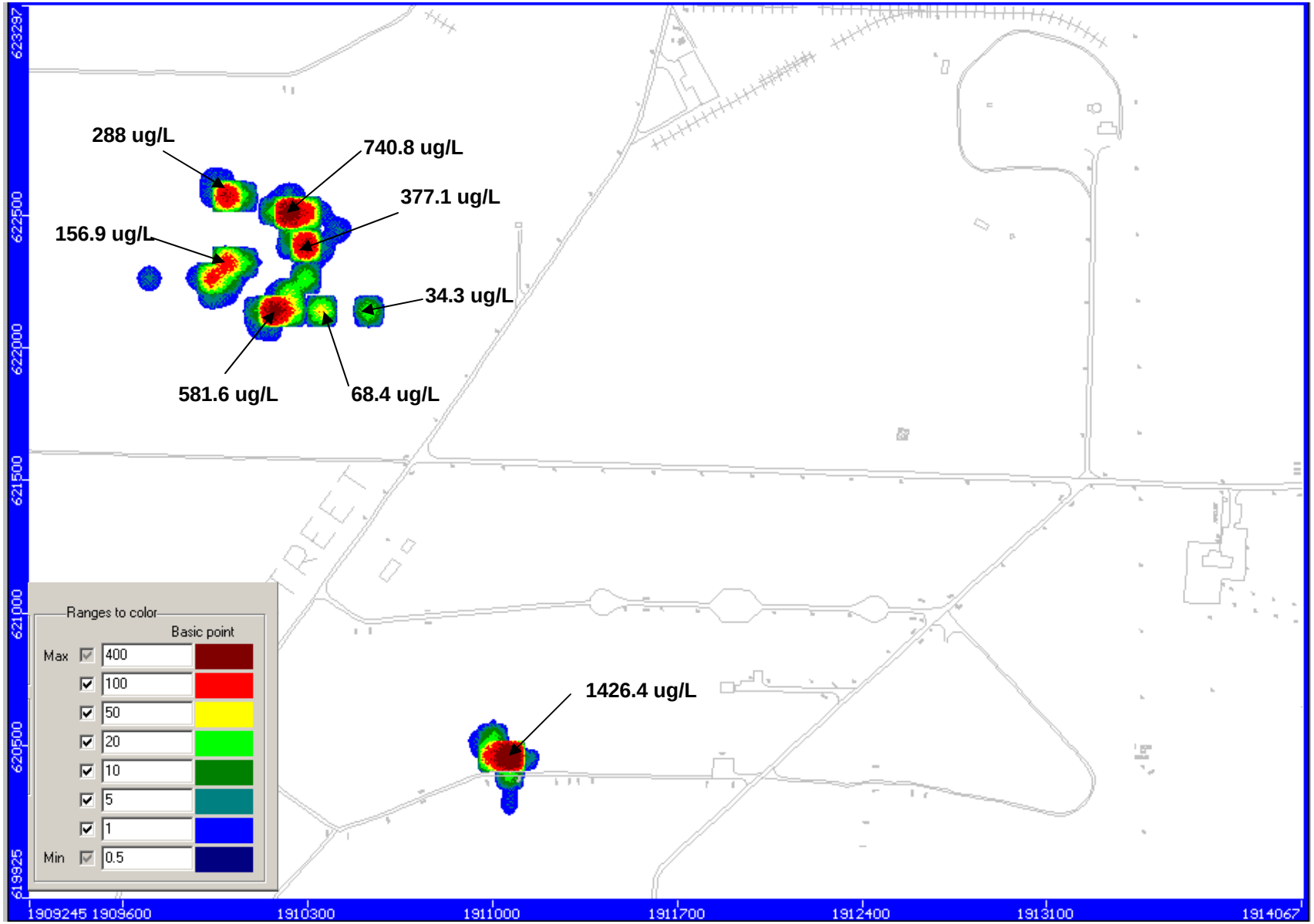

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Figure 5-9
Simulated 2,4-DNT Plumes in the TNT Area C and West Area Red Water Ponds Areas After 150 Years
In the Overburden – Layer 1
Simulation No. 3: Soil Excavation and In Situ Enhancement Bioremediation in the Overburden
Former Plum Brook Ordnance Works, Sandusky, Ohio

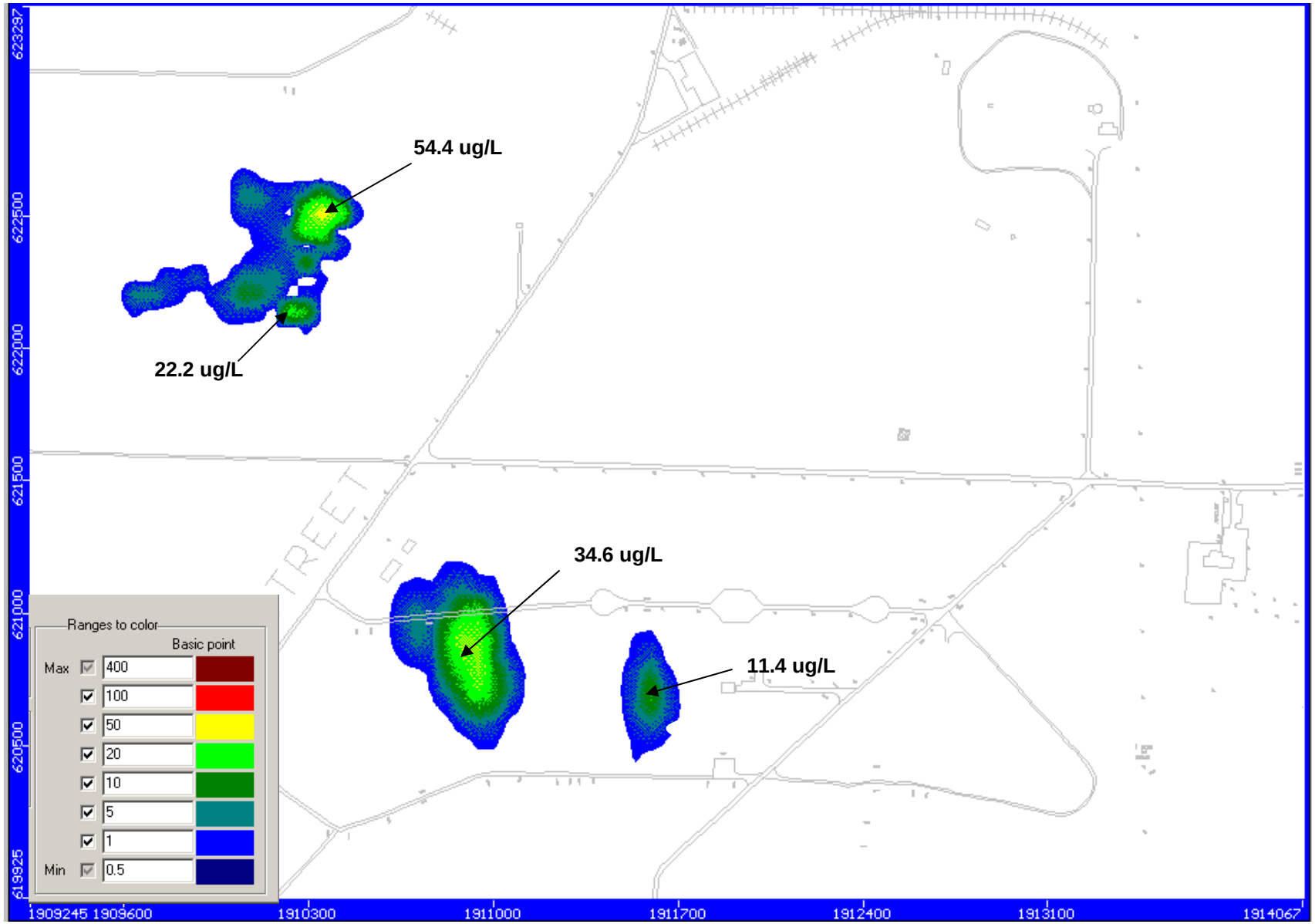

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Figure 5-10
Simulated 2,4-DNT Plumes in the West Area Red Water Ponds Area After 150 Years
In the Bedrock – Layer 3
Simulation No. 3: Soil Excavation and In Situ Enhanced Bioremediation in the Overburden
Former Plum Brook Ordnance Works, Sandusky, Ohio

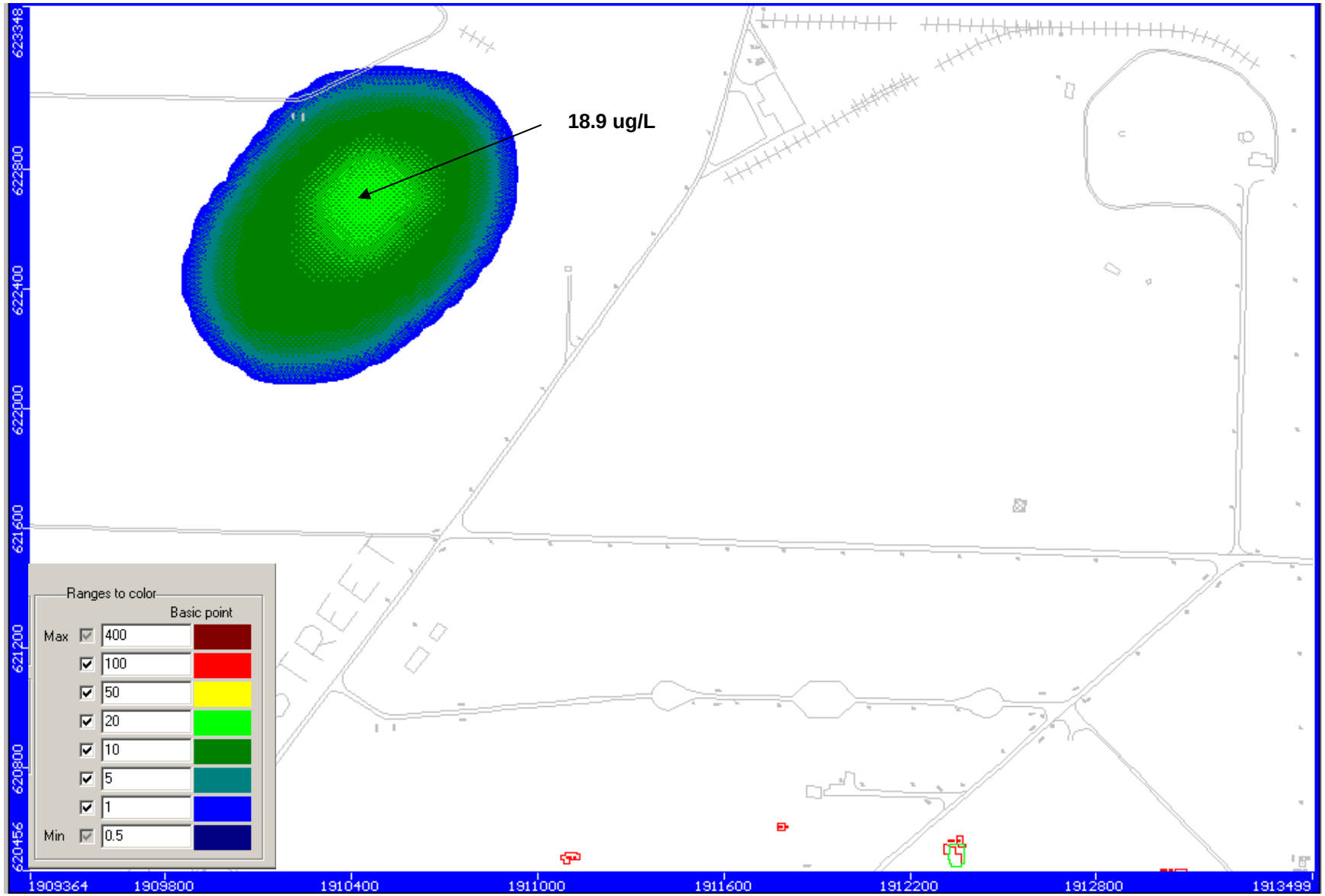

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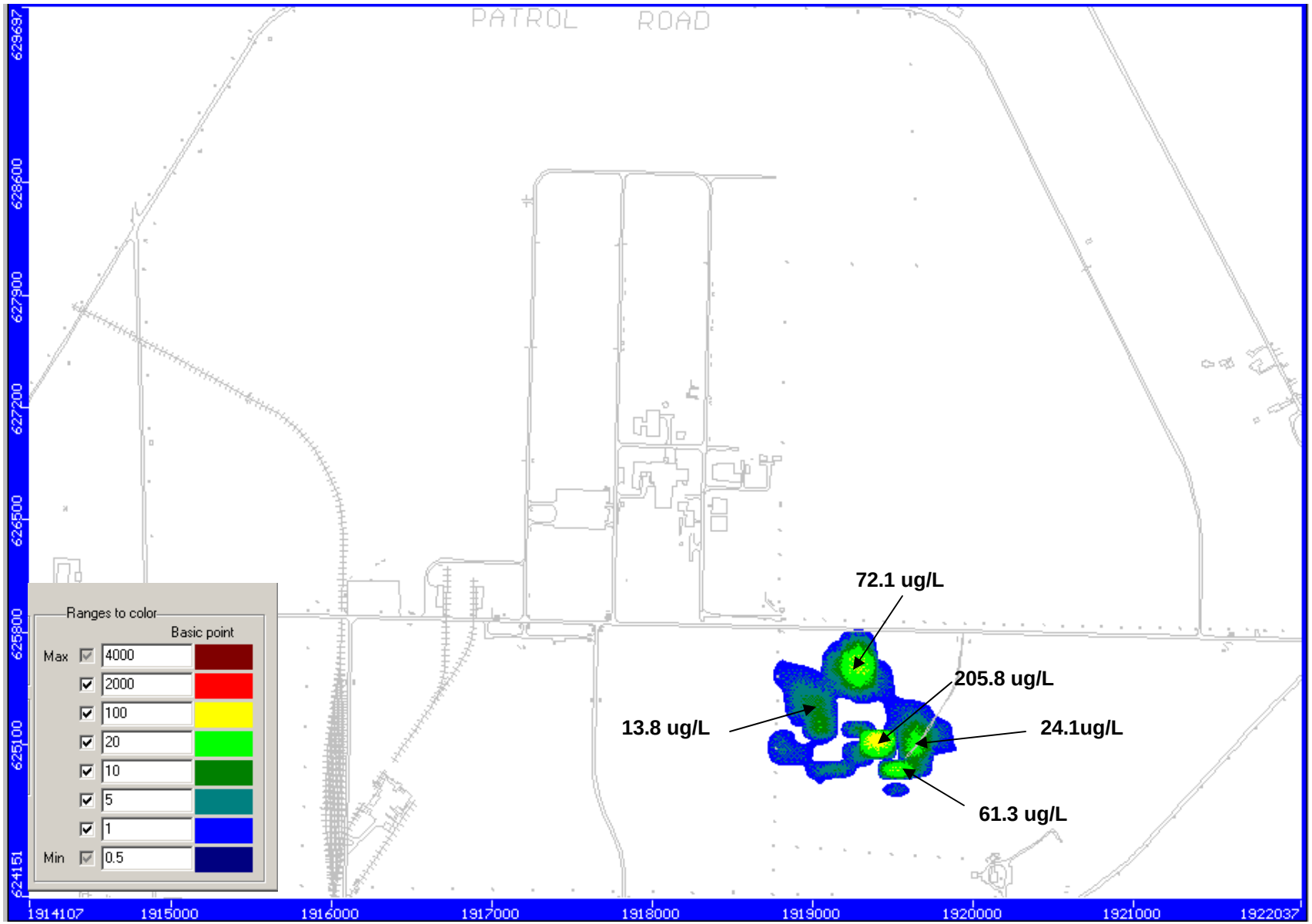
Figure 5-11
Simulated 2,4-DNT Plumes in the Pentolite Red Water Pond Area After 150 Years
In the Overburden – Layer 1
Simulation No. 3: Soil Excavation and In Situ Enhanced Bioremediation in the Overburden
Former Plum Brook Ordnance Works, Sandusky, Ohio



KN8\PBOW\TNT-RWP\FS\Final\APA\Fig5-11.ppt

Figure 5-12
Simulated 2,4-DNT Plumes in the Pentolite Red Water Pond Area After 150 Years
In the Bedrock – Layer 3
Simulation No. 3: Soil Excavation and In Situ Enhanced Bioremediation in the Overburden
Former Plum Brook Ordnance Works, Sandusky, Ohio

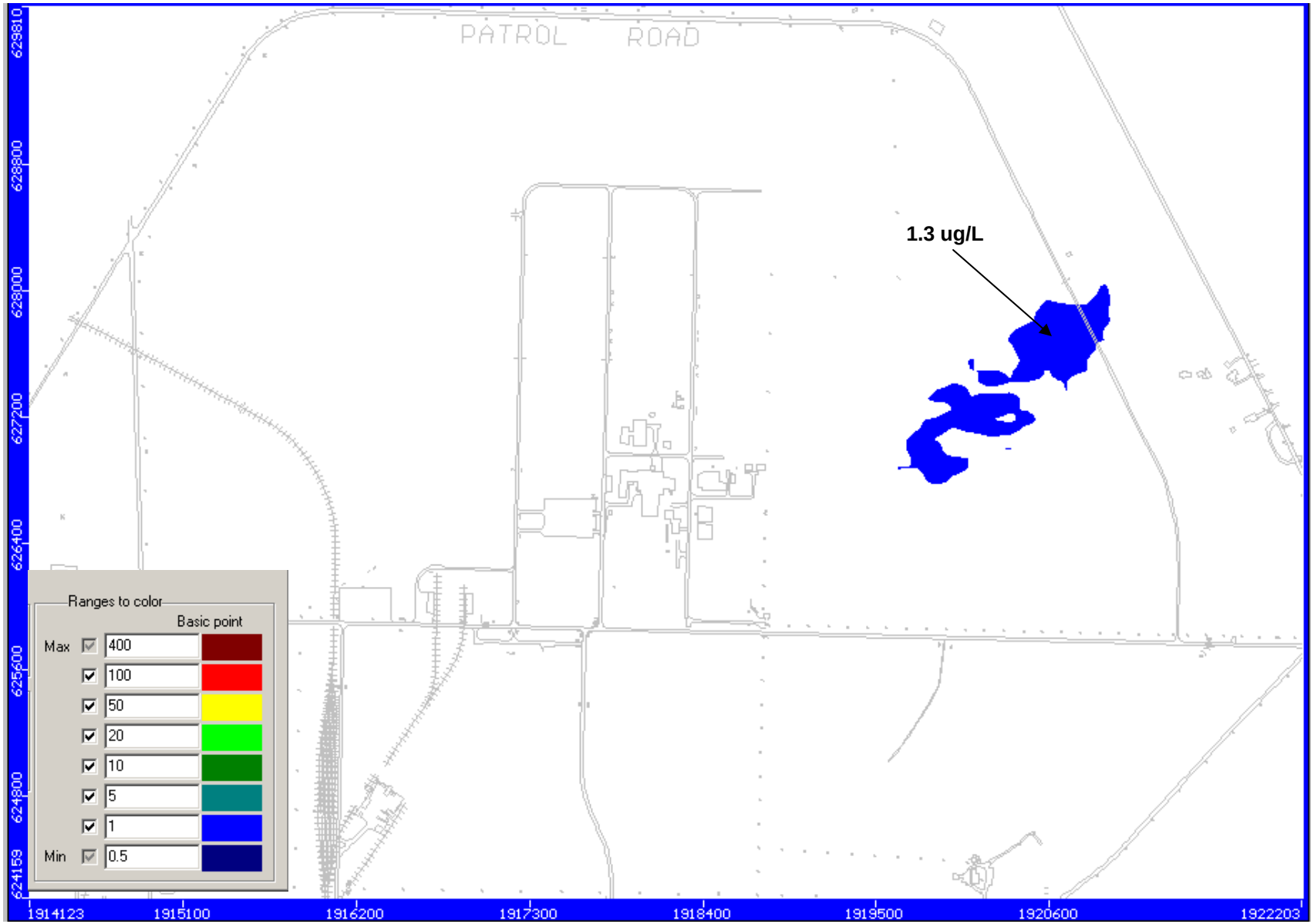


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Figure 5-13
Simulated 2,6-DNT Plumes in TNT Area A After 146 Years
In the Overburden – Layer 1
Simulation No. 3: Soil Excavation and In Situ Enhanced Bioremediation in the Overburden
Former Plum Brook Ordnance Works, Sandusky, Ohio

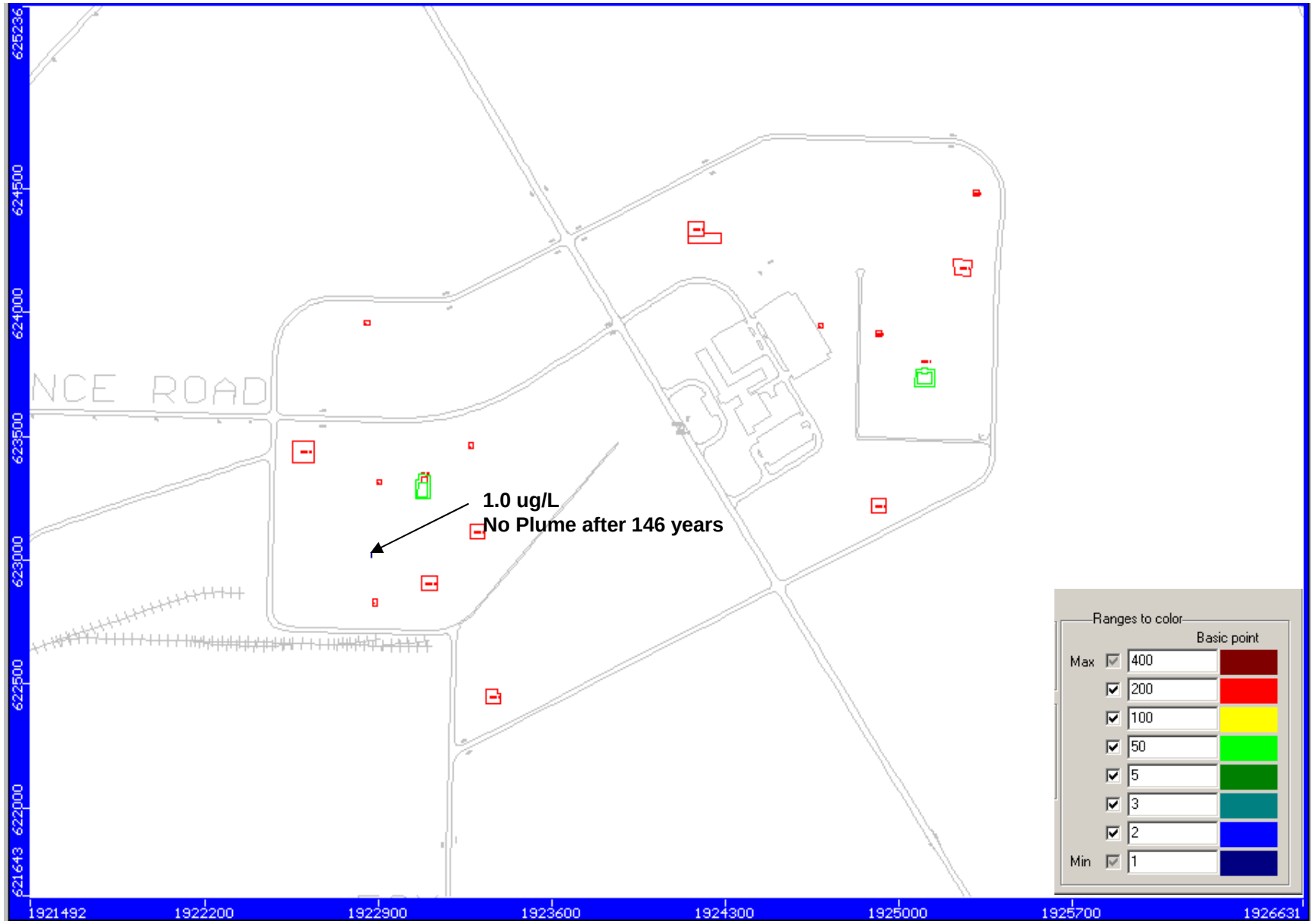

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Figure 5-14
Simulated 2,6-DNT Plumes in TNT Area A After 150 Years
In the Bedrock – Layer 3
Simulation No. 3: Soil Excavation and In Situ Enhanced Bioremediation in the Overburden
Former Plum Brook Ordnance Works, Sandusky, Ohio

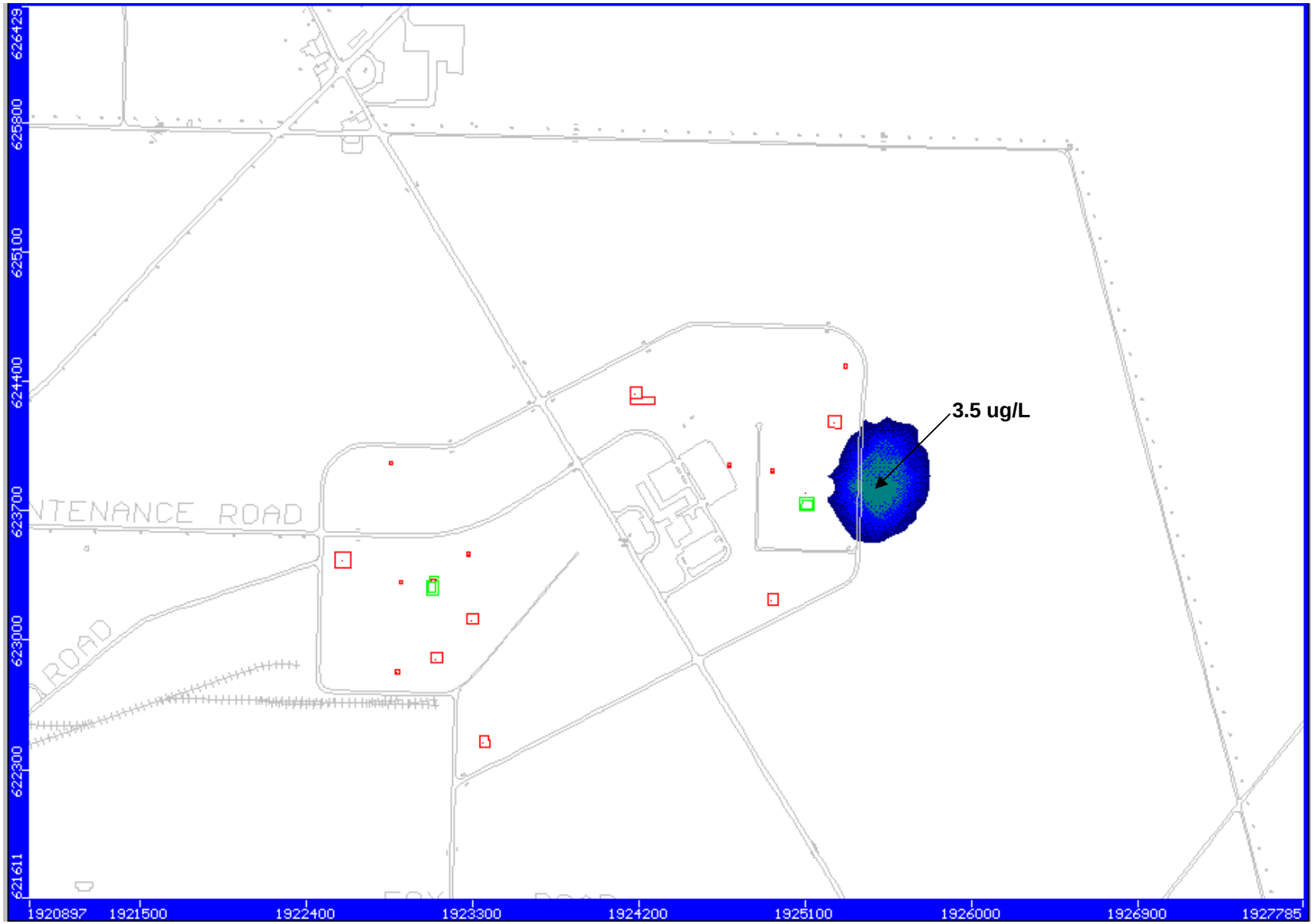

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Figure 5-15
Simulated 2,6-DNT Plumes in the TNT Area B After 45 Years (Maximum Concentration Occurs)
In the Overburden – Layer 1
Simulation No. 3: Soil Excavation and In Situ Enhanced Bioremediation in the Overburden
Former Plum Brook Ordnance Works, Sandusky, Ohio

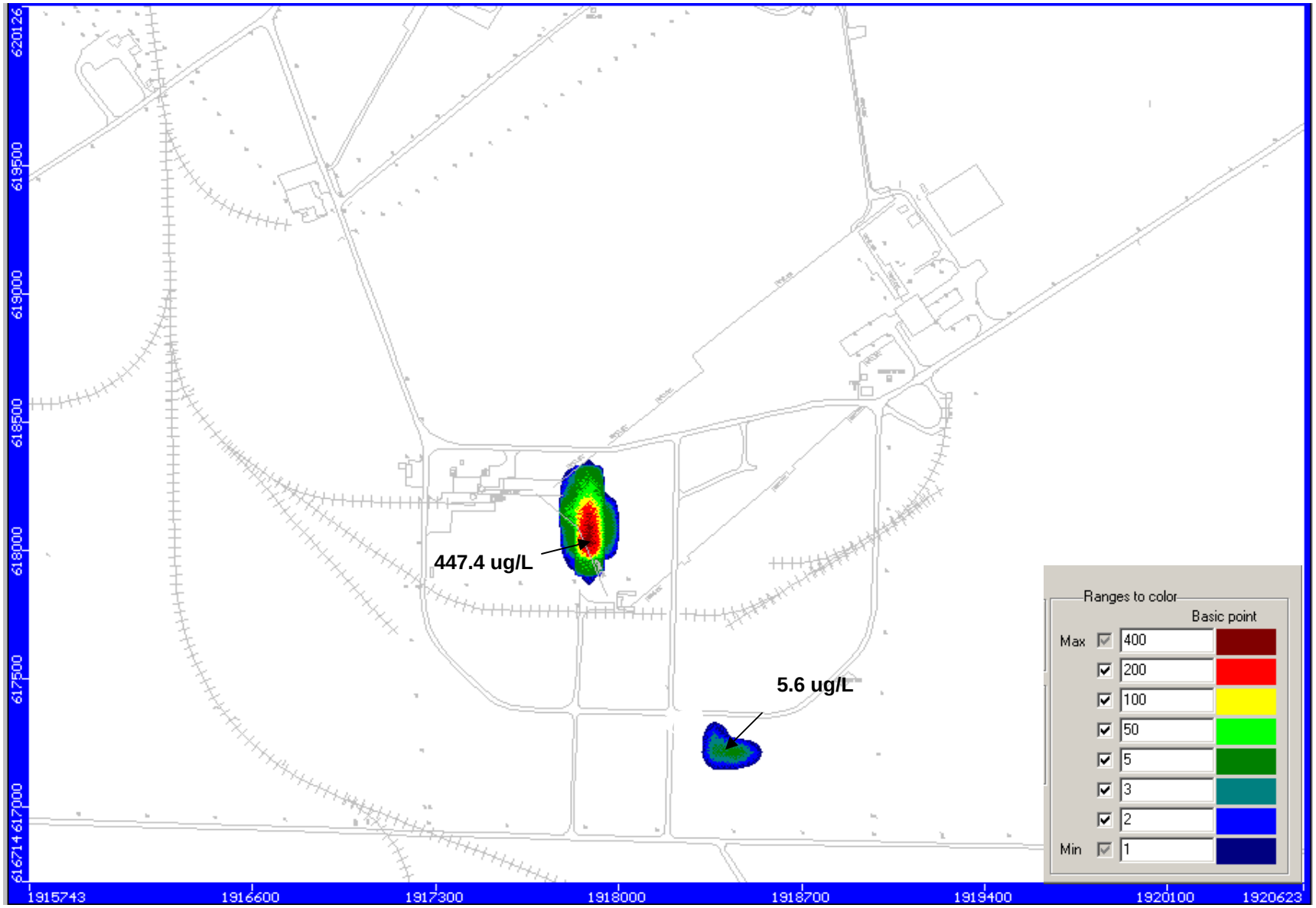

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Figure 5-16
Simulated 2,6-DNT Plumes in the TNT Area B After 150 Years
In the Overburden – Layer 1
Simulation No. 3: Soil Excavation and In Situ Enhanced Bioremediation in the Overburden
Former Plum Brook Ordnance Works, Sandusky, Ohio

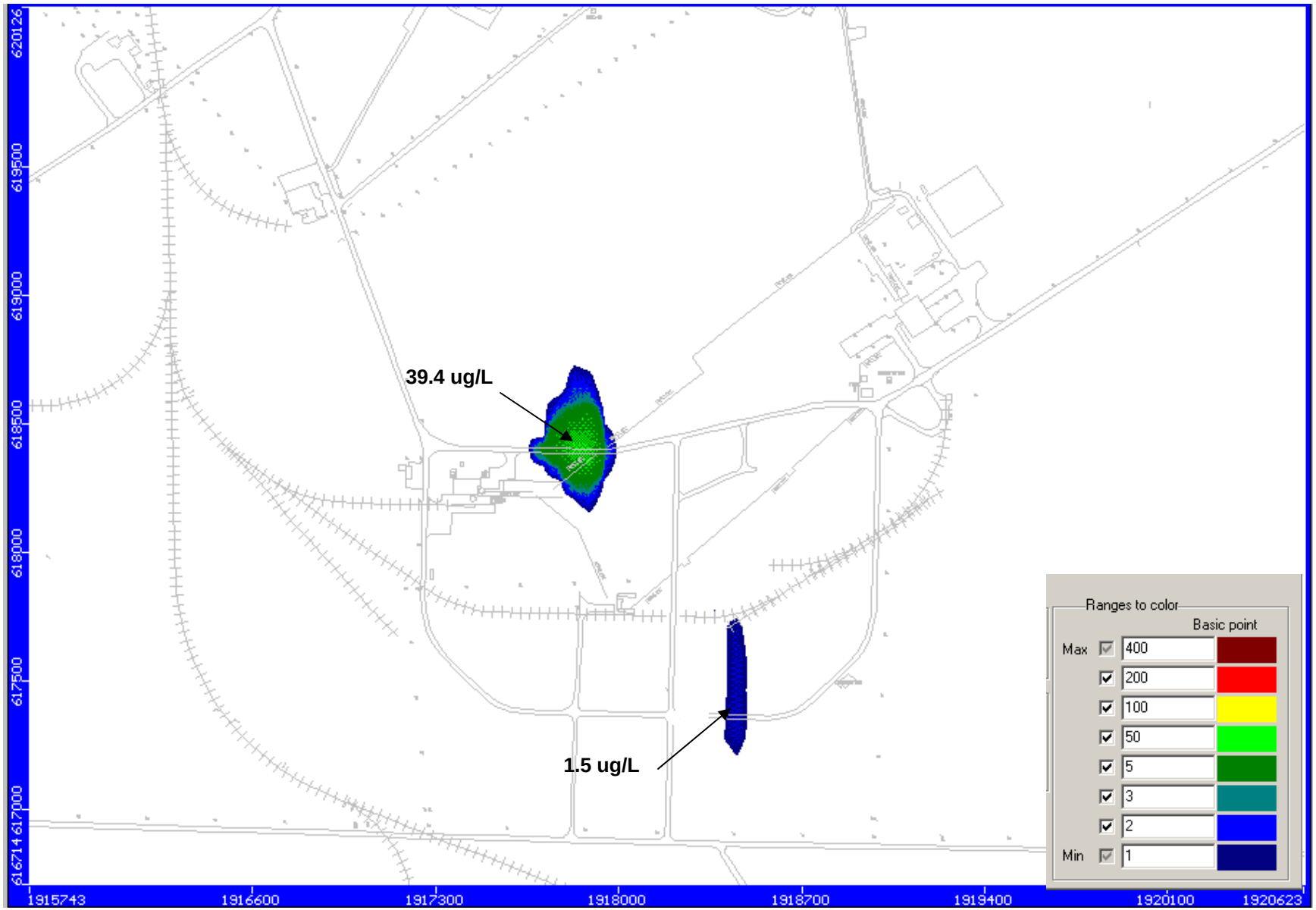

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Figure 5-17
Simulated 2,6-DNT Plumes in the TNT Area B After 150 Years
In the Bedrock – Layer 3
Simulation No. 3: Soil Excavation and In Situ Enhanced Bioremediation in the Overburden
Former Plum Brook Ordnance Works, Sandusky, Ohio

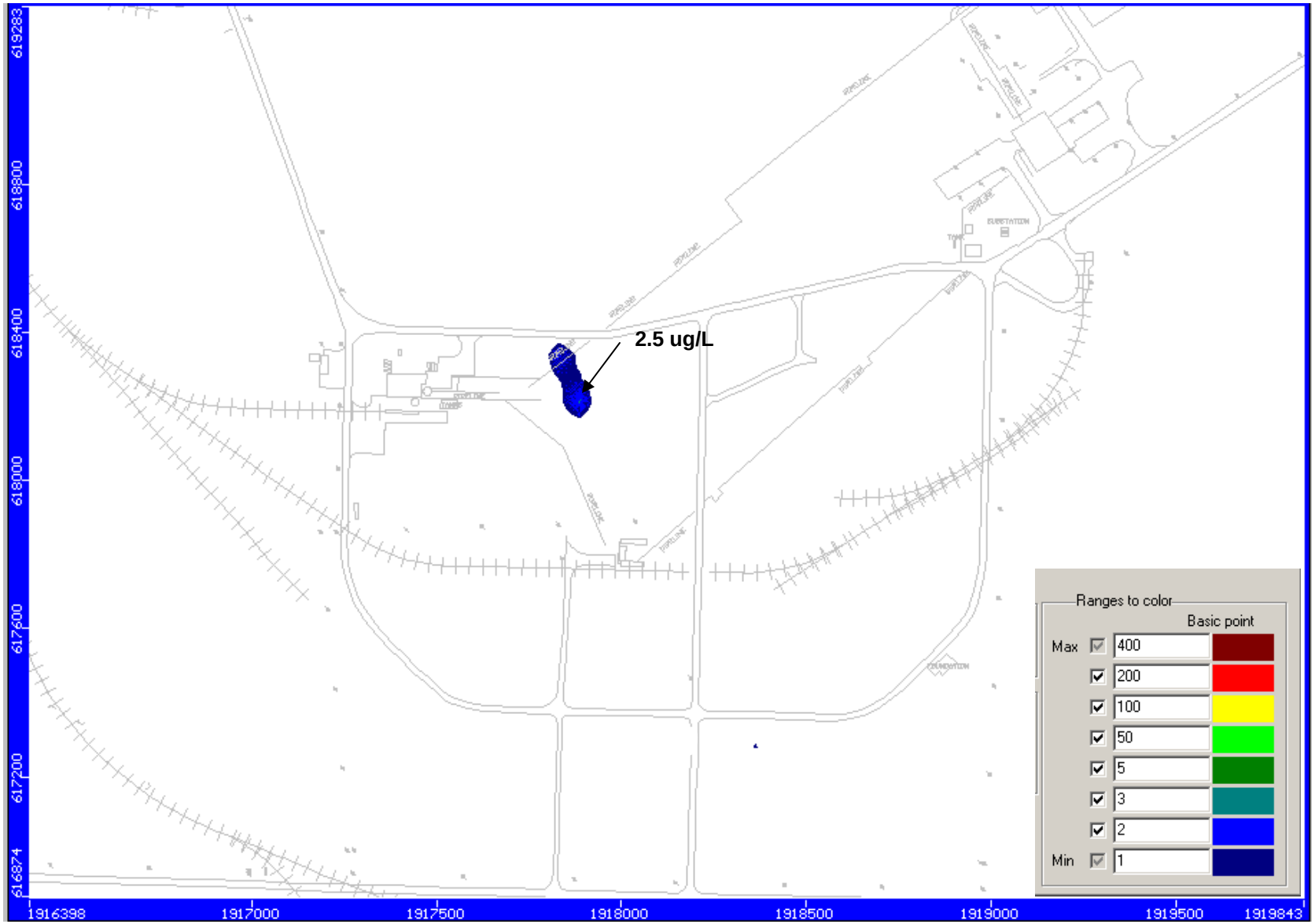

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Figure 5-18
Simulated 2,6-DNT Plumes in the TNT Area C and West Area Red Water Ponds Area After 8 Years
In the Overburden – Layer 1
Simulation No. 3: Soil Excavation and In Situ Enhanced Bioremediation in the Overburden
Former Plum Brook Ordnance Works, Sandusky, Ohio

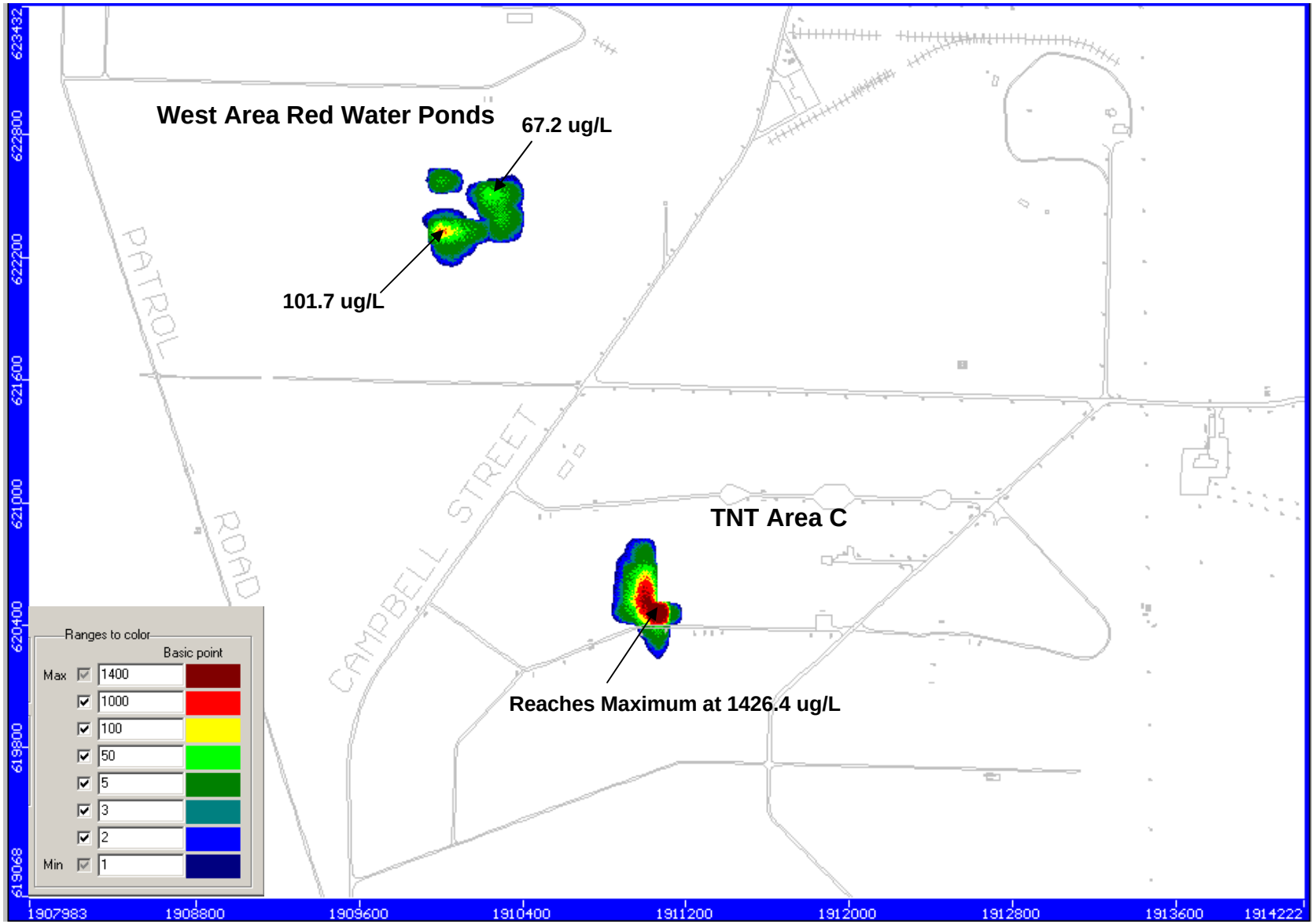

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Figure 5-19
Simulated 2,6-DNT Plumes in the TNT Area C and West Area Red Water Ponds Area After 150 Years
In the Overburden – Layer 1
Simulation No. 3: Soil Excavation and In Situ Enhanced Bioremediation in the Overburden
Former Plum Brook Ordnance Works, Sandusky, Ohio

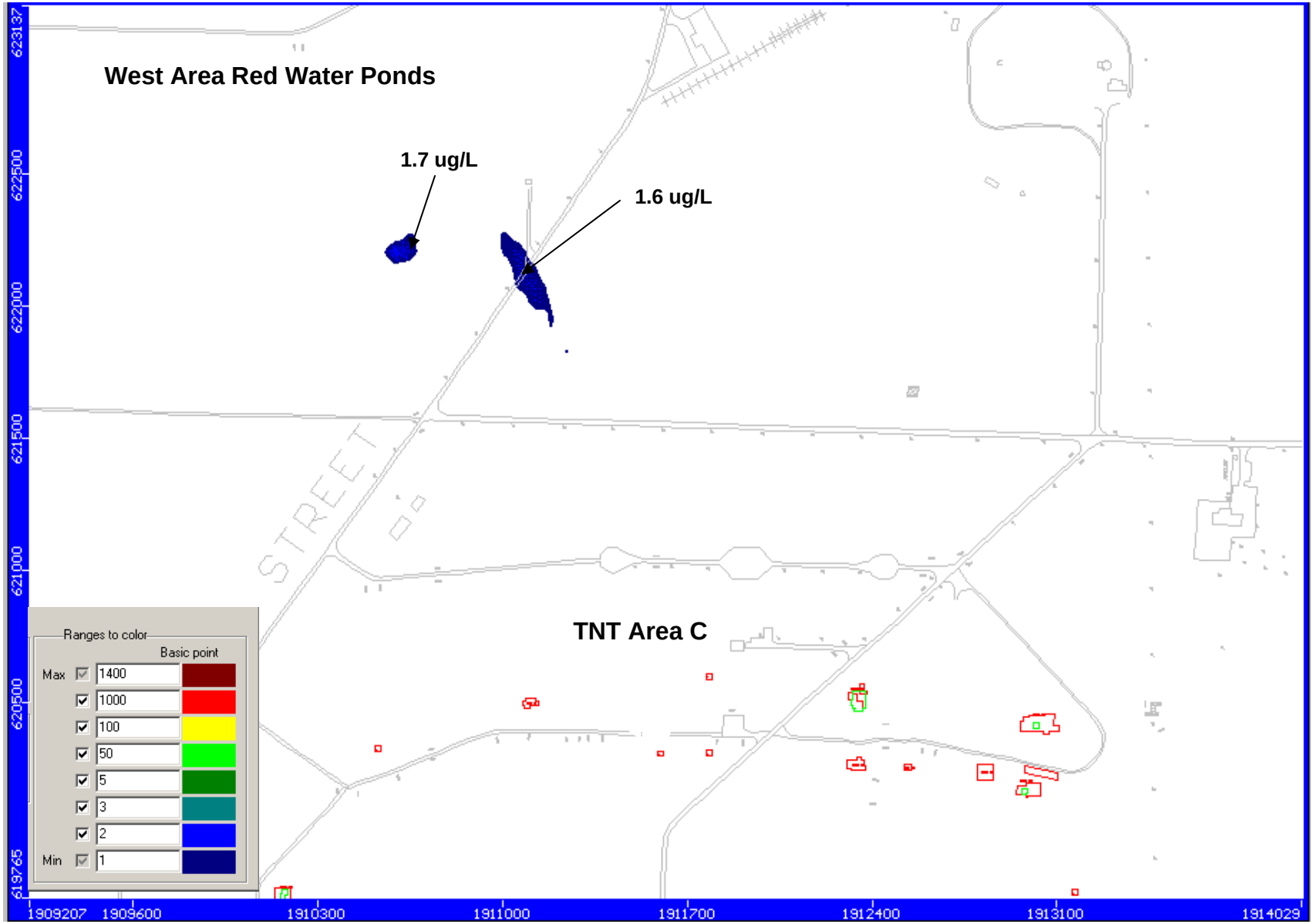

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Figure 5-20
Simulated 2,6-DNT Plumes in TNT Area C and West Area Red Water Ponds Area
After 145 Years (Maximum Conc. Occurs) In the Bedrock – Layer 3
Simulation No. 3: Soil Excavation and In Situ Enhanced Bioremediation in the Overburden
Former Plum Brook Ordnance Works, Sandusky, Ohio

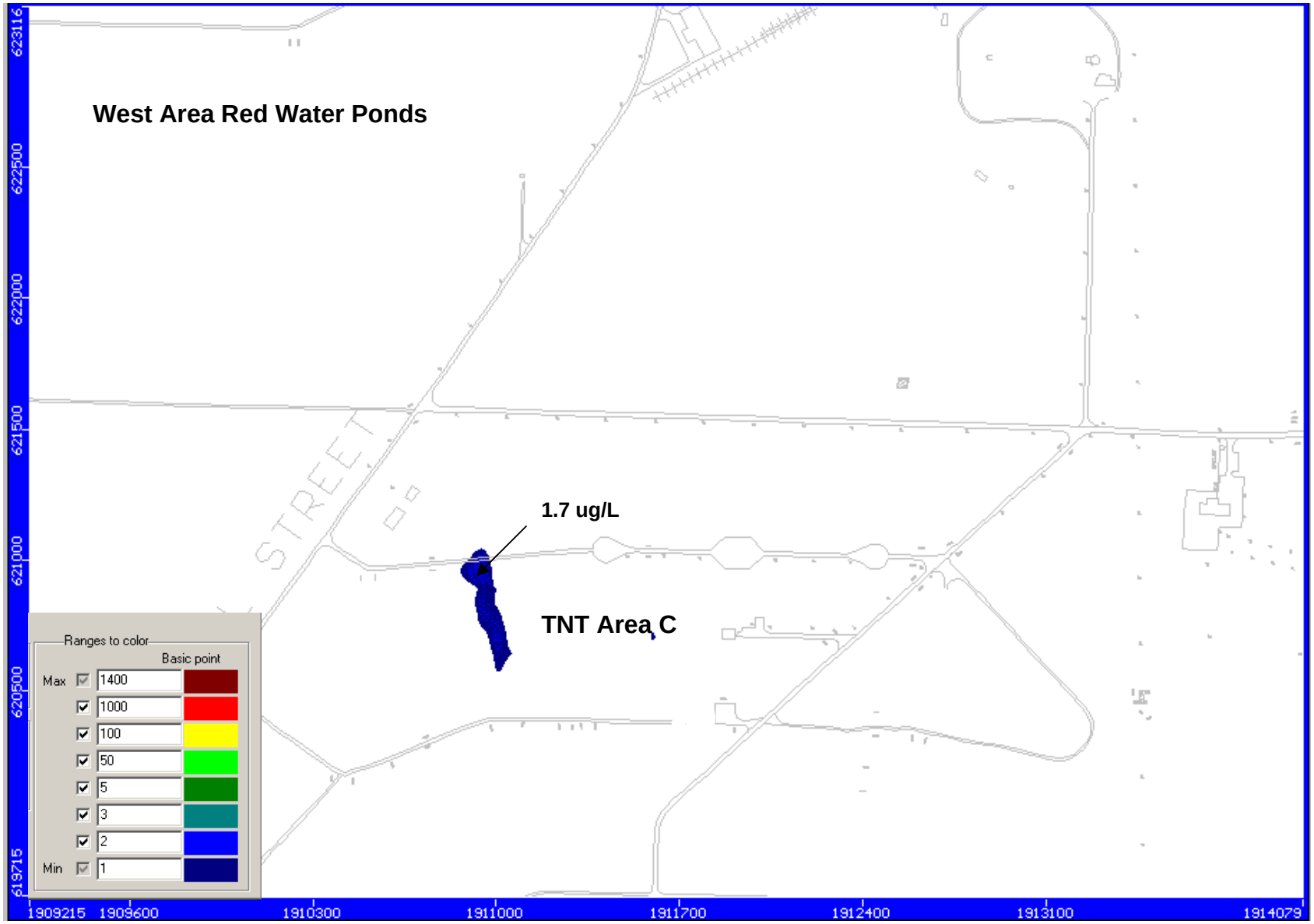

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Figure 5-21
Simulated 2,6-DNT Plumes in the Pentolite Red Water Pond Area
After 16 Years (Maximum Concentration Occurs) In the Overburden – Layer 1
Simulation No. 3: Soil Excavation and In Situ Enhanced Bioremediation in the Overburden
Former Plum Brook Ordnance Works, Sandusky, Ohio

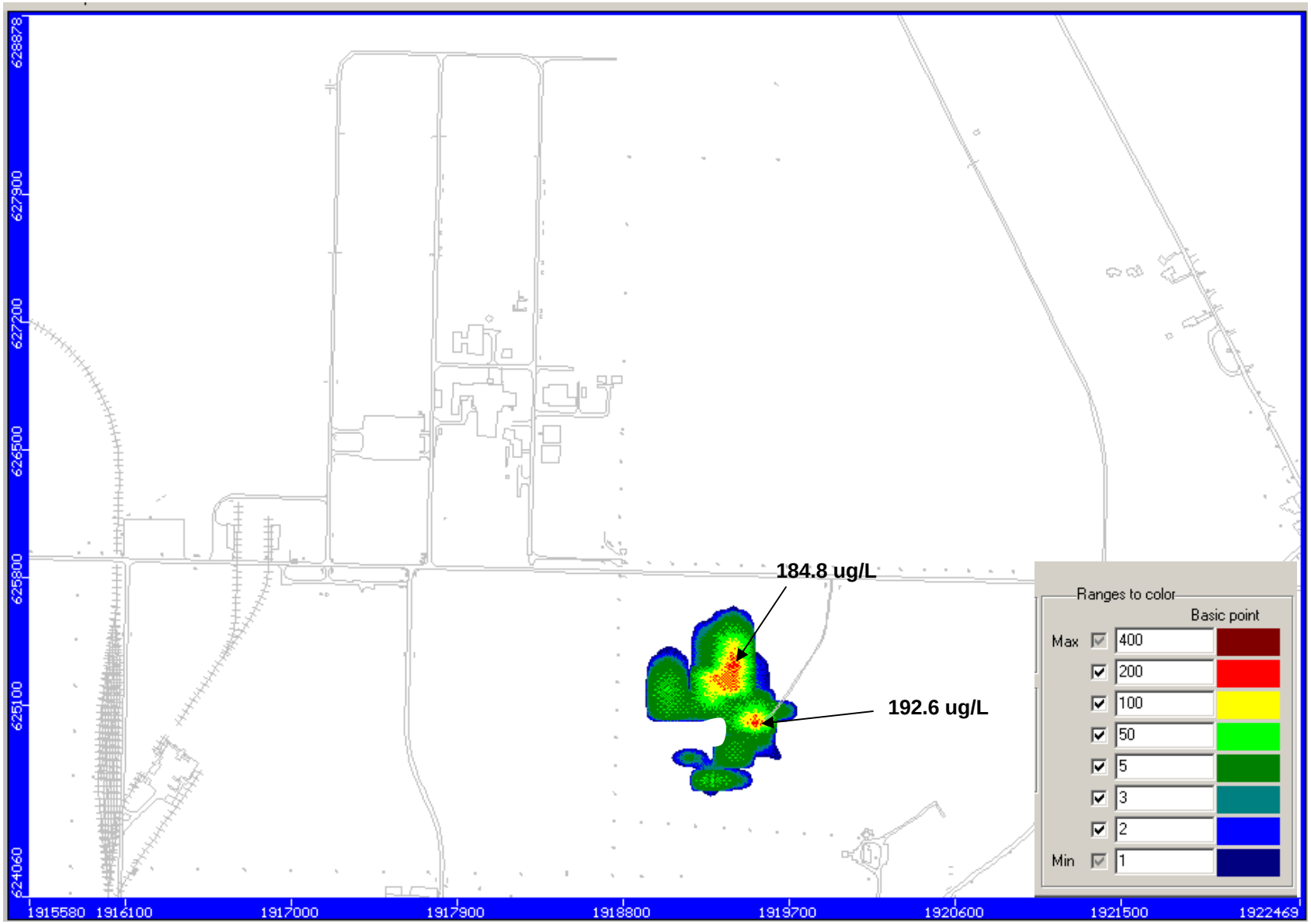

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Figure 5-22
Simulated 2,6-DNT Plumes in the Pentolite Red Water Pond Area After 150 Years
In the Overburden – Layer 1
Simulation No. 3: Soil Excavation and In Situ Enhanced Bioremediation in the Overburden
Former Plum Brook Ordnance Works, Sandusky, Ohio

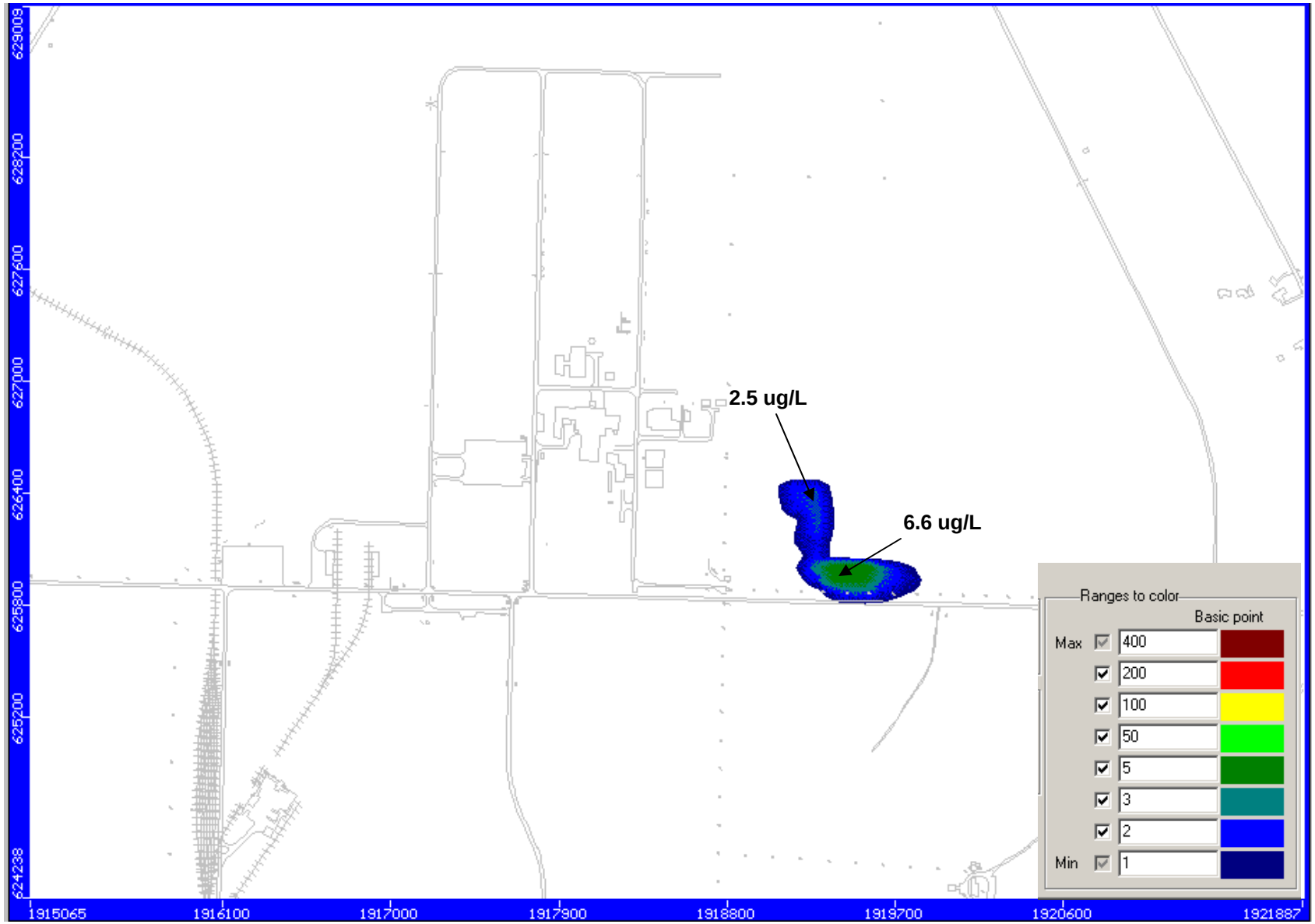

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Figure 5-23
Simulated 2,6-DNT Plumes in the Pentolite Red Water Pond Area After 150 Years
In the Bedrock – Layer 3
Simulation No. 3: Soil Excavation and In Situ Enhanced Bioremediation in the Overburden
Former Plum Brook Ordnance Works, Sandusky, Ohio

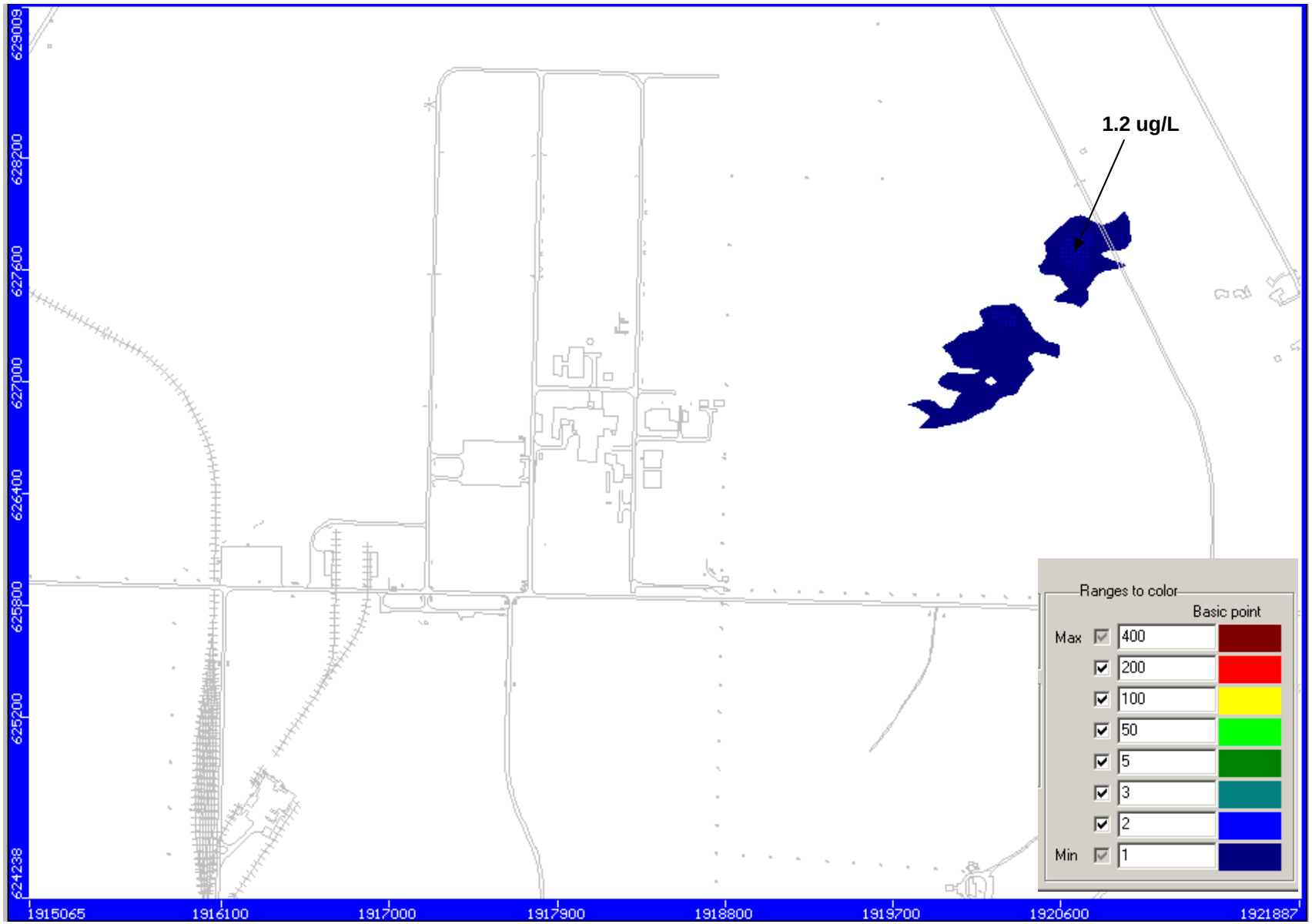

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Figure 5-24
Simulated 2,4-DNT Plumes in West Area Red Water Ponds Area After 150 Years
In the Bedrock – Layer 3
Simulation No. 4: Soil Excavation; In Situ Enhanced Bioremediation; Pump-and-Treat
Former Plum Brook Ordnance Works, Sandusky, Ohio

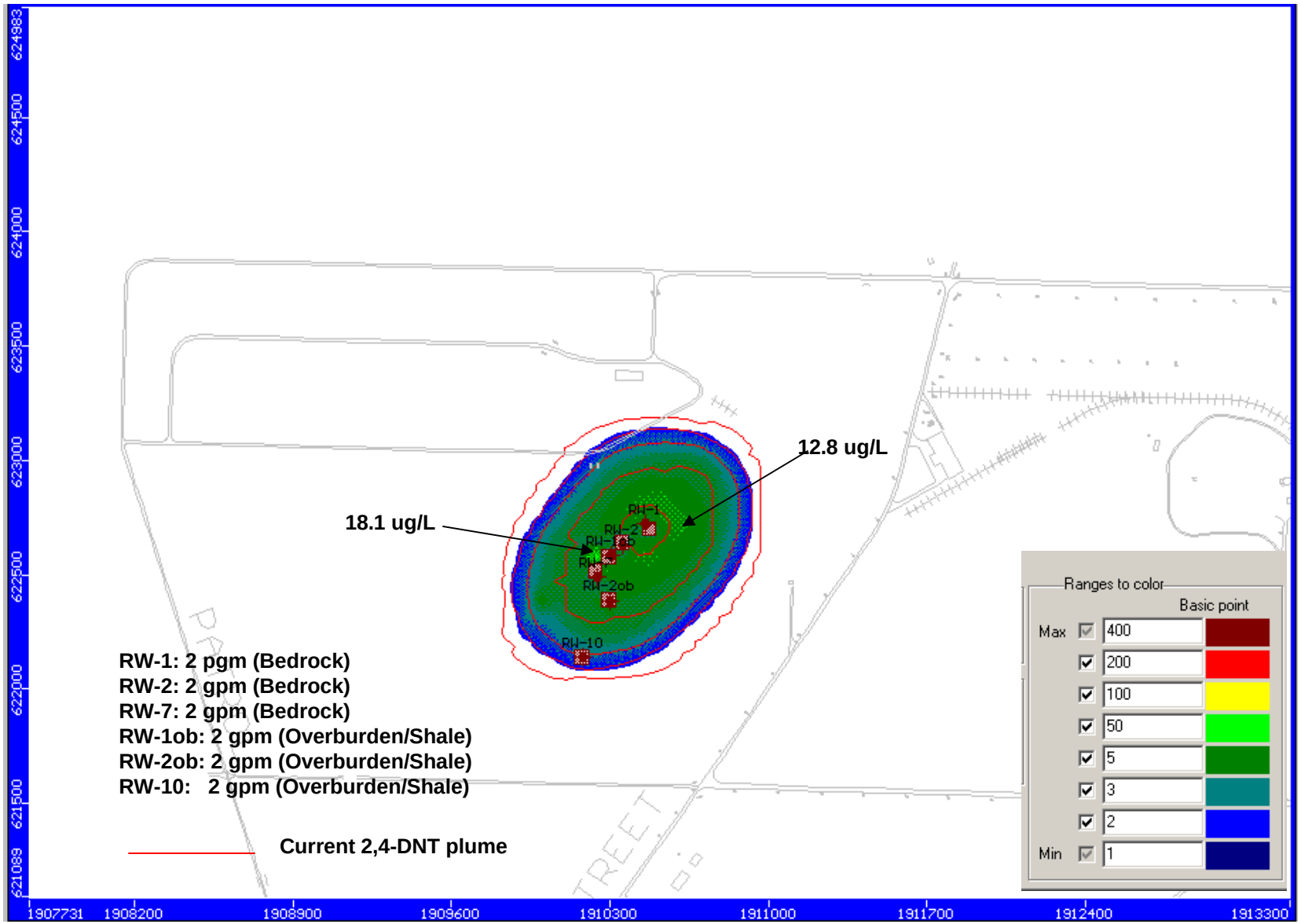

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Figure 5-25
Simulated 2,4-DNT Plumes in Pentolite Road Red Water Pond Area After 150 Years
In the Bedrock – Layer 3
Simulation No. 4: Soil Excavation; In Situ Enhanced Bioremediation; Pump-and-Treat
Former Plum Brook Ordnance Works, Sandusky, Ohio

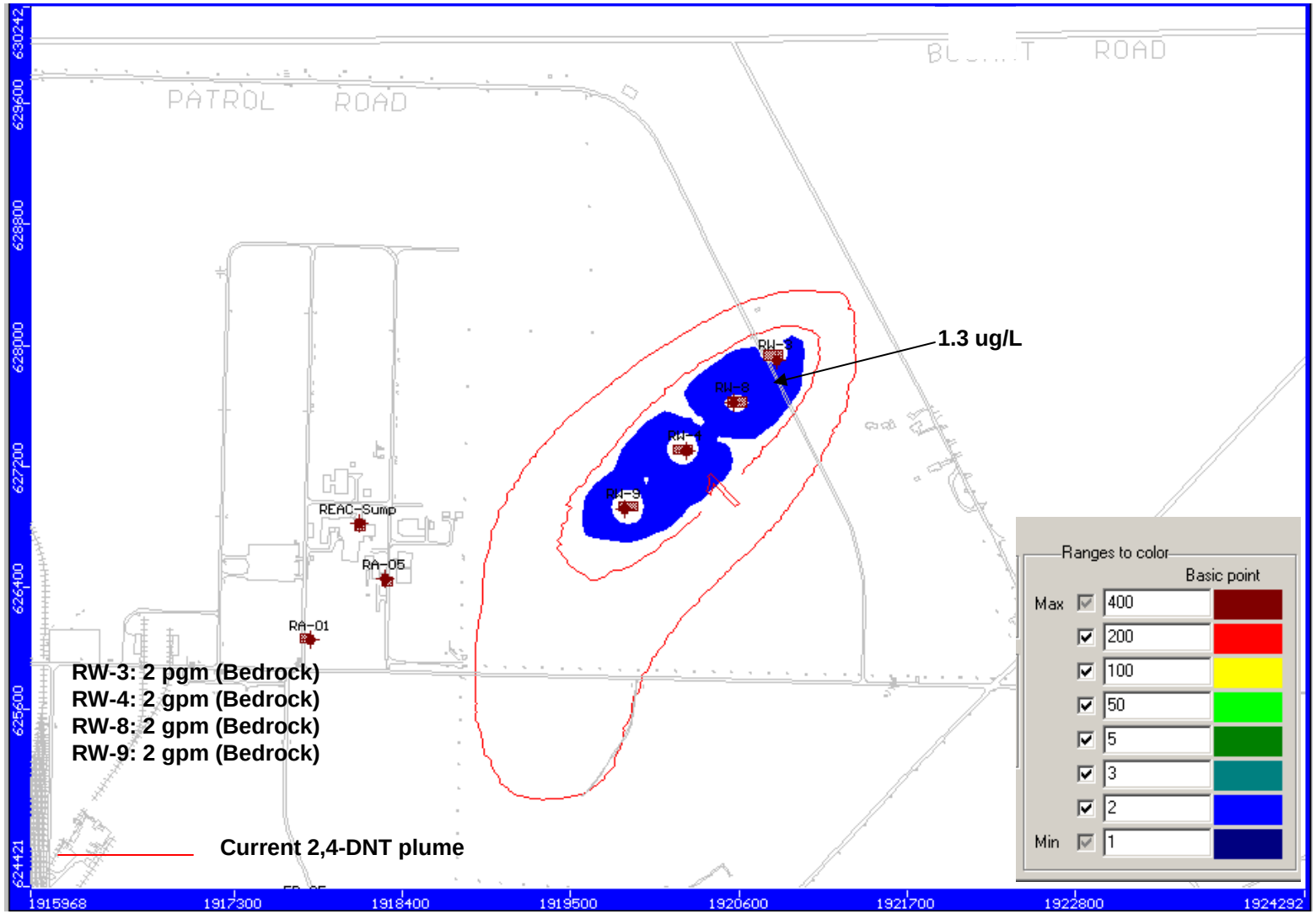

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Figure 5-26
Simulated 2,4-DNT Plumes in West Area Red Water Ponds Area After 150 Years in the Bedrock – Layer 3
Simulation No. 5a: Soil Excavation, In Situ Enhanced Bioremediation, Pump-and-Treat
Former Plum Brook Ordnance Works, Sandusky, Ohio

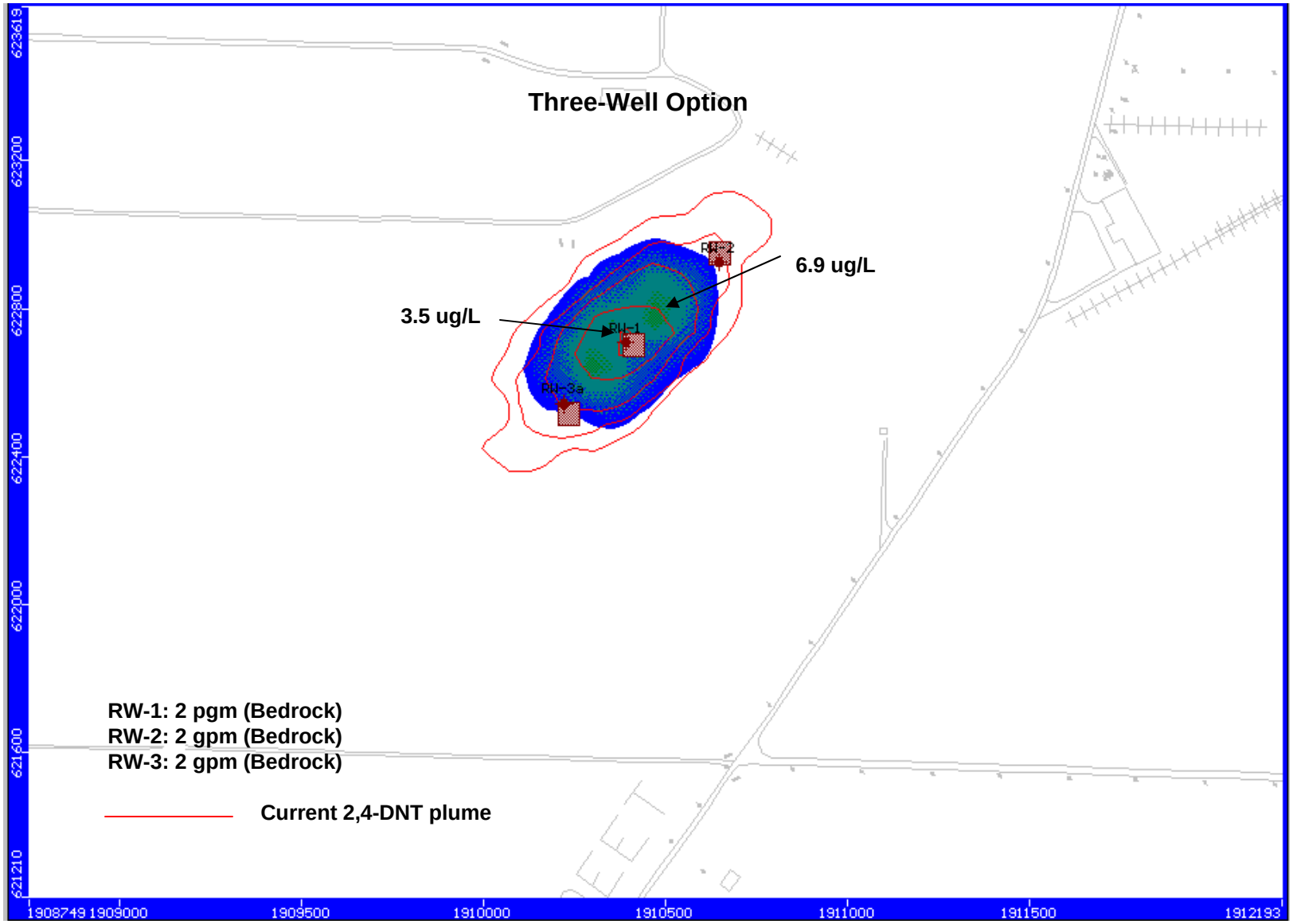

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Figure 5-27
Simulated 2,4-DNT Plumes in Pentolite Road Red Water Pond Area After 150 Years in the Bedrock – Layer 3
Simulation No. 5a: Soil Excavation, In Situ Enhanced Bioremediation, Pump-and-Treat
Former Plum Brook Ordnance Works, Sandusky, Ohio

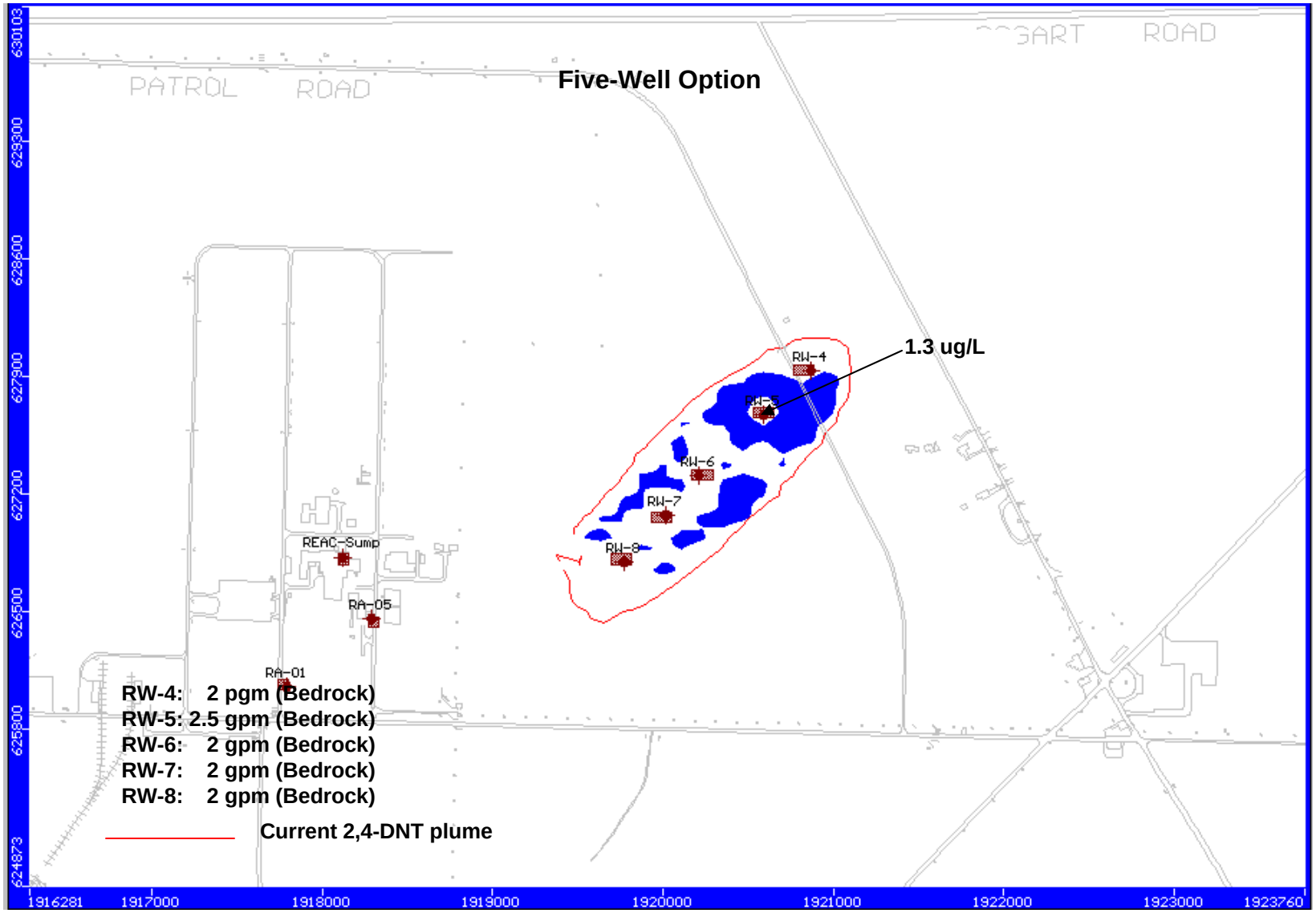

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Figure 5-28
Simulated 2,4-DNT Plumes in West Area Red Water Ponds Area after 150 years in the Bedrock – Layer 3
Simulation No. 5b: Soil Excavation, In Situ Enhanced Bioremediation, Pump-and-Treat
Former Plum Brook Ordnance Works, Sandusky, Ohio

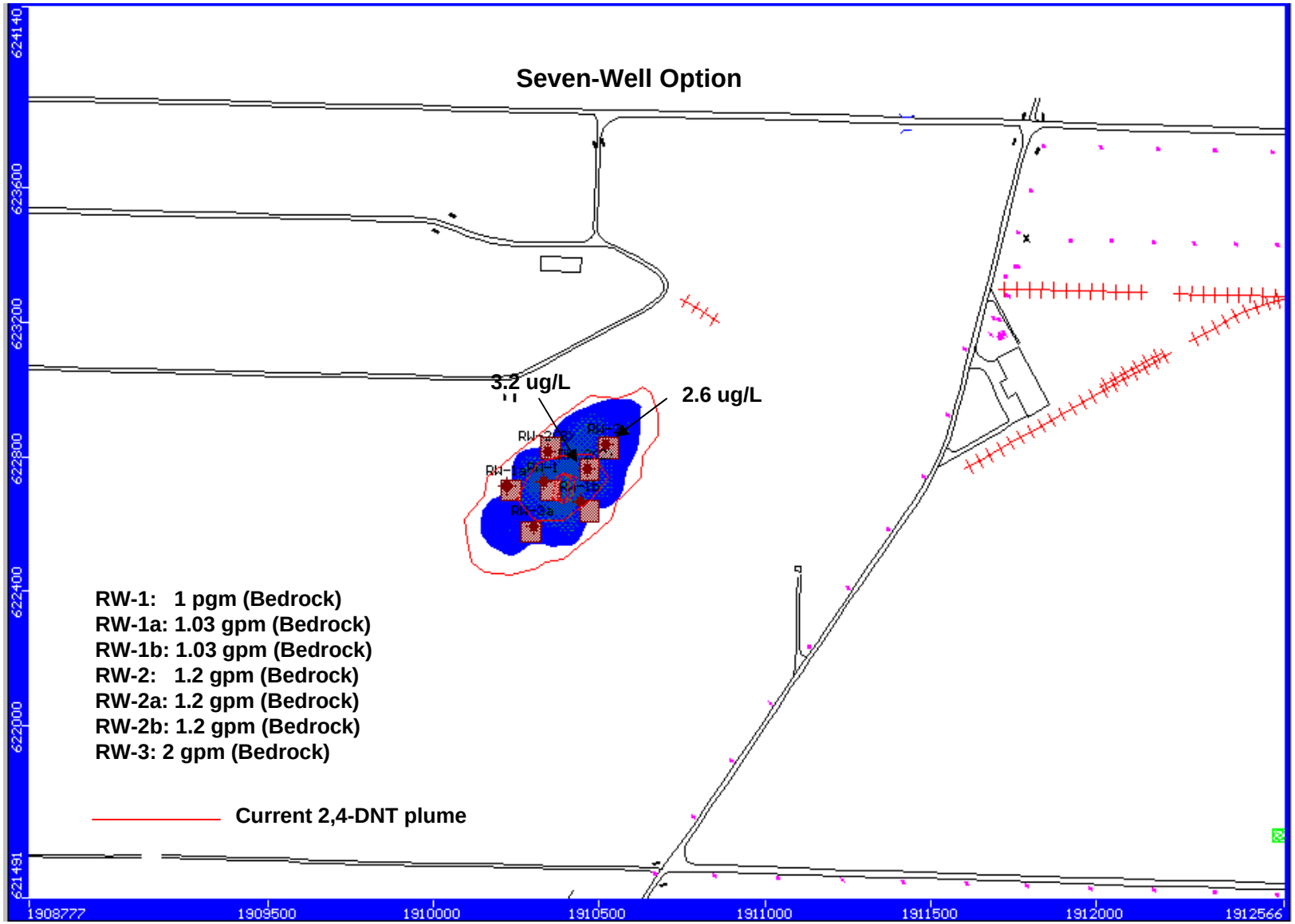

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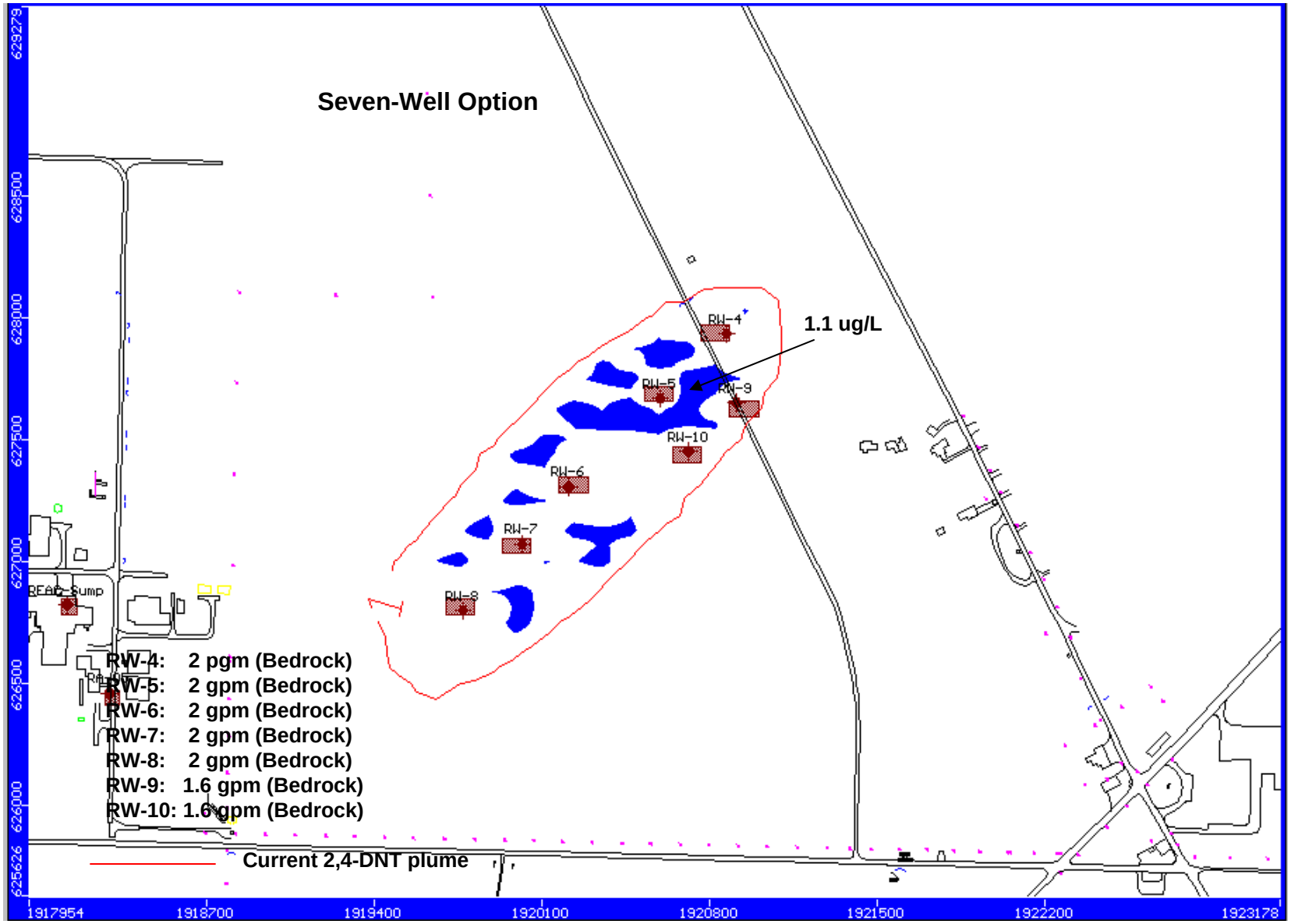
Figure 5-29
Simulated 2,4-DNT Plumes in Pentolite Road Red Water Pond Area after 150 Years in the Bedrock – Layer 3
Alternative 5b – Soil Excavation, In Situ Enhanced Bioremediation, Pump-and-Treat
Former Plum Brook Ordnance Works, Sandusky, Ohio



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ATTACHMENT A

SOIL DATA INPUT TABLES

Table 1

Soil Sample Locations and Analytical Data for Nitroaromatic Compound (2,4,6-TNT)
TNT Area A, Former Plum Brook Ordnance Works, Sandusky, Ohio

Location ID	Northing	Easting	Model Grid Column #	Model Grid Row #	Ground Elevation (feet msl)	Ground-Water Elevation (feet msl) Estimated	Depth to Ground Water (feet) Estimated	VLEACH Longitudinal Dispersivity (feet)	Building #	Projected Depth of Excavation (feet)	Sample Depth (feet below ground surface) and Concentrations (mg/kg)										Comments
											0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	
TNTA-S1	624547	1923783	194	75	632	629	5.00	0.12			4.9		580								
TNTA-S5	623816	1923318	187	87	636	633	4.00	0.05					0.3								SO334, 395, 396
TNTA-S15	623337	1922879	179	95	650	636	14.00	0.50				53									same location as S16, 19, SO033, 034
TNTA-S17	623260	1922852	179	96	650	637	13.00	0.48				1.1									
TNTA-S20	623121	1922699	176	98	653	637	16.02	0.54	**142**	**4**	**8.51**	**2.21**	31.2								same location as S13, S18, S19, S28, SO016, 017, 020,021, 022, 154, 155, 201, 238, 241, 242, 262, 263, 265, 266, 300, 311, 379, 380, SO403, 404
TNTA-S21	622833	1922881	179	103	658	642	16.00	0.54	**141**	**4**	40.7	17.9	**0.41**								same location as S001, 003, 297, 300, 349, 377
TNTA-S23	622800	1922908	180	103	658	642	16.00	0.54				0.483									same location as S298
TNTA-S25	622475	1923331	187	109	654	646	7.50	0.35	**192**	**4**			798								same as 061, 068, 069, 160, 161, 275-280, 359, 385
TNTA-S29	623297	1922840	178	95	645	636	9.00	0.39				19									
TNTA-S31	624527	1923495	190	76	649	646	3.00	0.02			0.9										
TNTA-S32	624571	1923587	191	75	634	631	3.00	0.02			3.2										
TNTA-SO012	622906	1923105	183	102	660	630	30.14	0.78	**195**	**7**			259			229					same as SO066, 248, 249, 387
TNTA-SO013	622924	1923123	183	101	660	640	20.10	0.62	**195**	**7**		0.285									same location as S250
TNTA-SO014	622915	1923140	184	102	661	640	20.50	0.63	**195**	**7**		0.483									same as SO014, 015, 245
TNTA-SO018	623184	1922684	176	97	650	637	13.00	0.48	**142**	**4**	2.48	2.21	0.124								same as SO019, 233, 234, 235
TNTA-SO024	623103	1922682	176	99	653	638	15.00	0.52	**142**	**4**	6.67										
TNTA-SO035	623314	1922907	180	95	651	635	16.24	0.55	**143**	**7**		8.9									same as 327-330, 350
TNTA-SO040	623323	1923086	183	95	654	635	19.48	0.61	**139**	**8**			7.21		0.317						same as 292, 375, 376
TNTA-SO045	623511	1923266	186	92	650	635	15.00	0.52	**133**	**6**	0.215			0.13							same location as S319
TNTA-SO047	623485	1923488	189	92	651	635	16.00	0.54					0.249								same as 53, 391
TNTA-SO048	623475	1923528	190	93	651	635	16.00	0.54					0.37								
TNTA-SO051	623510	1923527	190	92	651	635	16.00	0.54					4.08								same as 54,
TNTA-SO052	623547	1923490	189	91	651	635	16.00	0.54			0.507		5.04								same as 320
TNTA-SO053	623519	1923481	189	92	651	635	16.00	0.54					0.204								
TNTA-SO062	623116	1923300	186	98	659	638	21.29	0.64							2.88		15.9		5.35		same as 389, 390
TNTA-SO076	623938	1922842	178	85	636	633	3.20	0.02	**148**	**7**	0.252										
TNTA-SO077	623958	1922856	179	85	636	633	3.18	0.02	**148**	**7**		13.2									same location as SO218
TNTA-SO078	623403	1922581	174	94	639	635	4.00	0.05	**146**	**15**											same location as SO224
TNTA-SO079	623424	1922581	174	93	639	635	4.00	0.05	**146**	**15**	12000		103		530				260		same location as SO080, 222, 223, 309, 332, 383, 384
TNTA-SO081	623449	1922607	175	93	637	633	5.00	0.12	**146**	**15**	163		734		0.332						same location as SO081, 087, 225, 226, 310, 353, 38
TNTA-SO082	623401	1922606	175	94	639	635	4.00	0.05	**146**	**15**			0.647								same location as SO083, 232
TNTA-SO094	623221	1924923	214	97	653	637	16.42	0.55	**182**	**7**					0.331						same as 397, 398
TNTA-SO103	623727	1925141	217	89	651	635	16.00	0.54	**119**	**9**		0.483	0.153								same as 284, 315, 416, 484
TNTA-SO105	623763	1925105	217	88	649	635	14.35	0.51	**119**	**9**					1.56						same as 281, 283, 367, 368
TNTA-SO106	623734	1925074	216	88	650	635	15.00	0.52	**119**	**9**		2.1	0.36								same as 107, 288, 414
TNTA-SO109	623915	1924922	214	86	653	635	18.28	0.59	**111**	**6**		0.191			0.483						same as 111, 361
TNTA-SO110	623929	1924935	214	85	653	633	20.00	0.62	**111**	**6**	0.18		0.377								same as 305, 406
TNTA-SO121	624300	1925060	216	79	650	632	18.00	0.58						10.4	0.298				0.0851		same as 365, 366
TNTA-SO123	624158	1925236	219	82	656	632	23.62	0.68	**112**	**10**	0.982	284	39.1								same as 124, 125, 254, 323, 407
TNTA-SO126	624168	1925258	219	81	655	632	22.65	0.66	**112**	**10**	558	1298	0.312	29.9	64.4				8.57		same as 127, 128, 253, 255, 259, 324, 325, 363, 364, 408, 409
TNTA-SO129	624156	1925286	220	82	655	632	23.00	0.67	**112**	**10**				0.483							same as 130
TNTA-SO145	624575	1924697	210	75	634	629	5.00	0.12			1.12										
TNTA-SO146	624604	1924697	210	74	634	629	5.00	0.12			1.24										
TNTA-SO148	624524	1923827	195	76	632	629	3.00	0.02			0.178										
TNTA-SO149	624521	1923918	197	76	632	629	3.00	0.02				0.167									
TNTA-SO153	624592	1923811	195	75	632	629	3.00	0.02			0.404										
TNTA-SO162	624173	1924399	205	81	649	633	16.00	0.54			0.158										same as 163
TNTA-SO164	624137	1924431	205	82	650	633	17.00	0.56			0.328										same as 166, 167

Table 1

Soil Sample Locations and Analytical Data for Nitroaromatic Compound (2,4,6-TNT)
TNT Area A, Former Plum Brook Ordnance Works, Sandusky, Ohio

Location ID	Northing	Easting	Model Grid Column #	Model Grid Row #	Ground Elevation (feet msl)	Ground-Water Elevation (feet msl) Estimated	Depth to Ground Water (feet) Estimated	VLEACH Longitudinal Dispersivity (feet)	Building #	Projected Depth of Excavation (feet)	Sample Depth (feet below ground surface) and Concentrations (mg/kg)										Comments
											0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	
TNTA-SO186	623784	1923396	188	88	639	634	5.00	0.12			0.239										same as 338
TNTA-SO191	624487	1925204	218	76	638	630	8.00	0.36	**116**	**15**		0.435									
TNTA-SO196	624392	1925327	220	78	640	631	8.56	0.38	**116**	**15**		0.432									
TNTA-SO202	624472	1925333	220	77	638	631	7.00	0.33	**116**	**15**		0.373									
TNTA-SO203	624336	1924184	201	79	639	631	8.00	0.36	**126**	**11**	785	170	62.9								same as 205, 261, 267, 268, 269, 418, 419
TNTA-SO207	624286	1924182	201	80	639	631	8.00	0.36	**126**	**11**		0.333									same as 208, 269
TNTA-SO210	624274	1924261	202	80	640	631	9.00	0.39	**126**	**11**		0.408									same as 265
TNTA-SO212	624307	1924254	202	79	639	631	10.00	0.41	**126**	**11**	0.395	0.724	150						1.04		same as 213, 263, 372, 420-422
TNTA-SO221	623953	1922837	178	85	636	633	3.00	0.02	**148**	**7**		**0.126**									
TNTA-SO264	624305	1924286	203	79	639	630	9.00	0.39	**126**	**11**		1.36									
TNTA-SO270	624296	1924146	200	79	639	631	8.00	0.36			0.195										
TNTA-SO285	623711	1925073	216	89	650	639	11.00	0.43	**119**	**9**		0.295	0.353								same location as S415, 482
TNTA-SO291	623338	1923074	182	95	651	635	16.00	0.54	**139**	**8**			0.515								same as 296
TNTA-SO310	623449	1922607	175	93	639	635	4.00	0.05	**146**	**15**	1.62										
TNTA-SO348	623464	1923275	186	93	651	635	16.00	0.54	**133**	**6**				18.8							
TNTA-SO399	623734	1924758	211	88	655	635	20.00	0.62											0.483		
TNTA-SO405	623940	1924915	213	85	653	633	20.00	0.62	**111**	**6**	0.16										

Table 2

Soil Sample Locations and Analytical Data for Nitroaromatic Compound (2,4,6-TNT)
TNT Area B, Former Plum Brook Ordnance Works, Sandusky, Ohio

Location ID	Northing	Easting	Model Grid Column #	Model Grid Row #	Ground Elevation	Ground-Water Elevation	Depth to Ground Water	VLEACH Longitudinal Dispersivity	Building #	Excavation depth	Residual Excavation Concentration (mg/kg)	Sample Depth (feet below ground surface) and Concentrations (mg/kg)										Comments
					(feet msl)	(feet msl)	(feet)	(feet)		(feet)		0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	
						Estimated	Estimated															
PB-TNTB-S1	1910377	619640	124	169	661	657	3.90	0.046	**417**	**1.5**	**10.9**	12										same as SS050, 51, and 52
PB-TNTB-S2/S3	618668	1917759	125	170	663	657	5.50	0.169	**417**	**1.5**	**10.9**	1.6	2.7									same as S4, SS054
PB-TNTB-S4	1911507	621486	124	170	663	657	6.00	0.236	**417**	**1.5**	**10.9**	5	8.8									same as SS048, SS048,049, 242, 243and 284
PB-TNTB-S5/S6	618178	1918058	130	178	669	662	6.95	0.333	**466**	**4.5**	**ND**		1.5	51								same as S6, SS003,004, 073, 076, 077, 078, 079 and 376
PB-TNTB-S7	618163	1918117	131	178	669	662	7.09	0.336	**466**	**4.5**	**ND**		1.9	910								same as SS074, and 309
PB-TNTB-S9	618361	1918588	137	175	670	662	8.00	0.361	**456**	**4**	**ND**	6.9	2.3									same as SS031, SS173,182, 213, 216, 219, and 220
PB-TNTB-S10	618323	1918633	138	175	669	662	7.00	0.334	**456**	**4**	**ND**			0.9								same as S11, SO05,SO09, 14, 24, 27, 28, SS174-176, 210, 211, 212, 215, 217, 221, 222, 224-226,
PB-TNTB-S12	618302	1918648	138	176	669	662	7.00	0.334	**456**	**4**	**ND**	3.9										same as S13, SO029, SS223, 292,nd SS327-329
PB-TNTB-S17	618135	1918883	140	178	676	662	14.10	0.503	**453**	**8.5**	**ND**	390				2200						same as SO06, SS268, and 379
PB-TNTB-S18	618043	1918674	138	180	683	663	19.64	0.610	**452**	**10**	**76**	29000										same as S28
PB-TNTB-S23	617836	1918781	139	183	677	663	13.89	0.498				0.3										same as S21, S22, SS139, 270, and SS384
PB-TNTB-S24	617130	1918387	135	194	670	662	8.00	0.361	**412 A**	**6**	**ND**	0.8										same as S25, and SS387
PB-TNTB-SO001	618437	1918703	138	173	667	662	8.00	0.361				0.05										same as SS247 249, 401, and 402
PB-TNTB-SO002	617617	1918323	134	187	676	664	12.00	0.458							0.27							
PB-TNTB-SO007	618014	1917618	122	180	682	663	18.90	0.597	**473**	**10**	**4.44**				5.8							same as SS021, SS022, SO037, SS320, 397
TNTB-B463new	618022	1917878	127	180	676	662	14.00	0.501	**463**	**10**	**80.9**											
PB-TNTB-SO008	617927	1917963	128	182	676	662	14.00	0.501	**462**	**8**	**ND**	0.87						11				same as SS087, 088, 090, 245, 246
PB-TNTB-SO010	618007	1917813	126	180	676	662	14.00	0.501	**463**	**10**	**24**	0.4				1.6				46		same as SO11, SO36, SS061, and 389
PB-TNTB-SO012	617920	1917463	120	180	677	663	14.20	0.505	**472**	**5**	**ND**					27						same as SO40, SS017, SS008, 018, 390, 393-395
PB-TNTB-SO013	618054	1918677	138	180	677	663	14.20	0.505	**452**	**10**	**76**	66				6100				76		same as S18, 19, 20, SS151, 153, 154, 155, 258, 262, 263, 265, 266, 300, 375, and 380
PB-TNTB-SO015	618487	1917728	124	173	665	660	5.00	0.118				4.35										same as SO16, SS057, SS237,238, 239, and 336
PB-TNTB-SO017	618487	1917748	125	173	665	660	5.00	0.118				6.1										same as SS239
PB-TNTB-SO018	618612	1917683	124	171	661	658	4.00	0.050				2.9			0.28							same as SO19, SS047, SS282,and 362
PB-TNTB-SO020	618137	1917408	119	178	669	662	7.00	0.334	**476**	**3**	**ND**	720										SO21, 22, SS038, 235, 236, 310 to 315, 317, 318, 335
PB-TNTB-SO023	618064	1918677	138	179	680	662	18.00	0.580				33										same as SS290, 324, 325
PB-TNTB-SO026	618232	1917988	129	177	669	662	6.50	0.320	**466**	**7.5**	**ND**	23										SS025, 066, 080, 207, 208, 288, 289
PB-TNTB-SO030	617559	1917724	124	187	672	665	7.24	0.341				0.56										
PB-TNTB-SO032	618492	1918874	140	173	668	660	8.17	0.366	**466**	**7.5**	**ND**	7.6										same as SS183, 185, 230, and 231
PB-TNTB-SO035	618192	1918043	130	177	669	661	8.00	0.361	**466**	**7.5**	**ND**	7.6										same as SS069, 071, 232, and 333
PB-TNTB-SO038	617990	1917591	122	181	682	663	18.90	0.597				0.78										
PB-TNTB-SS020	618012	1917643	123	180	680	663	16.50	0.551							5.2							same as SS0021, 388, and 396
PB-TNTB-SS025	617572	1917588	122	187	678	665	13.00	0.479				0.01										
PB-TNTB-SS027	617587	1917658	123	187	672	665	7.00	0.334				0.14										same as SS035
PB-TNTB-SS039	618137	1917448	120	178	669	662	7.00	0.334				0.69										same as SS040
PB-TNTB-SS042	618252	1917735	124	176	670	661	9.00	0.387				0.2										
PB-TNTB-SS044	618313	1917735	124	175	670	661	9.00	0.387				0.06										

Table 2

Soil Sample Locations and Analytical Data for Nitroaromatic Compound (2,4,6-TNT)
TNT Area B, Former Plum Brook Ordnance Works, Sandusky, Ohio

Location ID	Northing	Easting	Model Grid Column #	Model Grid Row #	Ground Elevation (feet msl)	Ground-Water Elevation (feet msl) Estimated	Depth to Ground Water (feet) Estimated	VLEACH Longitudinal Dispersivity (feet)	Building #	Excavation depth (feet)	Residual Excavation Concentration (mg/kg)	Sample Depth (feet below ground surface) and Concentrations (mg/kg)										Comments
												0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	
PB-TNTB-SS046	618232	1917853	126	177	669	662	7.20	0.340				0.1										same as SS195
PB-TNTB-SS055	618617	1917763	125	171	662	659	3.00	0.017				0.46										
PB-TNTB-SS056	618517	1917663	124	172	662	659	3.00	0.017				0.01										
PB-TNTB-SS058	618517	1917763	125	172	662	659	3.00	0.017				0.76										
PB-TNTB-SS059	618027	1917793	125	180	679	664	15.00	0.521				0.5			0.28							same as SS060, 062, and 398
PB-TNTB-SS063	618062	1917783	125	179	679	664	14.80	0.517				0.43										same as SS064
PB-TNTB-SS065	618227	1917953	128	177	669	662	7.20	0.340				0.2										same as 197
PB-TNTB-SS067	618227	1918038	130	177	669	662	6.50	0.320				0.72										
PB-TNTB-SS081	617942	1917963	128	181	677	663	14.00	0.501	**462**	**8**	**ND**	0.37										same as SS322 and 392
PB-TNTB-SS082	617932	1917981	129	182	676	663	13.00	0.479				0.01										same as SS083-86
PB-TNTB-SS091	617737	1917963	128	185	677	664	13.00	0.479				2.4										same as SS092, to 095, 247 to 250, and 391
PB-TNTB-SS096	617542	1918068	130	188	671	665	6.30	0.284				0.39										same as SS102 and 106
PB-TNTB-SS098	617522	1918098	131	188	671	665	6.30	0.284				0.01										
PB-TNTB-SS105	617722	1918038	130	185	677	664	13.00	0.479				0.01										
PB-TNTB-SS122	617567	1918348	135	187	673	665	7.50	0.348				0.15										
PB-TNTB-SS123	617552	1918338	135	188	672	665	7.00	0.334				0.01										
PB-TNTB-SS127	617712	1918553	137	185	671	664	6.60	0.323				0.09										
PB-TNTB-SS130	617662	1918583	137	186	671	664	6.60	0.323				0.01										
PB-TNTB-SS155	618037	1918653	125	171	663	659	4.00	0.050				0.2										
PB-TNTB-SS161	618022	1918618	137	180	678	664	14.00	0.501				0.32										same as SS162
PB-TNTB-SS171	618387	1918723	138	174	667	661	6.00	0.236				0.12										same as SS296
PB-TNTB-SS177	618297	1918618	137	176	669	662	7.00	0.334	**456**	**4**	**ND**	3.5										same as 178, 180, and 330
PB-TNTB-SS192	617507	1917963	128	188	671	665	6.30	0.284				0.01										
PB-TNTB-SS194	617970	1918616	137	181	677	663	14.00	0.501				0.01										
PB-TNTB-SS196	618252	1917853	126	176	669	661	8.20	0.366				0.68										
PB-TNTB-SS198	618247	1917953	128	176	669	661	8.00	0.361				0.36										
PB-TNTB-SS199	617467	1918448	136	189	672	665	6.80	0.328				0.31										
PB-TNTB-SS204	618247	1917913	127	176	669	661	8.20	0.366				0.3										
PB-TNTB-SS205	618237	1917913	127	177	669	661	8.20	0.366				0.89										same as 206
PB-TNTB-SS241	618697	1917743	125	169	661	658	3.00	0.017				0.08										
PB-TNTB-SS278	618439	1918273	133	173	671	660	11.40	0.444				0.23										
PB-TNTB-SS279	618219	1918263	133	177	669	661	7.50	0.348				0.21										
PB-TNTB-SS281	617467	1918163	132	189	671	665	6.30	0.284				0.36										
PB-TNTB-SS283	618517	1917728	124	172	663	659	3.50	0.030				0.45										
PB-TNTB-SS321	618005	1917712	124	180	679	662	17.00	0.561				0.09										
PB-TNTB-SS334	618137	1917998	129	178	670	663	7.00	0.334				0.78										
PB-TNTB-SS370	618172	1918458	136	178	670	661	9.00	0.387						0.52		25						

Table 2

Soil Sample Locations and Analytical Data for Nitroaromatic Compound (2,4,6-TNT)
TNT Area B, Former Plum Brook Ordnance Works, Sandusky, Ohio

Location ID	Northing	Easting	Model Grid Column #	Model Grid Row #	Ground Elevation	Ground-Water Elevation	Depth to Ground Water	VLEACH Longitudinal Dispersivity	Building #	Excavation depth	Residual Excavation Concentration (mg/kg)	Sample Depth (feet below ground surface) and Concentrations (mg/kg)										Comments
					(feet msl)	(feet msl)	(feet)	(feet)		(feet)		0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	
						Estimated	Estimated															
PB-TNTB-SS371	618394	1918398	136	174	667	660	6.80	0.328						0.07		0.5						

Table 3

Soil Sample Locations and Analytical Data for Nitroaromatic Compound (2,4,6-TNT)
TNT Area C, Former Plum Brook Ordnance Works, Sandusky, Ohio

Location ID	Northing	Easting	Model Grid Column #	Model Grid Row #	Ground Elevation (feet msl)	Ground-Water Elevation (feet msl) Estimated	Depth to Ground Water (feet) Estimated	VLEACH Longitudinal Dispersivity (feet)	Building #	Projected Depth of Excavation (feet)	Sample Depth (feet below ground surface) and Concentrations (mg/kg)										Comments
											0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	
TNTC-SO001	619782	1913168	79	152	673	662	11.30	0.44	**689**	**8**	4.76				1.96						same as 249, 401, 402
TNTC-SO015	619871	1912606	70	150	676	661	15.50	0.53				0.197		0.288							same as 277
TNTC-SO026	619955	1912015	60	149	679	657	22.50	0.66				0.127									same as 030
TNTC-SO051	619640	1910377	32	154	677	655	21.80	0.65					0.82								same as 054
TNTC-SO065	619784	1910176	29	152	669	655	13.65	0.49	**629**	**10**	0.442		**38**			**5.19**			**84.2**		same as 066, 269, 272, 278, 363, 364
TNTC-SO071	620304	1910619	36	143	655	650	5.00	0.12					0.878								same as 072
TNTC-SO074	620326	1910527	35	143	654	650	6.00	0.24	**626**	**8**		3.87	1.41		0.259						same as 075, 395
TNTC-SO084	620376	1910525	35	142	654	650	4.06	0.05	**626**	**8**	**3.87**		**1.41**		**0.259**						
TNTC-SO085	620237	1911076	44	144	655	651	4.00	0.05					5.9								same as 085, 093, 096
TNTC-SO098	620517	1911087	44	140	655	649	6.00	0.24	**616**	**8**		**1.36**									same as 110, 262-264
TNTC-SO100	620500	1911118	45	140	654	648	5.81	0.21	**616**	**8**	**797**		2226		**4.81**				**8.66**		same as 251, 252, 253, 317, 361, 362
TNTC-SO104	620462	1911172	46	141	657	650	7.00	0.33	**616**	**8**			0.194								
TNTC-SO106	620475	1911121	45	141	657	650	7.00	0.33	**616**	**8**		1.13		**0.23**							same as 254, 258
TNTC-SO107	620480	1911094	44	141	657	648	10.00	0.41	**616**	**8**	**0.556**	**1.1**		**47.3**							same as 108, 261, 379, 380
TNTC-SO120	620303	1911568	53	143	666	652	14.00	0.50	**603**	**8**		2.73				**5.44**			**15.1**		same as 123, 125
TNTC-SO134	620311	1911785	56	143	668	650	18.23	0.58	**602**	**6**	1.03	**0.89**	**0.049**			0.395					same as 135, 331,377
TNTC-SO137	620871	1912711	72	134	647	644	3.40	0.03			0.677										same as 141
TNTC-SO138	620840	1912712	72	135	648	644	3.50	0.03			0.25										
TNTC-SO143	620400	1912951	76	142	655	652	3.00	0.02	**686**	**4**		0.139	9.19								same as 144
TNTC-SO145	620398	1913031	77	142	655	652	4.00	0.05	**686**	**4**	5067	**2588**	0.132								same as 151, 301, 303-305, 325
TNTC-SO146	620389	1913056	78	142	657	654	3.00	0.02	**686**	**4**	159	8.33									same as 147, 149, 150, 306, 307, 330
TNTC-SO148	620402	1913116	79	142	658	654	4.00	0.05			1.64										
TNTC-SO152	620438	1912984	76	141	658	653	5.00	0.12	**686**	**4**			0.692								
TNTC-SO157	620154	1912987	76	146	671	657	13.90	0.50	**682**	**4**		8.35									same as 309-311, 369
TNTC-SO158	620155	1913006	77	146	671	657	13.90	0.50	**682**	**4**		0.463									
TNTC-SO165	620182	1913008	77	145	669	657	11.55	0.45	**682**	**8**	**54969**	1343			3.43				4.14		same as 280, 312-314, 367, 368
TNTC-SO171	620231	1912827	74	145	666	657	10.00	0.41	**683**	**9**					448				173		same as 399, 400
TNTC-SO173	620256	1912537	69	144	666	655	11.35	0.44	**693**	**7**		**8.07**							0.33		same as 175, 407, 408
TNTC-SO178	620506	1912291	65	140	655	652	10.00	0.41	**696**	**12**	878	**46.2**	251								same as191, 192, 291-295, 326-328. 333, 374
TNTC-SO179	620480	1912297	65	141	655	652	3.00	0.02	**696**	**12**		1.37									
TNTC-SO184	620493	1912462	67	140	655	652	3.00	0.02				0.253									same as185
TNTC-SO186	620502	1912395	66	140	655	652	3.00	0.02	**696**	**12**	2.75	13.9									same as187, 189, 190, 288-290, 295
TNTC-SO193	620625	1911754	55	138	650	647	3.00	0.02				0.29									same as195
TNTC-SO198	620564	1911771	56	139	652	647	5.00	0.12	**606**	**7**		0.884									
TNTC-SO200	620565	1911808	57	139	654	649	5.00	0.12			0.638	0.289									same as 205
TNTC-SO202	620536	1911868	58	140	655	650	10.00	0.41			0.569	1.42			0.233				0.213		same as 203, 381, 382
TNTC-SO218	621420	1911523	52	125	644	638	5.70	0.19			0.56			0.489		0.367					same as 222, 225, 365, 366
TNTC-SO228	620290	1912340	65	144	670	655	15.00	0.52	**692**	**8**		489	**0.63**								**same as 229, 243, 244, 279, 284**

Table 3

Soil Sample Locations and Analytical Data for Nitroaromatic Compound (2,4,6-TNT)
TNT Area C, Former Plum Brook Ordnance Works, Sandusky, Ohio

Location ID	Northing	Easting	Model Grid Column #	Model Grid Row #	Ground Elevation (feet msl)	Ground-Water Elevation (feet msl) Estimated	Depth to Ground Water (feet) Estimated	VLEACH Longitudinal Dispersivity (feet)	Building #	Projected Depth of Excavation (feet)	Sample Depth (feet below ground surface) and Concentrations (mg/kg)										Comments
											0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	
TNTC-SO231	620253	1912367	66	144	670	655	15.00	0.52	**692**	**8**	**0.84**	1319			**2.55**						same as 241, 283, 285, 286, 320, 405
TNTC-SO235	620091	1910655	37	147	665	651	14.00	0.50				2.98									same as 236
TNTC-SO281	620224	1913088	78	145	670	665	5.00	0.12	**682**	**8**	47.5										
TNTC-SO302	620426	1913019	77	141	658	654	10.00	0.41	**686**	**4**	902	22.5			0.192				0.555		same as 324, 335, 336, 371, 372
TNTC-SO321	619963	1910507	35	149	670	652	18.00	0.58				0.172									
TNTC-SO383	619869	1911170	46	150	679	654	24.66	0.70							0.662						

Table 4

Soil Sample Locations and Analytical Data for Nitroaromatic Compound (2,4,6-TNT)
PRRWP Area, Former Plum Brook Ordnance Works, Sandusky, Ohio

Location ID	Northing	Easting	Model Grid Column #	Model Grid Row #	Ground Elevation (feet msl)	Ground-Water Elevation (feet msl) Estimated	Depth to Ground Water (feet) Estimated	VLEACH Longitudinal Dispersivity (feet)	Projected Depth of Excavation (feet)	Residual Excavation Concentration (mg/kg)	Sample Depth (feet below ground surface) and Concentrations (mg/kg)												Comments
											0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	
PR-S1	625010	1918890	140	66	634	631	5.00	0.12					0.3										
PR-S13	625063	1919318	143	73	634	631	10.00	0.41								0.5							
PR-S14	624889	1919309	143	70	634	631	10.00	0.41	**4-5**	**1440**				12000		340							
PR-S22	625103	1919222	143	66	632	629	6.00	0.24			0.74												same as SB16
PRRP-DP02	625232	1918802	139	64	634	631	10.00	0.41											0.38				
PRRP-DP11	624841	1919355	144	71	634	630	12.00	0.46					1.4								0.23		
PR-new-1	624880	1919399	144	70	634	631	10.00	0.41	**4-5**	**121**													
PR-new-2	624942	1919278	144	69	634	631	6.00	0.24	**4-5**	**24.8**													same cell as DP23
PR-new-3	624942	1919278	143	69	634	631	6.00	0.24	**4-5**	**19.3**													same cell as ITSB14

Table 5

Soil Sample Locations and Analytical Data for Nitroaromatic Compound (2,4,6-TNT)
WARWP Area, Former Plum Brook Ordnance Works, Sandusky, Ohio

Location ID	Northing	Easting	Model Grid Column #	Model Grid Row #	Ground Elevation	Ground-Water Elevation	Depth to Ground Water	VLEACH Longitudinal Dispersivity	Sample Depth (feet below ground surface) and Concentrations (mg/kg)										Comments
					(feet msl)	(feet msl)	(feet)	(feet)	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	
						Estimated	Estimated												
PB-WA-S5	622251	1909944	25	112	633	630	5.00	0.12			0.3								
PB-WA-S10	622125	1910177	29	114	633	630	5.00	0.12				0.4							
PB-WA-S14	622135	1910554	35	114	631	628	5.00	0.12			0.3								
PB-WA-S17	622418	1910299	31	110	633	630	10.00	0.41						3					same as S24
SB12	622306	1910340	32	111	633	630	3.00	0.02	0.68										
DP09	622547	1909995	26	107	639	635	12.00	0.46					1						
DP10	622147	1910023	26	111	635	632	6.00	0.24					0.38						

Table 6

Soil Sample Locations and Analytical Data for Nitroaromatic Compound (2,4-DNT)
TNT Area A, Former Plum Brook Ordnance Works, Sandusky, Ohio

Location ID	Northing	Easting	Model Grid Column #	Model Grid Row #	Ground Elevation	Ground-Water Elevation	Depth to Ground Water	VLEACH Longitudinal Dispersivity	Sample Depth (feet below ground surface) and Concentrations (mg/kg)										Comments
					(feet msl)	(feet msl)	(feet)	(feet)	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	
						Estimated	Estimated												
TNTA-S1	624546.78	1923782.88	194	75	632	629	5.00	0.12	4.9		4.8								
TNTA-S15	623337.00	1922879.24	179	95	650	636	14.00	0.50	1.5										same location as S16, 19, SO033, 034
TNTA-S17	623260.22	1922852.32	179	96	650	637	13.00	0.48	0.5										
TNTA-S20	623141.302	1922676.45	176	98	653.02	637	16.02	0.54	0.73		2.7		0.0555						same location as SO016, 017, 021, 022, 201, 238, 241, 242, 311, 379
TNTA-S21	622833.49	1922880.53	179	103	658	642	16.00	0.54		3.68									same location as S001, 003, 297, 300, 349, 377
TNTA-S22	622792.55	1922874.24	179	104	659.1	644.9	14.20	0.50	45										same location as SO299
TNTA-S23	622799.59	1922908.42	180	103	658	642	16.00	0.54		0.2									same location as S298
TNTA-S25	622467.459	1923363.163	187	109	653.5	646	7.50	0.35	0.6	**299**	**976.5**								same as 061, 068, 069, 160, 161, 275-280, 356, 357, 359, 385
TNTA-S29	623296.93	1922840.13	178	95	645	636	9.00	0.39	2.7										
TNTA-S30	622479.24	1923301.21	186	109	654	646	8.00	0.36		0.7									same as S24, SO066, 067, 272
TNTA-S32	624571.08	1923586.67	191	75	634	631	3.00	0.02	0.3										
TNTA-SO012	622905.612	1923104.883	183	102	660.14	630	30.14	0.78	257		8912								same as SO066, 248, 249, 387
TNTA-SO013	622923.95	1923122.61	183	101	660.1	640	20.10	0.62		0.13									same location as S250
TNTA-SO014	622914.56	1923140.27	184	102	660.5	640	20.50	0.63		0.43									same as SO014, 015, 245
TNTA-SO018	623183.98	1922683.72	176	97	650	637	13.00	0.48	1.23	0.275									same as SO018, 233, 234, 235
TNTA-SO020	623148.41	1922693.96	220	76	638	630	8.00	0.36					0.64						same as SO403, 404
TNTA-SO031	623268.94	1922822.14	178	96	646	637	9.00	0.39	0.079										
TNTA-SO035	623313.775	1922906.958	180	95	651.24	635	16.24	0.55	0.194	1.08									same as 327-330, 350
TNTA-SO040	623323.211	1923085.764	183	95	654.48	635	19.48	0.61			20.4		1.08						same as 292, 375, 376
TNTA-SO047	623484.78	1923487.92	189	92	651	635	16.00	0.54			0.11								same as 53, 391
TNTA-SO051	623509.89	1923526.96	190	92	651	635	16.00	0.54			0.241								same as 54,
TNTA-SO052	623546.68	1923489.74	189	91	651	635	16.00	0.54	0.172		0.189								same as 320
TNTA-SO053	623519.19	1923481.41	189	92	651	635	16.00	0.54			0.11								
TNTA-SO059	623015.11	1922916.81	180	100	658.6	640	18.60	0.59	0.086	0.341									same location as S321
TNTA-SO062	623115.683	1923300.046	186	98	659.29	638	21.29	0.64					3.53		30.9		59		same as 389, 390
TNTA-SO071	622390.07	1923341.36	187	110	653.8	647	6.80	0.33	0.217										
TNTA-SO077	623958.052	1922855.83	179	85	636.18	633	3.18	0.02		0.344									same location as SO218
TNTA-SO078	623403.09	1922580.67	174	94	639	635	4.00	0.05	4.59										same location as SO224
TNTA-SO080	623441.95	1922581.90	174	93	636.69	633	3.69	0.04	130										
TNTA-SO081	623448.734	1922606.772	175	93	636.74	633	3.74	0.04			2.825								same location as SO081, 087, 225, 226, 310, 353, 383
TNTA-SO082	623400.82	1922606.09	175	94	639	635	4.00	0.05		0.106									same location as SO083, 232
TNTA-SO094	623220.827	1924922.54	214	97	653.42	637	16.42	0.55			0.072		51.5		38.1				same as 397, 398
TNTA-SO095	623223.18	1924901.13	213	97	653	643	10.00	0.41		0.373									
TNTA-SO097	623236.85	1924923.89	214	96	653	643	10.00	0.41			0.147								
TNTA-SO098	623237.67	1924901.83	213	96	653	643	10.00	0.41		0.825									
TNTA-SO103	623727.19	1925141.42	217	89	651	635	16.00	0.54	2.105	2.895	0.59								same as 284, 315, 416, 484
TNTA-SO104	623725.64	1925161.07	218	89	649.2	633	16.20	0.55	0.072		0.192								same as 417
TNTA-SO105	623762.93	1925105.48	217	88	649.35	637	12.35	0.47		0.228			344.5						same as 281, 283, 367, 368
TNTA-SO106	623734.07	1925073.67	216	88	650	637	13.00	0.48		4.07	1.25								same as 107, 288, 414
TNTA-SO109	623911.70	1924945.61	214	86	653.28	635	18.28	0.59		0.62	0.37		6				0.085		same as 111, 361
TNTA-SO110	623928.88	1924935.28	214	85	653	633	20.00	0.62	1.325		0.377								same as 305, 406
TNTA-SO114	624016.53	1924685.86	210	84	653.2	635	18.20	0.58					0.147						
TNTA-SO116	623947.19	1924687.243	210	85	653.2	635	18.20	0.58			13.85		0.54						same as 303
TNTA-SO121	624299.828	1925060.15	216	79	650	632	18.00	0.58					0.062				0.087		same as 365, 366
TNTA-SO123	624157.941	1925235.974	219	82	655.62	632	23.62	0.68	0.267	0.278	0.07	0.134							same as 124, 125, 254, 323, 407
TNTA-SO126	624168.25	1925258.04	219	81	654.65	632	22.65	0.66	7.78	432.5		2.11	0.275				0.108		same as 127, 128, 253, 255, 259, 324, 325, 363, 364, 408, 409
TNTA-SO129	624155.57	1925285.62	220	82	655	632	23.00	0.67		0.072	0.063								same as 130

Table 6

Soil Sample Locations and Analytical Data for Nitroaromatic Compound (2,4-DNT)
TNT Area A, Former Plum Brook Ordnance Works, Sandusky, Ohio

Location ID	Northing	Easting	Model Grid Column #	Model Grid Row #	Ground Elevation	Ground-Water Elevation	Depth to Ground Water	VLEACH Longitudinal Dispersivity	Sample Depth (feet below ground surface) and Concentrations (mg/kg)										Comments
TNTA-SO148	624523.77	1923826.59	195	76	632	629	3.00	0.02	0.158										
TNTA-SO164	624137.24	1924430.92	205	82	650	633	17.00	0.56	0.24										same as 166, 167
TNTA-SO203	624335.77	1924183.965	201	79	639	631	8.00	0.36	0.665		0.383								same as 205, 261, 267, 268, 269, 418, 419
TNTA-SO207	624285.52	1924181.81	201	80	639	631	8.00	0.36		0.14									same as 208, 269
TNTA-SO212	624306.956	1924253.582	202	79	639	631	8.00	0.36		0.045	0.67								same as 213, 263, 372, 420-422
TNTA-SO218	623949.18	1922852.57	179	85	636	633	3.00	0.02		0.052									
TNTA-SO222	623442.50	1922568.62	174	93	639	635	10.00	0.41			0.451								same as 308, 332, 384
TNTA-SO243	622929.04	1923171.04	184	101	660	644	16.00	0.54			0.229								
TNTA-SO264	624304.74	1924286.02	203	79	639	630	9.00	0.39		0.336									
TNTA-SO285	623711.26	1925072.59	216	89	650	639	11.00	0.43		2.67	1.01								same location as S415, 482
TNTA-SO291	623338.10	1923073.72	182	95	651	635	16.00	0.54			0.162								same as 296
TNTA-SO304	623959.48	1924675.87	209	85	653.3	633	20.30	0.62			0.07								
TNTA-SO348	623463.94	1923274.69	186	93	651	635	16.00	0.54				0.469							
TNTA-SO355	622501.11	1923302.48	186	108	655	650	5.00	0.12		0.7									same as 271
TNTA-SO358	622469.01	1923384.81	188	109	655	650	5.00	0.12		0.235									
TNTA-SO399	623733.757	1924757.501	211	88	655	635	20.00	0.62									0.77		
TNTA-SO413	623742.26	1925036.05	215	88	650	637	13.00	0.48		0.077									
TNTA-SO422	624319.86	1924257.13	202	79	639	633	6.00	0.24		0.045									

Table 7

Soil Sample Locations and Analytical Data for Nitroaromatic Compound (2,4-DNT)
TNT Area B, Former Plum Brook Ordnance Works, Sandusky, Ohio

Location ID	Northing	Easting	Model Grid Column #	Model Grid Row #	Ground Elevation (feet msl)	Ground-Water Elevation (feet msl)	Depth to Ground Water (feet)	VLEACH Longitudinal Dispersivity (feet)	Building #	Depth of Excavation (feet)	Residual Excavation Concentration (mg/kg)	Sample Depth (feet below ground surface) and Concentrations (mg/kg)										Comments
												0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	
						Estimated	Estimated															
PB-TNTB-S1	1910376.77	619640.18	124	169	660.9	657	3.90	0.05	**417**	**1.5**	**ND**	12										same as SS050, 51, and 52
PB-TNTB-S2/S3	618668.093	1917758.516	125	170	662.5	657	5.50	0.17	**417**	**1.5**	**ND**	1.6	2.7									same as S4, SS054
PB-TNTB-S4	1911507.23	621486.31	124	170	663	657	6.00	0.24	**417**	**1.5**	**ND**	5	8.8									same as SS048, SS048,049, 242, 243and 284
PB-TNTB-S5/S6	618177.97	1918057.696	130	178	668.95	662	6.95	0.33	**466**	**4.5**	**ND**		1.5	51								same as S6, SS003,004, 073, 076, 077, 078, 079 and 376
PB-TNTB-S7	618162.81	1918117.29	131	178	669.09	662	7.09	0.34	**466**	**4.5**	**ND**		1.9	910								same as SS074, and 309
PB-TNTB-S9	618361.375	1918588.018	265	219	670	662	8.00	0.36	**456**	**4**	**ND**	6.9	2.3									same as SS031, SS173,182, 213, 216, 219, and 220
PB-TNTB-S10	618323.003	1918633.085	138	175	669	662	7.00	0.33	**456**	**4**	**ND**			0.9								same as S11, SO05,SO09, 14, 24, 27, 28, SS174-176, 210, 211, 212, 215, 217, 221,
																						222, 224-226, 293-295 326, 337, 374, 376, and 378
PB-TNTB-S17	618134.966	1918883.284	140	178	676.1	662	14.10	0.50	**453**	**8.5**	**ND**	390				2200						same as SO06, SS268, and 379
PB-TNTB-S18	623120.55	1922698.72	176	98	653.02	637	16.02	0.54	**452**	**10**	**ND**	810										same location as S13, S18, S19, S28, SO016, 017, 021, 022, 154, 155, 201,
																						238, 241, 242, 262, 263, 265, 266, 300, 311, 379, 380
PB-TNTB-S23	617836.12	1918780.745	139	183	676.89	663	13.89	0.50				1.1										same as S21, S22, SS139, 270, and SS384
PB-TNTB-S24	617129.71	1918386.725	135	194	670	662	8.00	0.36	**412 A**	**6**	**75**	11000										same as S25, and SS387
PB-TNTB-S26	617132.1	1918408.3	136	194	670	662	8.00	0.36	**412 A**	**6**	**75**	7700										
PB-TNTB-SO001	618436.84	1918702.91	138	173	666.8	662	4.80	0.10				0.05										same as SS247 249, 401, and 402
PB-TNTB-SO002	617616.84	1918322.91	134	187	676	664	12.00	0.46							0.27							
PB-TNTB-SO007	618013.84	1917617.91	122	180	681.9	663	18.90	0.60	**473**	**10**	**ND**				5.8							same as SS021, SS022, SO037, SS320, 397
PB-TNTB-SO008	617926.84	1917962.91	128	182	676	662	14.00	0.50	**462**	**8**	**ND**							3.2				same as SS087, 088, 090, 245, 246
PB-TNTB-SO010	618006.84	1917812.91	126	180	676	662	14.00	0.50	**463**	**10**	**240**	0.057								254.5		same as SO11, SO36, SS061, and 389
PB-TNTB-SO012	617919.84	1917462.91	120	180	677.2	663	14.20	0.50	**472**	**5**	**ND**	0.26				4.4						same as SO40, SS017, SS008, 018, 390, 393-395
PB-TNTB-SO013	618053.84	1918676.91	138	180	677.2	663	14.20	0.50	**452**	**10**	**ND**					2400						same as S18, 19, 20, SS151, 153, 154, 155, 258, 262, 263, 265, 266, 300, 375, and 380
PB-TNTB-SO015	618486.84	1917727.91	124	173	665	660	5.00	0.12				0.39										same as SO16, SS057, SS237,238, 239, and 336
PB-TNTB-SO017	618486.84	1917747.91	125	173	665	660	5.00	0.12				0.76										same as SS239
PB-TNTB-SO018	618611.84	1917682.91	124	171	661.1	659	2.10	0.00				0.059										same as SO19, SS047, SS282,and 362
PB-TNTB-SO020	618136.84	1917407.91	119	178	669	662	7.00	0.33	**476**	**3**	**ND**	0.41										SO21, 22, SS038, 235, 236, 310 to 315, 317, 318, 335
PB-TNTB-SO023	618063.84	1918676.91	138	179	680	662	18.00	0.58				1.3										same as SS290, 324, 325
PB-TNTB-SO032	618491.98	1918874.07	140	173	668.17	660	8.17	0.37	**NE Nail House**	**3.5**	**ND**	0.38										same as SS183, 185, 230, and 231
PB-TNTB-SO035	618191.84	1918042.91	130	177	669	661	8.00	0.36	**466**	**7.5**	**ND**	1.6										same as SS069, 071, 232, and 333
PB-TNTB-SO038	617989.84	1917590.91	122	181	681.9	663	18.90	0.60				0.34										
PB-TNTB-SS002	617691.84	1917492.91	120	183	677	663	14.00	0.50				0.11										
PB-TNTB-SS013	617861.84	1917497.91	120	185	678.6	664	14.60	0.51				0.01										
PB-TNTB-SS020	618011.84	1917642.91	123	180	679.5	663	16.50	0.55				0.83										same as SS0021, 388, and 396
PB-TNTB-SS091	617736.84	1917962.91	128	185	677	664	13.00	0.48				6.2										same as SS092, to 095, 247 to 250, and 391
PB-TNTB-SS096	617541.84	1918067.91	130	188	671.3	665	6.30	0.28				2.6										same as SS102 and 106
PB-TNTB-SS098	617521.84	1918097.91	131	188	671.3	665	6.30	0.28				4.8										
PB-TNTB-SS111	617106.84	1918417.91	136	195	672	666	6.00	0.24	**412 B**	**6**	**ND**	9.7										
PB-TNTB-SS114	617116.84	1918352.91	135	195	671	665.5	5.50	0.17	**412 C**	**6**	**9.03**	23										
PB-TNTB-SS278	618438.84	1918272.91	133	173	671.4	660	11.40	0.44				7.6										
TNTB-B463new	618021.80	1917878.30	127	180	676	662	14.00	0.50	**463**	**10**	**7.4**											

Table 8

Soil Sample Locations and Analytical Data for Nitroaromatic Compound (2,4-DNT)
TNT Area C, Former Plum Brook Ordnance Works, Sandusky, Ohio

Location ID	Northing	Easting	Model Grid Column #	Model Grid Row #	Ground Elevation	Ground-Water Elevation	Depth to Ground Water	VLEACH Longitudinal Dispersivity	Sample Depth (feet below ground surface) and Concentrations (mg/kg)										Comments
					(feet msl)	(feet msl)	(feet)	(feet)	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	
TNTC-S8	620601.27	1910719.07	38	139	650	646	4.00	0.05	7.6										
TNTC-S16	620369.35	1911119.67	45	142	655	650	5.00	0.12	1										
TNTC-S22	620249.51	1910712.69	38	144	658	650	8.00	0.36	8.7										same as 240 and 274
TNTC-S26	620297.67	1911324.90	48	144	665	652	13.00	0.48	0.3										
TNTC-SO001	619782.41	1913167.75	79	152	673.30	662	11.30	0.44	4.16				1.825						same as 249, 401, 402
TNTC-SO002	619822.69	1913196.36	80	151	676.50	662	14.50	0.51	0.136										
TNTC-SO005	619822.69	1913140.52	79	151	676.50	662	14.50	0.51	0.152										
TNTC-SO007	619803.31	1912939.39	75	151	676.00	662	14.00	0.50					0.448				0.07		same as 397, 398
TNTC-SO015	619870.60	1912605.63	70	150	676.00	660.5	15.50	0.53		0.184		0.095							same as 277
TNTC-SO016	619896.54	1912638.68	71	150	676.00	660.5	15.50	0.53		0.064	0.32	0.095	0.079						same as 017, 409
TNTC-SO019	619866.76	1912351.82	66	150	681.10	660	21.10	0.64	0.153										
TNTC-SO026	619954.88	1912014.61	60	149	679.00	656.5	22.50	0.66		0.081									same as 030
TNTC-SO036	619926.70	1911773.81	56	150	680.00	655	25.00	0.70	0.073										
TNTC-SO044	619891.53	1910946.89	42	150	675.70	655	20.70	0.63		0.082									same as 048
TNTC-SO046	619839.58	1910943.46	42	151	675.70	655	20.70	0.63		0.061									
TNTC-SO051	619640.18	1910376.77	32	154	676.80	655	21.80	0.65		0.068	0.18								same as 054
TNTC-SO065	619783.62	1910176.12	29	152	668.65	655	13.65	0.49	0.705	0.169	20.4			259.5			22.8		same as 066, 269, 272, 278, 363, 364
TNTC-SO078	620294.11	1910486.34	34	144	655.00	650	5.00	0.12		0.111									
TNTC-SO084	620375.83	1910524.72	35	142	654.06	650	4.06	0.05	0.116										
TNTC-SO085	620236.71	1911076.28	44	144	655.00	651	4.00	0.05		0.096									same as 085, 093, 096
TNTC-SO098	620516.78	1911086.63	44	140	655.00	649	6.00	0.24		0.061									same as 110, 262-264
TNTC-SO107	620480.09	1911093.92	44	141	657.00	648	10.00	0.41						4.45			28.05		same as 108, 123, 261, 379, 380
TNTC-SO120	620303.19	1911567.77	53	143	666.00	652	14.00	0.50		0.151									same as 125
TNTC-SO134	620311.15	1911784.86	56	143	668.23	650	18.23	0.58	0.366		0.645			1.695					same as 135, 331,377
TNTC-SO145	620398.29	1913030.69	77	142	659.00	654.5	4.50	0.08	0.795	0.074									same as 151, 301, 303-305, 325
TNTC-SO146	620389.10	1913056.30	78	142	657.00	654	3.00	0.02	1.135										same as 147, 149, 150, 306, 307, 330
TNTC-SO157	620153.86	1912987.41	76	146	670.90	657.00	13.90	0.50	0.137	0.69			0.091						same as 309-311, 369
TNTC-SO158	620154.55	1913005.60	77	146	670.90	657.00	13.90	0.50		0.105									
TNTC-SO165	620182.46	1913007.90	77	145	668.55	657.00	11.55	0.45	11.05	0.314	0.062						0.097		same as 280, 312-314, 367, 368
TNTC-SO171	620230.93	1912827.40	74	145	666.02	657.00	9.02	0.39					118				23.9		same as 399, 400
TNTC-SO173	620256.00	1912537.08	69	144	666.35	655	11.35	0.44		0.144			0.072				0.412		same as 175, 407, 408
TNTC-SO178	620505.55	1912290.99	65	140	655.00	652	10.00	0.41	1.85		0.353						0.063		same as191, 192, 291-295, 326-328. 333, 374
TNTC-SO186	620501.64	1912394.77	66	140	655.00	652	3.00	0.02		0.096									same as187, 189, 190, 288-290, 295
TNTC-SO200	620564.70	1911808.02	57	129	654.00	649	5.00	0.12	0.078										same as 205
TNTC-SO215	620868.67	1910525.41	35	134	648.00	645	3.00	0.02	0.066										
TNTC-SO218	621419.93	1911523.24	52	125	643.70	638	5.70	0.19				0.474							same as 222, 225, 365, 366
TNTC-SO228	620290.41	1912339.96	65	144	670.00	655	15.00	0.52		493									same as 229, 243, 244, 279, 284
TNTC-SO231	620253.16	1912367.14	66	144	670.00	655	15.00	0.52		320			0.213						same as 241, 283, 284, 285, 286, 320, 405
TNTC-SO235	620091.19	1910654.62	37	147	665.00	651	14.00	0.50		0.505									same as 236
TNTC-SO238	620131.82	1910612.88	37	146	660.00	650	10.00	0.41		0.063									
TNTC-SO281	620223.54	1913087.52	78	145	670.00	665	5.00	0.12	0.433										
TNTC-SO383	619869.44	1911169.52	46	150	678.66	654	24.66	0.70					1.69						

Table 9

Soil Sample Locations and Analytical Data for Nitroaromatic Compound (2,4-DNT)
PRRWP Area, Former Plum Brook Ordnance Works, Sandusky, Ohio

Location ID	Northing	Easting	Model Grid Column #	Model Grid Row #	Ground Elevation (feet msl)	Ground-Water Elevation (feet msl)	Depth to Ground Water (feet)	VLEACH Longitudinal Dispersivity (feet)	Projected Depth of Excavation (feet)	Remaining Conc.	Sample Depth (feet below ground surface) and Concentrations (mg/kg)												Comments
											0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	
PR-S1	625010.23	1918889.63	140	66	634.0	631	5.00	0.12						0.4									
PR-S4			141	68	633.0	630	10.00	0.41				1.1		5.7				2.8					
PR-S6			142	67	632.0	629	10.00	0.41				2.1		8.7				7.6					
PR-S7			142	70	633.0	630	10.00	0.41				0.4		3.4				0.3					
PR-S9			142	65	633.0	630	10.00	0.41				2.4		3.8				2					
PR-S10	624970.66	1919213.16	142	68	633.0	630	10.00	0.41			0.3			2.6				2.2					same as S21
PR-S12	625291.87	1919317.91	143	63	633.0	629	12.00	0.46						1.2				1.6			26		
PR-S13	625062.60	1919317.91	143	73	634.0	631	10.00	0.41						0.4				5.2					
PR-S14	624888.81	1919308.73	143	70	634.0	631	10.00	0.41	**4-5**	**3.71**								19					
PR-S15	625151.05	1919417.99	144	65	633.0	630	10.00	0.41				0.6		0.3				14					
PR-S16	624907.82	1919391.23	144	68	633.0	630	12.00	0.46									8.9		12	15	26		same as DP10
PR-S17	624712.30	1919402.86	144	72	633.0	630	3.00	0.02															
PR-S18	625270.92	1919498.30	64	145	632.0	629	10.00	0.41										1					same as S19
PR-S20	624911.31	1919506.44	145	68	632.0	630	2.00	0.00			19												same as SB18
PR-S22	625103.34	1919222.47	143	66	632.0	629	6.00	0.24			3.2				16								same as SB16
PR-S23	625206.91	1919305.10	143	64	632.0	629	3.00	0.02			1												
PR-S24	625237.17	1919405.19	144	64	632.0	629	3.00	0.02			1.1												
PR-S8	625248.81	1919059.54	142	62	634.0	630	4.00	0.05															
PRRP-DP01	624939.62	1918740.53	139	69	633.0	630	10.00	0.41							0.96				0.29				
PRRP-DP02	625232.21	1918802.48	139	64	633.0	630	10.00	0.41											0.28				
PRRP-DP03	625038.03	1919102.57	141	67	633.0	630	12.00	0.46			1.2				25						0.48		
PRRP-DP06	624951.14	1918911.07	140	69	633.0	630	10.00	0.41												1.1			
PRRP-DP09	625348.26	1919218.20	142	63	633.0	630	6.00	0.24							0.056								
PRRP-DP11	624840.675	1919354.541	144	71	633.0	630	12.00	0.46					1.3		1.6				1.2				
PRRP-DP15	625066.49	1919559.32	145	67	633.0	630	10.00	0.41											0.19				
ITSB-13	624680.51	1919243.51	143	73	634.4	631	3.40	0.03			2.2												
ITSB-14	624942.15	1919278.06	143	69	634.7	631	6.00	0.24	**4-5**	**16.3**	20												
ITSB-17	624790.96	1919170.55	142	71	634.0	631	3.00	0.02			1.1												
PR-new-1	624879.6	1919398.9	144	70	634.00	631	10.00	0.41	**4-5**	**20.2**													
PR-new-2	624942.15	1919278.06	144	69	634.00	631	6.00	0.24	**4-5**	**16.4**													same cell as DP23

Table 10

Soil Sample Locations and Analytical Data for Nitroaromatic Compound (2,4-DNT)
WARWP Area, Former Plum Brook Ordnance Works, Sandusky, Ohio

Location ID	Northing	Easting	Model Grid Column #	Model Grid Row #	Ground Elevation	Ground-Water Elevation	Depth to Ground Water	VLEACH Longitudinal Dispersivity	Sample Depth (feet below ground surface) and Concentrations (mg/kg)											Comments
					(feet msl)	(feet msl)	(feet)	(feet)	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	11-12	
						Estimated	Estimated													same as S21
PB-WA-S5	622250.73	1909943.6	25	112	633	630	5.00	0.12	0.3			1.3								
PB-WA-S6	622244.41	1909722.4	21	112	635	632	3.00	0.02	3											
PB-WA-S10	622124.533	1910176.5	29	114	633	630	5.00	0.12				5.1								
PB-WA-S13	622148.16	1910331.5	32	114	633	630	5.00	0.12				0.6								
PB-WA-S14	622135.14	1910554.4	35	114	631	628	5.00	0.12	0.4			0.3								
PB-WA-S17	622417.97	1910298.6	31	110	633	630	10.00	0.41						3.3						same as S24
PB-WA-S18	622275.08	1910321.4	31	112	633	630	10.00	0.41				0.7		0.3						
PB-WA-S20	622176.6	1910238.6	30	113	633	630	5.00	0.12			0.4									same as S23
DP09	622546.607	1909995.2	26	107	639.02	635	12.00	0.46					0.71				0.49		2.7	
DP10	622147.233	1910023.3	26	111	635	632	6.00	0.24					1.4							
DP11	622016.752	1909999.7	26	116	633	630	3.00	0.02	0.043											
DP13	622543.21	1910216.5	30	108	637.75	634	12.00	0.46					0.29				6.3		6.5	
DP16	622425.108	1910395.1	33	109	633	630	4.00	0.05				0.052								
SB07	622213.1	1909867.6	24	113	635	632	3.00	0.02	0.23											
SB12	622305.8	1910340.4	32	111	633	630	3.00	0.02	0.91											

Table 11

Soil Sample Locations and Analytical Data for Nitroaromatic Compound (2,6,-DNT)
TNT Area A, Former Plum Brook Ordnance Works, Sandusky, Ohio

Location ID	Northing	Easting	Model Grid Column #	Model Grid Row #	Ground Elevation (feet msl)	Ground-Water Elevation (feet msl) Estimated	Depth to Ground Water (feet) Estimated	VLEACH Longitudinal Dispersivity (feet)	Building #	Projected Depth of Excavation (feet) (ft)	Sample Depth (feet below ground surface) and Concentrations (mg/kg)										Comments
											0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	
TNTA-S1	624547	1923783	194	75	632	629	5.00	0.12			4.9										
TNTA-S15	623337	1922879	179	95	650	636	14.00	0.50			1.3										same location as S16, 19, SO033, 034
TNTA-S20	623141	1922676	176	98	653.02	637	16.02	0.54	**142**	**4**	0.73		1.77		0.056						**same location as S13, S18, S19, S28, SO016, 017, 020,021, 022, 154, 155, 201, 238, 241, 242, 262, 263, 265, 266, 300, 311, 379, 380, SO403, 404**
TNTA-S21	622833	1922881	179	103	658	642	16.00	0.54			**1.4**	3.68	1.35		**0.141**						same location as S001, 003, 297, 300, 349, 377
TNTA-S22	622793	1922874	179	104	659.1	644.9	14.20	0.50			47										same location as SO299
TNTA-S23	622800	1922908	180	103	658	642	16.00	0.54			0.4										same location as S298
TNTA-S25	622475	1923331	187	109	653.5	646	7.50	0.35				**299**	**976.5**								same as 061, 068, 069, 160, 161, 275-280, 359, 385
TNTA-S30	622479	1923301	187	110	654	646	8.00	0.36				0.7									same as SO066, 067, 271, 272
TNTA-SO012	622906	1923105	183	102	660.14	630	30.14	0.78	**195**	**7**	5600		**10274**								same as SO066, 248, 249, 387
TNTA-SO013	622924	1923123	183	101	660.1	640	20.10	0.62	**195**	**7**		0.13									same location as S250
TNTA-SO014	622915	1923140	184	102	660.5	640	20.50	0.63	**195**	**7**		0.43									same as SO014, 015, 245
TNTA-SO018	623184	1922684	176	97	650	637	13.00	0.48	**142**	**4**	1.23	0.175									same as SO019, 233, 234, 235
TNTA-SO031	623269	1922822	178	96	646	637	9.00	0.39			0.079										
TNTA-SO035	623314	1922907	180	95	651.24	635	16.24	0.55	**143**	**7**	0.194	1.08									same as 327-330, 350
TNTA-SO040	623323	1923086	183	95	654.48	635	19.48	0.61	**139**	**8**			20.4		**0.054**				**0.153**		same as 292, 375, 376
TNTA-SO047	623485	1923488	189	92	651	635	16.00	0.54					0.11								same as 53, 391
TNTA-SO051	623510	1923527	190	92	651	635	16.00	0.54					0.241								same as 54,
TNTA-SO052	623547	1923490	189	91	651	635	16.00	0.54			0.172		0.189								same as 320
TNTA-SO053	623519	1923481	189	92	651	635	16.00	0.54					0.11								
TNTA-SO059	623015	1922917	180	100	658.6	640	18.60	0.59			0.086	0.341									same location as S321
TNTA-SO062	623116	1923300	186	98	659.29	638	21.29	0.64	**131**	**13**					3.53		30.9		59		same as 389, 390
TNTA-SO071	622390	1923341	187	110	653.8	647	6.80	0.33			0.217										
TNTA-SO077	623958	1922856	179	85	636.18	633	3.18	0.02	**148**	**7**	0.344										same location as SO218
TNTA-SO078	623403	1922581	174	94	639	635	4.00	0.05	**146**	**15**	4.59										same location as SO224
TNTA-SO081	623449	1922607	175	93	636.74	633	3.74	0.04	**146**	**15**			2.825								same location as SO081, 087, 225, 226, 310, 353, 383
TNTA-SO082	623401	1922606	175	94	639	635	4.00	0.05	**146**	**15**		0.106									same location as SO083, 232
TNTA-SO094	623221	1924923	214	97	653.42	637	16.42	0.55	**182**	**7**			0.072		51.5		38.1				same as 397, 398
TNTA-SO095	623223	1924901	213	97	653	643	10.00	0.41	**182**	**7**		0.373									
TNTA-SO097	623237	1924924	214	96	653	643	10.00	0.41	**182**	**7**			0.147								
TNTA-SO098	623238	1924902	213	96	653	643	10.00	0.41	**182**	**7**		0.825									same as 099
TNTA-SO103	623727	1925141	217	89	651	635	16.00	0.54	**119**	**9**	2.105	2.895	0.59								same as 284, 315, 416, 484
TNTA-SO104	623726	1925161	218	89	649.2	633	16.20	0.55	**119**	**9**	0.072		0.192								same as 417
TNTA-SO105	623763	1925105	217	88	649.35	637	12.35	0.47	**119**	**9**		0.228			344.5						same as 281, 283, 367, 368
TNTA-SO106	623734	1925074	216	88	650	637	13.00	0.48	**119**	**9**		4.07	1.25								same as 107, 288, 414
TNTA-SO109	623912	1924946	214	86	653.28	635	18.28	0.59	**111**	**6**		0.62	0.37		6				0.085		same as 111, 361
TNTA-SO110	623929	1924935	214	85	653	633	20.00	0.62	**111**	**6**	1.325		0.377								same as 305, 406
TNTA-SO114	624017	1924686	210	84	653.2	635	18.20	0.58	**129**	**7**					0.147						
TNTA-SO116	623947	1924687	210	85	653.2	635	18.20	0.58					13.85		0.54						same as 303

Table 11

Soil Sample Locations and Analytical Data for Nitroaromatic Compound (2,6,-DNT)
TNT Area A, Former Plum Brook Ordnance Works, Sandusky, Ohio

Location ID	Northing	Easting	Model Grid Column #	Model Grid Row #	Ground Elevation (feet msl)	Ground-Water Elevation (feet msl) Estimated	Depth to Ground Water (feet) Estimated	VLEACH Longitudinal Dispersivity (feet)	Building #	Projected Depth of Excavation (feet) (ft)	Sample Depth (feet below ground surface) and Concentrations (mg/kg)										Comments
											0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	
TNTA-SO121	624300	1925060	216	79	650	632	18.00	0.58							0.062				0.087		same as 365, 366
TNTA-SO123	624158	1925236	219	82	655.62	632	23.62	0.68	**112**	**10**	0.267	0.278	0.07	0.1335							same as 124, 125, 254, 323, 407
TNTA-SO126	624168	1925258	219	81	654.65	632	22.65	0.66	**112**	**10**	7.78	432.5		2.11	0.275				0.108		same as 127, 128, 253, 255, 259, 324, 325, 363, 364, 408, 409
TNTA-SO129	624156	1925286	220	82	655	632	23.00	0.67	**112**	**10**		0.0715	0.0625								same as 130
TNTA-SO148	624524	1923827	195	76	630.5	629	1.50	0.00			0.158										
TNTA-SO164	624137	1924431	205	82	650	633	17.00	0.56			0.24										same as 166, 167
TNTA-SO203	624336	1924184	201	79	639	631	8.00	0.36	**126**	**11**	0.665		0.3825								same as 205, 261, 267, 268, 269, 418, 419
TNTA-SO207	624286	1924182	201	80	639	631	8.00	0.36	**126**	**11**		0.14									same as 208, 269
TNTA-SO212	624307	1924254	202	79	639	631	8.00	0.36	**126**	**11**		0.045	0.67								same as 213, 263, 372, 420-422
TNTA-SO218	623949	1922853	179	85	635	633	2.00	0.00	**148**	**7**		0.052									
TNTA-SO222	623443	1922569	174	93	639	635	10.00	0.41			0.18		2.83						0.147		same location as SO080, 223, 309, 332, 383, 384
TNTA-SO243	622929	1923171	184	101	660	644	16.00	0.54	**195**	**7**			0.229								
TNTA-SO264	624305	1924286	203	79	639	630	9.00	0.39	**126**	**11**			0.336								
TNTA-SO285	623711	1925073	216	89	650	639	11.00	0.43	**119**	**9**		2.67	1.01								same location as S415, 482
TNTA-SO291	623338	1923074	182	95	651	635	16.00	0.54	**139**	**8**		**0.162**									same as 296
TNTA-SO304	623959	1924676	209	85	653.3	633	20.30	0.62	**129**	**7**			0.07								
TNTA-SO309	623442	1922582	209	85	653.3	633	20.30	0.62			0.18										
TNTA-SO348	623464	1923275	186	93	651	635	16.00	0.54	**133**	**6**				0.469							
TNTA-SO355	622501	1923302	186	108	655	650	5.00	0.12				0.7									same as 271
TNTA-SO358	622469	1923385	188	109	655	650	5.00	0.12				0.235									
TNTA-SO399	623734	1924758	211	88	655	635	20.00	0.62											0.77		
TNTA-SO413	623742	1925036	215	88	650	637	13.00	0.48				0.0765									
TNTA-SO422	624320	1924257	202	79	639	633	6.00	0.24				0.045									

Table 12

Soil Sample Locations and Analytical Data for Nitroaromatic Compound (2,6,-DNT)
TNT Area B, Former Plum Brook Ordnance Works, Sandusky, Ohio

Location ID	Northing	Easting	Model Grid Column #	Model Grid Row #	Ground Elevation (feet msl)	Ground-Water Elevation (feet msl) Estimated	Depth to Ground Water (feet) Estimated	VLEACH Longitudinal Dispersivity (feet)	Building #	Depth of Excavation (feet)	Residual Excavation Concentration (mg/kg)	Sample Depth (feet below ground surface) and Concentrations (mg/kg)										Comments
												0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	
PB-TNTB-S1	1910377	619640	124	169	661	657	5.00	0.12	**417**	**1.5**	**ND**	12	5.6									same as SS050, 51, and 52
PB-TNTB-S2/S3	618668	1917759	125	170	663	657	5.50	0.17	**417**	**1.5**	**ND**	1.6	2.7									same as S4, SS054
PB-TNTB-S4	1911507	621486	124	170	663	657	6.00	0.24	**417**	**1.5**	**ND**	5	8.8									same as SS048, SS048,049, 242, 243and 284
PB-TNTB-S5/S6	618178	1918058	130	178	669	662	6.95	0.33	**466**	**4.5**	**ND**		1.5	51								same as S6, SS003,004, 073, 076, 077, 078, 079 and 376
PB-TNTB-S7	618163	1918117	131	178	669	662	7.09	0.34	**466**	**4.5**	**ND**		1.9	910								same as SS074, and 309
PB-TNTB-S9	618361	1918588	137	175	670	662	8.00	0.36				6.9	2.3									same as SS031, SS173,182, 213, 216, 219, and 220
PB-TNTB-S10	618323	1918633	138	175	669	662	7.00	0.33						0.9								same as S11, SO05,SO09, 14, 24, 27, 28, SS174-176, 210, 211, 212, 215, 217, 221, 222, 224-226,
PB-TNTB-S12	618302	1918648	138	176	669	662	7.00	0.33														same as S13, SO029, SS223, 292,nd SS327-329
PB-TNTB-S17	618135	1918883	140	178	676	662	14.10	0.50	**453**	**8.5**	**ND**	390				2200						same as SO06, SS268, and 379
PB-TNTB-S18	623121	1922699	176	98	653	637	16.02	0.54	**452**	**10**	**ND**	230										same location as S13, S18, S19, S28, SO016, 017, 021, 022, 154, 155, 201, 238, 241, 242, 262, 263, 265, 266,
PB-TNTB-S23	617836	1918781	139	183	677	663	13.89	0.50				2.2										same as S21, S22, SS139, 270, and SS384
PB-TNTB-S24	617130	1918387	135	194	670	662	8.00	0.36	**412 A**	**6**	**0.9**	**12000**										same as S25, and SS387
PB-TNTB-S26	617132	1918408	136	194	670	662	8.00	0.36	**412 A**	**6**	**0.9**	8300										same as SS305
PB-TNTB-SO001	618437	1918703	138	173	667	662	4.80	0.10				0.05										same as SS247 249, 401, and 402
PB-TNTB-SO002	617617	1918323	134	187	676	664	12.00	0.46							0.27							
PB-TNTB-SO007	618014	1917618	122	180	682	663	18.90	0.60	**473**	**10**	**ND**				5.8							same as SS021, SS022, SO037, SS320, 397
PB-TNTB-SO008	617927	1917963	128	182	676	662	14.00	0.50	**462**	**8**	**ND**							1				same as SS087, 088, 090, 245, 246
PB-TNTB-SO010	618007	1917813	126	180	676	662	14.00	0.50	**463**	**7.5**	**180**									180		same as SO11, SO36, SS061, and 389
PB-TNTB-SO013	618054	1918677	138	180	677	663	14.20	0.50	**452**	**10**	**ND**					1500						same as S18, 19, 20, SS151, 153, 154, 155, 258, 262, 263, 265, 266, 300, 375, and 380
PB-TNTB-SO015	618487	1917728	124	173	665	660	5.00	0.12				0.093										same as SO16, SS057, SS237,238, and 336
PB-TNTB-SO020	618137	1917408	119	178	669	662	7.00	0.33	**476**	**3**	**ND**	0.044										SO21, 22, SS038, 235, 236, 310 to 315, 317, 318, 335
PB-TNTB-SO035	618192	1918043	130	177	669	661	8.00	0.36	**466**	**7.5**	**ND**	0.28										same as SS069, 071, 232, and 333
PB-TNTB-SS114	617117	1918353	135	195	671	666	5.50	0.17	**412 C**	**6**	**7.44**	7.44										

Table 13

Soil Sample Locations and Analytical Data for Nitroaromatic Compound (2,6,-DNT)
TNT Area C, Former Plum Brook Ordnance Works, Sandusky, Ohio

Location ID	Northing	Easting	Model Grid Column #	Model Grid Row #	Ground Elevation (feet msl)	Ground-Water Elevation (feet msl) Estimated	Depth to Ground Water (feet) Estimated	VLEACH Longitudinal Dispersivity (feet)	Building #	Projected Depth of Excavation (feet)	Sample Depth (feet below ground surface) and Concentrations (mg/kg)										Comments
											0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	
TNTC-S8	620601	1910719	38	139	650	646	4.00	0.05			1.9										
TNTC-S16	620369	1911120	45	142	655	650	5.00	0.12			1										
TNTC-S22	620250	1910713	38	144	658	650	8.00	0.36			1										same as 240 and 274
TNTC-S26	620298	1911325	48	144	665	652	13.00	0.48			0.5										
TNTC-SO001	619782	1913168	79	152	673.30	662	11.30	0.44	**689**	**8**	4.16				1.825						same as 249, 401, 402
TNTC-SO002	619823	1913196	80	151	676.50	662	14.50	0.51			0.136										
TNTC-SO005	619823	1913141	79	151	676.50	662	14.50	0.51			0.152										
TNTC-SO007	619803	1912939	75	151	676.00	662	14.00	0.50							0.448				0.07		same as 397, 398
TNTC-SO015	619871	1912606	70	150	676.00	660.5	15.50	0.53				0.184		0.095							same as 277
TNTC-SO016	619897	1912639	71	150	676.00	660.5	15.50	0.53				0.064	0.32	0.095	0.079						same as 017, 409
TNTC-SO019	619867	1912352	66	150	681.10	660	21.10	0.64			0.153										
TNTC-SO026	619955	1912015	60	149	679.00	656.5	22.50	0.66				0.081									same as 030
TNTC-SO036	619927	1911774	56	150	680.00	655	25.00	0.70			0.073										
TNTC-SO044	619892	1910947	42	150	675.70	655	20.70	0.63				0.082									same as 048
TNTC-SO046	619840	1910943	42	151	675.70	655	20.70	0.63				0.061									
TNTC-SO051	619640	1910377	32	154	676.80	655	21.80	0.65				0.068	0.18								same as 054
TNTC-SO065	619784	1910176	29	152	668.65	655	13.65	0.49	**629**	**10**	0.705	**0.15**	20.4			**159.5**			**228**		same as 066, 269, 272, 278, 363, 364
TNTC-SO078	620294	1910486	34	144	655.00	650	5.00	0.12				0.111									
TNTC-SO084	620376	1910525	35	142	654	650	4.06	0.05			0.116		**0.111**								
TNTC-SO085	620237	1911076	44	144	655	651	4.00	0.05				0.096									same as 085, 093, 096
TNTC-SO098	620517	1911087	44	140	655	649	6.00	0.24	**616**	**8**		0.061									same as 110, 262-264
TNTC-SO107	620480	1911094	44	141	657	648	9.00	0.39	**616**	**8**	**0.93**								**28.05**		same as 108, 123, 261, 379, 380
TNTC-SO120	620303	1911568	53	143	666	652	14.00	0.50	**603**	**8**		0.151				**4.45**			**8.4**		same as 125
TNTC-SO134	620311	1911785	56	143	668	650	18.23	0.58	**602**	**6**	0.366	**0.089**	0.645			1.695					same as 135, 331,377
TNTC-SO145	620398	1913031	77	142	655	655	0.50	0.00	**686**	**4**	0.795	0.074									same as 151, 301, 303-305, 325
TNTC-SO146	620389	1913056	78	142	657	654	3.00	0.02	**686**	**4**	1.135										same as 147, 149, 150, 306, 307, 330
TNTC-SO157	620154	1912987	76	146	671	657	13.90	0.50	**682**	**4**	0.137	0.69			0.091						same as 309-311, 369
TNTC-SO158	620155	1913006	77	146	671	657	13.90	0.50	**682**	**4**		0.105									
TNTC-SO165	620182	1913008	77	145	669	657	11.55	0.45	**682**	**4**	11.05	0.314	0.062						0.097		same as 280, 312-314, 367, 368
TNTC-SO171	620231	1912827	74	145	666	657	10.00	0.41	**683**	**4**					118				23.9		same as 399, 400
TNTC-SO173	620256	1912537	69	144	666	655	11.35	0.44	**693**	**7**		0.144			0.072				0.412		same as 175, 407, 408
TNTC-SO178	620506	1912291	65	140	655	652	10.00	0.41	**696**	**12**	1.85	**0.154**	0.353						0.063		same as191, 192, 291-295, 326-328. 333, 374
TNTC-SO186	620502	1912395	66	140	655	652	3.00	0.02	**696**	**12**		0.096									same as187, 189, 190, 288-290, 295
TNTC-SO200	620565	1911808	57	129	654	649	5.00	0.12			0.078										same as 205
TNTC-SO215	620869	1910525	35	134	648	645	3.00	0.02			0.066										
TNTC-SO218	621420	1911523	52	125	644	638	5.70	0.19						0.474							same as 222, 225, 365, 366
TNTC-SO228	620290	1912340	65	144	670	655	15.00	0.52	**692**	**8**		**493**	**0.07**								**same as 229, 243, 244, 279, 284**
TNTC-SO231	620253	1912367	66	144	670	655	15.00	0.52		**8**	**0.14**	**320**			0.488						same as 241, 283, 285, 286, 320, 405
TNTC-SO235	620091	1910655	37	147	665	651	14.00	0.50				0.067									same as 236
TNTC-SO281	620224	1913088	78	145	670	665	5.00	0.12			0.433										
TNTC-SO383	619869	1911170	46	150	679	654	24.66	0.70							1.69						

Table 14

Soil Sample Locations and Analytical Data for Nitroaromatic Compound (2,6,-DNT)
PRRWP Area, Former Plum Brook Ordnance Works, Sandusky, Ohio

Location ID	Northing	Easting	Model Grid Column #	Model Grid Row #	Ground Elevation	Ground-Water Elevation	Depth to Ground Water	VLEACH Longitudinal Dispersivity	Projected Depth of Excavation	Remaining Conc.	Sample Depth (feet below ground surface) and Concentrations (mg/kg)												Comments
					(feet msl)	(feet msl)	(feet)	(feet)	(feet)		0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	
PR-S4	624996	1919022	141	68	633.00	630	10.00	0.41						0.5									
PR-S6	625099	1919114	142	67	632	629	10.00	0.41				0.4		3.6				0.5					
PR-S7	624894	1919109	142	70	633	630	10.00	0.41						0.4									
PR-S9	625192	1919216	142	65	633	630	3.00	0.02				0.8											
PR-S12	625292	1919318	143	63	633.00	629	12.00	0.46						0.3				0.3					
PR-S13	625063	1919318	143	73	634.00	631	10.00	0.41										0.5					
PR-S14	624889	1919309	143	70	634.00	631	10.00	0.41	**4-5**	**4.88**								2.9					
PR-S15	625151	1919418	144	65	633.00	630.00	10.00	0.41										2					
PR-S16	624908	1919391	144	68	633.00	630.00	12.00	0.46										1					same as DP10
PR-S20	624911	1919506	145	68	633.00	630.00	3.00	0.02			2.7												same as SB18
PR-S22	625103	1919222	143	66	633.00	629	6.00	0.24			0.53				1.5								same as SB16
PRRP-DP01	624940	1918741	139	69	633.00	630.00	10.00	0.41							0.35								
PRRP-DP03	625038	1919103	141	67	633.00	630.00	12.00	0.46							0.58						0.48		
PRRP-DP11	624841	1919355	144	71	633.00	630.00	12.00	0.46					0.57		0.29				0.3		0.25		
PRRP-DP16	624826	1919459	145	71	633.00	630.00	10.00	0.41											0.5				
ITSB-17	624791	1919171	142	71	634.00	631.00	3.00	0.02			0.082												
PR-new-1	624880	1919399	144	70	634.00	631	10.00	0.41	**4-5**	**7.24**													
PR-new-2	624942	1919278	144	69	634.00	631	6.00	0.24	**4-5**	**14.2**													same cell as DP23
PR-new-3	624942	1919278	143	69	634.00	631	6.00	0.24	**4-5**	**ND**													same cell as ITSB14

Table 15

Soil Sample Locations and Analytical Data for Nitroaromatic Compound (2,6,-DNT)
WARWP Area, Former Plum Brook Ordnance Works, Sandusky, Ohio

Location ID	Northing	Easting	Model Grid Column #	Model Grid Row #	Ground Elevation	Ground-Water Elevation	Depth to Ground Water	VLEACH Longitudinal Dispersivity	Sample Depth (feet below ground surface) and Concentrations (mg/kg)											Comments
					(feet msl)	(feet msl)	(feet)	(feet)	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	11-12	
						Estimated	Estimated													
PB-WA-S10	622125	1910177	29	114	633	630	5.00	0.12				0.3								
PB-WA-S17	622418	1910299	31	110	633	630	10.00	0.41						0.3						same as S24
DP09	622547	1909995	26	107	639.02	635	12.00	0.46					0.35						0.27	
DP10	622147	1910023	26	111	635	632	6.00	0.24					1.5							
DP13	622543	1910217	30	108	637.75	634	12.00	0.46											0.64	

APPENDIX B

EVALUATION FOR MONITORED NATURAL ATTENUATION OF NITROAROMATICS IN BEDROCK

APPENDIX B

EVALUATION FOR MONITORED NATURAL ATTENUATION OF NITROAROMATICS IN BEDROCK

Appendix B

Evaluation for Monitored Natural Attenuation of Nitroaromatics in Bedrock Former Plum Brook Ordnance Works Sandusky, Ohio

1.0 Introduction

At the former Plum Brook Ordnance Works (PBOW) in Sandusky, Ohio, 2,4,6-trinitrotoluene (TNT) was manufactured for use in explosives. During the time TNT was produced and stored, the compound infiltrated the groundwater and is now present in the overburden/shale water-bearing zone overlaying the limestone bedrock and, to a lesser extent, the bedrock itself. This memorandum has been developed to support the ongoing groundwater feasibilty study at PBOW.

Only low detections (less than 20 micrograms per liter [µg/L]) of nitroaromatics have been detected in limestone bedrock groundwater. By comparison, samples collected from the limited overburden/shale groundwater have shown concentrations of nitroaromatics exceeding 10,000 µg/L. This seemingly dichotomous distribution can be explained by geologic and hydrogeologic controls governing groundwater movement and contaminant transport as well as natural attenuation. The purpose of this memorandum is to summarize the groundwater quality characteristics and evaluate the potential for nitroaromatic degradation, with the focus on the deep limestone aquifer. The limestone aquifer represents the greatest potential for off-site transport of PBOW contamination.

2.0 Geologic Controls on Contaminant Transport

As noted in the previous section, high levels (>10,000 µg/L) of groundwater contamination are present in the upper overburden/shale. Monitoring wells installed in the deeper shale units and limestone bedrock indicate little or no groundwater contamination. This is evident in a number of site wells installed in both the shale and limestone at TNT Area A (TNTA) (TNTA-BEDGW-001), TNT Area B (TNTB) (TNTB-BEDGW003), and TNT Area C (TNTC) (TNTC-BEDGW-001). The major controlling factor in these areas seems to be the presence of relatively thick (i.e., 30 feet or more) shale. At TNTA, limestone well TNTA-BEDGW001 was completed in an area of very high overburden/shale contamination at Building 146 (Wash House). While

concentrations in the overburden/shale groundwater exceeded 11,000 µg/L, nitroaromatics were not detected in the underlying limestone bedrock groundwater. At this location, the weathered shale/shale unit was in excess of 50 feet thick. Further, hydrogen sulfide and up to 16 feet of free product petroleum were reported in this location. At TNTB, TNTB-BEDGW003 was completed within competent shale immediately downgradient of the bi-tri house (Building 453). While the soil had very high levels of contamination detected, nitroaromatics were not detected in this site well. A similar condition exists at TNTC, although the well, TNTC-BEDGW-001, was completed through the shale into the limestone.

The above conditions of thick, weathered, and competent shale support an interpretation of limited vertical migration at these sites. However, at two of the PBOW sites, the West Area Red Water Pond (WARWP) and the Pentolite Road Red Water Pond (PRRWP), there is known contamination in the limestone bedrock groundwater. At these two sites, the shale unit is thin or nonexistent, resulting in overburden soils resting on top of the limestone. Where the overburden is thin, the transport or leaching of nitroaromatics is by soil matrix desorption and transport of contamination through soil pores and fractures directly into the limestone bedrock groundwater. At BED-MW14 in the WARWP Area, nitroaromatics have been detected in the bedrock at up to 19 µg/L in two sampling events. Although the levels of contamination seem to fluctuate very significantly, with numerous other sampling rounds showing no nitroaromatic contamination, there appears to be some direct communication between the overburden and limestone at this location. The maximum nitroaromatics concentrations in the overburden groundwater at the WARWP Area are 50 times higher than the limestone bedrock concentrations. At the PRRWP Area, a similar situation exists, with limited to no shale present between the overburden and limestone water-bearing zones. At this location, nitroaromatics were detected in groundwater from wells BED-GW15 and BED-GW27. While the concentrations in these two wells are relatively low (maximum detection of 1.6 µg/L), the wells are interpreted to fall on the same groundwater flowpath emanating from the PRRWP Area. The nitroaromatics concentrations in the PRRWP Area overburden groundwater are more than three orders of magnitude higher than those in the limestone bedrock groundwater. It should be noted however, that the nearest downgradient wells are over 1,000 feet from the source area. This distance likely results in greater attenuation, be it from dilution or from degradation.

Based on the above discussion, there are a number of factors that affect contaminant movement at PBOW. The first seems to be the presence of shale and weathered shale across most of the site. The shale weathers to a silty clay that characteristically has a lower hydraulic conductivity and a greater capacity to sorb contaminants. In the deeper limestone at the two red water ponds, low levels (less than 20 µg/L) of contamination are present. While the saturated overburden and

limestone are in direct contact, the concentrations in the lower limestone unit are much lower than those in the overburden. Two scenarios could be responsible or this observation. The first is that there is limited downward migration of contaminants, which then get diluted quickly in the limestone bedrock. The second scenario is that higher levels of contamination may be initially present in the limestone bedrock immediately below the overburden sources, but the naturally reducing conditions in the limestone may be effectively degrading the nitroaromatics. Dilution may contribute further to the relatively low concentrations observed in the limestone bedrock groundwater. The reducing conditions in the limestone bedrock are likely associated with the presence of naturally occurring petroleum.

In this region of northern Ohio, the bedrock often contains naturally occurring hydrocarbons which can provide a carbon source for microbes. Microorganisms in groundwater that have an available carbon source often deplete available oxygen, creating anoxic conditions. Under anaerobic/reducing conditions, TNT can be attenuated by a single microbial pathway, co-metabolic pathways, and abiotic pathways (Esteve-Nunez, et Al., 2001; U.S. Army Corps of Engineers, 1999). This report evaluates the potential for natural attenuation of nitroaromatics, primarily TNT, and its manufacturing precursors and breakdown products in the limestone bedrock water-bearing zone underlying PBOW. Two lines of evidence were examined in this evaluation. The first is contaminant loss and daughter product formation. The second line of evidence includes the groundwater geochemical parameters to determine if groundwater conditions are favorable for the reduction of TNT, its breakdown products, and by-products of the manufacturing process.

3.0 Contaminant Levels

The first line of evidence used to demonstrate the reduction of nitroaromatics by natural attenuation is the evaluation of contaminant loss and daughter product concentrations in monitoring wells. During biotic or abiotic degradation of TNT, nitro groups are reduced to amino groups, creating the aminodinitrotoluene (ADNT) isomers 2-amino-4,6-dinitrotoluene (2-A-4,6-DNT) and 4-amino-2,6- dinitrotoluene (4-A-2,6-DNT). Also, during the production of TNT, nitrobenzenes, nitrotoluenes, 2,4-dinitroluene (2,4-DNT) and 2,6-dinitrotoluene (2,6-DNT) may be formed. The degradation of 2,4-DNT can result in the formation of 2-amino-4 nitrotoluene. The final product of TNT reduction is the formation of triaminotoluene (TAT). This compound absorbs to soil and, therefore, is not detected during groundwater analysis (Downey, et al., 2005).

TNT was detected from December 1994 to October 2001 in 6 of the 22 bedrock wells at PBOW. In five of these six wells, IT-AA2-BEDGW-001, PB-BED-MW16, PB-BED-MW22, PB-BED-MW24, and TNTC-BEDGW-001, TNT was only detected during one sampling event; TNT was detected only in a single field split sample from TNTC-BEDGW-001. In the sixth well, PB-BED-MW15, TNT was detected during three of six nonconsecutive sampling events and ranged from 1.2 to 1.6 μg/L. The limited and sporadic detections of TNT suggest that degradation is occurring, resulting in the removal of the contaminant of concern (COC) from the limestone bedrock groundwater.

2-A-4,6-DNT and 4-A-2,6-DNT are daughter products formed during the reduction of TNT. During sampling events from December 1994 through October 2002, one or both of these compounds were detected in PB-BED-MW13, PB-BED-MW15, PB-BED-MW16, PB-BED-MW17, PB-BED-MW18, PB-BED-MW19, PB-BED-MW27, PB-REACTOR2, TNTA-BEDGW-001, and TNTC-BEDGW-001. With respect to wells PB-BED-MW19 and TNTC-BEDGW-001, an ADNT isomer was detected in only a single field split sample for each. The presence of the ADNT isomers indicates that the reduction of TNT is occurring in the limestone bedrock groundwater at PBOW. Similar to the trends observed for TNT, the detections of 2-A-4,6-DNT and 4-A-2,6-DNT are limited and sporadic, indicating further degradation of these daughter products in the bedrock environment.

Isomers 2,6-DNT and 2,4-DNT, by-products from the production of TNT, have also been observed throughout PBOW. 2,4-DNT can be reduced to 2-amino-4-nitrotoluene, which was observed in monitoring well PB-BED-MW14 during the December 1994 sampling event at 11 μg/L; note that 2-amino-4-dinitrotoluene was analyzed for only in the samples collected during December 1994. The presence of 2-amino-4-dinitrotoluene indicates the presence of degradation of the DNTs at PB-BEDGW-14 in 1994. This limited data suggests that degradation of the DNT isomers and their daughter products is also occurring.

4.0 Geochemical Parameters

The second line of evidence examines changes in geochemical parameters that directly correlate to groundwater conditions that influence the reduction of nitroaromatics. As TNT is reduced, the electron-donating character of amino constituents weakens the electron deficiency originally present in TNT (Downey, et al., 2005). Therefore, reaction rates for anaerobic reduction decrease with the number of nitro groups being converted into amino groups. Consequently, the complete abiotic reduction of TNT into TAT requires reducing conditions which occur at

oxidation reduction potential (ORP) levels less than -200 millivolts (mV) (Esteve, et al., 2001). Similarly, highly reducing conditions favor the degradation of the other nitroaromatic compounds detected in site groundwater. To determine if the groundwater conditions are favorable for the anaerobic biological or abiotic reduction of nitroaromatics, geochemical parameters that directly correlate to microbial activity are evaluated. Field and biodegradation parameters, dissolved oxygen (DO), ORP, pH, temperature, nitrate, sulfate, and total organic carbon (TOC) were collected from limestone bedrock monitoring wells during various sampling events.

Anaerobic DO levels (less than 1 milligram per liter [mg/L]) are favorable for the reduction of nitroaromatics. The DO values at PBOW were artificially elevated during many of the sampling events due to the use of bailers to collect groundwater. Therefore, some of the DO data could not to be used for this evaluation. Using the limited valid DO values associated with the main sources (TNTA, TNTB, PRRWP Area, and WARWP Area), DO concentrations ranged from the detection limit (0.00 mg/L) to 0.29 mg/L from years 2001 to 2004.

The ORP measures the electro-potential in the groundwater. As discussed previously, the ORP required for abiotic reduction of TNT to TAT is below -200 mV. ORP values were collected in eight limestone bedrock wells from December 1994 to April 2002. At each well, the ORP values were at or below 0.0 mV, which is favorable for the biodegradation of TNT. In four of the eight wells, PB-BED-MW17, PB-BED-MW18, PB-BED-MW19, and PB-BED-MW24, ORP levels ranged from -297.6 to -358.4 mV. The ORP data suggest that conditions are reducing and favorable for the biotic and abiotic reduction of nitroaromatics in the limestone bedrock water-bearing zone at PBOW.

Following DO, nitrate is the primary competing electron acceptor during the biological reduction of nitroaromatics. Once nitrate is consumed, TNT becomes the primary nitrogen source for microorganisms present in groundwater (Boopathy, et al., 1992). Elevated nitrate concentrations were observed in only one well, PB-BED-MW14, at up to 79.3 mg/L (April 2002). In December 1994, monitoring wells PB-BED-MW15, PB-BED-MW17, PB-BED-MW18, and PB-BED-MW19 were sampled, and low levels of nitrate were observed from 0.0005 to 0.2 mg/L. These data suggest that nitrate has been consumed and is not a competing electron donor, leaving TNT as the sole nitrogen source.

Sulfate levels were observed in wells from TNTA, TNTC, the PRRWP Area, and the WARWP Area. The sulfate concentrations ranged from 5.0 mg/L at PB-BED-MW13 to 1030 mg/L at TNTC-BEDGW-001 between December 1994 and April 2002. The elevated sulfate

concentrations observed throughout the site may inhibit some abiotic degradation of the COCs. Nevertheless, sulfate reduction occurs at -220 mV (Air Force Center for Environmental Excellence, 1995) which is below the value required for biodegradation and near that of abiotic degradation of TNT. In addition, several limestone bedrock wells exhibited elevated levels of hydrogen sulfide (H_2S), which is one of the sulfate breakdown products. The presence of H_2S, especially at elevated levels, indicates that biological sulfate reduction is an active process in the limestone bedrock groundwater at PBOW.

TOC levels indicate the amount of carbon that may be available to microorganisms. TOC concentrations at PBOW have ranged from 2.0 to 160 mg/L during sampling events. These data suggest that sufficient carbon is present at the site for the reduction of nitroaromatics.

The optimal pH range for microbial activities is between 5 and 9 standard units. At PBOW, the pH ranged from 6.64 to 7.7 standard units, between December 1994 and April 2004. These data suggest that the pH is within favorable levels for the reduction of nitroaromatics.

During the collection of soil borings and groundwater sampling at PBOW, hydrocarbons were observed and H_2S fumes were detected. Both H_2S and hydrocarbons as a free product were observed in well TNTA-BEDGW-001 located on the western side of the TNTA Area, in BED-MW23 located northwest of the PRRWP Area, and west of the WARWP Area in BED-MW24 (Table 3-2). At well TNTA-BEDGW-001, thickness of the hydrocarbon has been as great as 16-feet encountered during routine water level measurements. The detection of hydrocarbons indicates that a sufficient amount of carbon is available to support anaerobic activity. Also, the presence of H_2S, formed during anaerobic degradation of sulfate, suggests that anoxic conditions, which support the degradation of nitroaromatics, exist in these areas.

5.0 Summary and Conclusions

Elevated concentrations of nitroaromatics have been detected in overburden/shale at numerous areas across PBOW. However, the limited and sporadic detections of TNT and other nitroaromatic compounds, including TNT daughter products, in the limestone suggest that natural attenuation is occurring in limestone bedrock groundwater at PBOW. This attenuation is particularly evident at the red water ponds, where concentrations in the overburden are up to three orders of magnitude higher than those in the limestone. Within a few hundred feet downgradient of the WARWP, concentrations of nitroaromatics drop from greater than 900 µg/L in the overburden to less than 20 µg/L in the limestone bedrock groundwater. At the PRRWP

Area, concentrations again drop from greater than 6,000 µg/L in the overburden to less than 2 µg/L at wells located 1,000 feet downgradient.

In addition to the observed changes in contaminant levels, the geochemical groundwater parameters indicate that conditions favorable to degrade nitroaromatics exist in the bedrock groundwater bearing zone. The DO levels were below 1.0 mg/L, which corresponds with low ORP values and low nitrate levels, all suggesting that existing conditions are favorable for the reduction of TNT. The presence of free product hydrocarbons and H_2S suggest that a sufficient amount of carbon is available and anoxic conditions presently exist. Therefore, the presence of degradation products along with favorable groundwater geochemical conditions indicate that natural attenuation of nitroaromatics is occurring in the limestone bedrock groundwater-bearing zone at PBOW. By extension, should nitroaromatic compounds migrate from the overburden into the bedrock, they will likely undergo degradation, provided that the current geochemical conditions persist.

6.0 References

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APPENDIX C

IDENTIFICATION OF CHEMICALS OF CONCERN AND DERIVATION OF REMEDIAL GOAL OPTIONS

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Identification of Chemicals of Concern and Derivation of Remedial Goal Options

1.0 Introduction

Remedial goal options (RGO) have been identified for groundwater contaminants of concern (COC) for TNT Area A (TNTA), TNT Area B (TNTB), and TNT Area C (TNTC), the Pentolite Road Red Water Pond (PRRWP) Area, and the West Area Red Water Ponds (WARWP) Area at the former Plum Brook Ordnance Works (PBOW) (IT Corporation, 2002, 2000a,b; Shaw Environmental, Inc., [Shaw] 2006). This appendix provides the methods for identifying COCs, a description of the RGO value derivations, and the RGO value for each COC. Promulgated values, such as Safe Drinking Water Act maximum contaminant levels (MCL) or State of Ohio groundwater protection standards (Ohio Administrative Code 3745-81-11), were identified only for two of the COCs, nitrate and toluene.

RGOs for the COCs identified for both the limestone bedrock and overburden/shale groundwater RGOs were derived primarily based on the evaluation of the risk assessments performed on the TNT areas, red water pond areas, and the underlying groundwater. The baseline human health risk assessment (BHHRA) of groundwater was performed assuming that bedrock groundwater underlying the TNT and red water pond areas would be used for residential purposes, including drinking and bathing (Shaw, 2006). However, the overburden/shale groundwater in the vicinity of the red water pond and TNT areas is isolated, discontinuous, and seasonally dependent, generally resulting in low and undependable production where it exists. Therefore, this overburden/shale groundwater was identified in the BHHRA as not being a suitable drinking water source in the vicinity of these five areas of concern. For this reason, the U.S. Army Corps of Engineers and Ohio Environmental Protection Agency (OEPA) agreed to quantitatively characterize risks associated with limestone bedrock groundwater in the groundwater BHHRA, but only qualitatively characterize risks associated with overburden/shale groundwater (Shaw, 2006). Because the overburden/shale groundwater was not quantitatively evaluated in the BHHRA, risk-based screening concentrations (RBSC) were used as RGOs for the additional COCs identified only for overburden/shale groundwater (Section 3.2).

2.0 Identification of Contaminants of Concern

Groundwater COCs were identified separately for the limestone bedrock groundwater and the overburden/shale groundwater, and groundwater COCs were identified separately for each of the three TNT areas and the two red water pond areas within these two groundwater zones.

2.1 Limestone Bedrock Groundwater Contaminants of Concern

The limestone COCs were identified based on three general criteria (or a combination thereof): 1) significant contribution to risks and/or hazards in the groundwater BHHRA; 2) chemicals identified as soil COCs that were determined as reasonably likely to leach; and 3) status as an isomer of a groundwater COC that was found to co-occur with its related groundwater COC in soil and/or overburden groundwater. Integral to the BHHRA and COC identification is the assumption that the limestone bedrock groundwater will be used as the primary residential source of water for drinking and other household purposes.

Significant contribution to risks or hazards, listed above as criterion No. 1, is defined as the contribution of a hazard quotient (HQ) of 0.1 or greater to a target organ-specific hazard index (HI) that is greater than 1, or contribution or a chemical-specific lifetime cancer risk of 1E-6 or greater to an overall cancer risk of greater than 1E-5. Where groundwater COCs were identified based partly on their status as soil COCs, potential leachability was implicitly considered.

Limestone bedrock groundwater COCs for each of the five PBOW site areas are provided in Table C-1. Only nitroaromatics (whether identified as explosives or semivolatile organic compounds) or other chemicals identified as site related based on site history, the groundwater BHHRA, and/or the soil BHHRAs were considered for inclusion as COCs. The following subsections discuss in detail the specific basis for identification of each of the limestone bedrock COCs in each site area.

2.1.1 TNTA COCs

Five of the eight TNTA limestone bedrock groundwater COCs were identified based on significant contribution to risks in the groundwater BHHRA. These five are 2,4-dinitrotoluene (2,4-DNT), 2,6-dinitrotoluene (2,6-DNT), 4-amino-2,6-dinitrotoluene (4ADNT), 2-nitrotoluene, and nitrobenzene. Each of the other three TNTA groundwater COCs (2,4,6-trinitrotoluene [TNT], 2-amino-4,6-dinitrotoluene [2ADNT], and 4-nitrotoluene) were also identified as TNTA soil COCs, which played a role in the inclusion of these chemicals as groundwater COCs. Additionally, TNT was added as a groundwater COC because of its prevalence and high

concentrations in TNTA soil, and 2ADNT was added as a groundwater COC because of its prevalence in TNTA soil and association with TNT and 4ADNT. 4-Nitrotoluene was included as a groundwater COC because of its association with 2-nitrotoluene in TNTA soil and groundwater and its relatively similar toxicity to 2-nitrotoluene.

2.1.2 TNTB COCs

All five of the TNTB limestone bedrock groundwater COCs (TNT, 2,4-DNT, 2,6-DNT, 2ADNT, and 4ADNT) were identified as such based on their high soil concentrations and prevalence in TNTB soils. Each of these TNTB limestone bedrock groundwater COCs was also identified as a TNTB soil COC.

2.1.3 TNTC COCs

All five of the TNTC limestone bedrock groundwater COCs (TNT, 2,4-DNT, 2,6-DNT, 2ADNT, and 4ADNT) were identified as such based on their high soil concentrations and prevalence in TNTC soils. Each of these TNTC limestone bedrock groundwater COCs was also identified as a TNTC soil COC.

2.1.4 PRRWP Area COCs

Four of the six limestone bedrock PRRWP Area groundwater COCs were identified based on significant contribution to risks in the groundwater BHHRA. These four are 2,4-DNT, 2,6-DNT, 4ADNT, and nitrobenzene. TNT was selected as a groundwater COC based on its status as a PRRWP soil COC and its prevalence and high concentrations found in PRRWP Area soil. The other groundwater COC, 2ADNT, was selected because of its association with TNT and 4ADNT.

2.1.5 WARWP Area COCs

Five of the six WARWP Area limestone bedrock groundwater COCs were identified based on significant contribution to risks in the groundwater BHHRA. These are 2,4-DNT, nitrobenzene, 4,6-dinitro-2-methylphenol, 3-nitroaniline, and nitrate. The other groundwater COC, 2,6-DNT, was selected because of its association with 2,4-DNT. It is noted that three analytes identified as site-related risk drivers in the groundwater BHHRA are excluded as COCs in the feasibility study. These are cobalt, nickel, and nitrite-nitrate. Cobalt and nickel were excluded because they have no history of use at the TNT manufacturing areas. Also, these were not identified as groundwater or soil COCs at the TNT manufacturing areas; note that the WARWP received wastewater from TNTC during the operational period. Nitrite-nitrate was not included as a COC because the only WARWP bedrock groundwater sample in which the analysis was performed

had a concentration (514 micrograms per liter [µg/L]) that was substantially less than the RGO (10,000 µg/L).

2.2 Overburden/Shale Bedrock Contaminants of Concern

The overburden/shale COCs were selected based on the assumption that wells would be installed into this discontinuous groundwater and that this groundwater would be used as the primary source of drinking water and other household purposes. COC identification for the overburden/shale groundwater was based on the following criteria (or a combination of these): 1) significant contribution to risks and/or hazards as indicted by the exceedance of the RGO developed for limestone groundwater (refer to Section 3.1) or surrogate concentration (Section 3.2); 2) chemicals identified as soil COCs that were determined as reasonably likely to leach to overburden/shale groundwater; and 3) status as an isomer of another overburden/shale groundwater COC that was found to co-occur with its related groundwater COC in soil.

Overburden/shale groundwater COCs for each of the five PBOW site areas are provided in Table C-2. Only nitroaromatics (whether identified as explosives or semivolatile organic compounds) or other chemicals identified as site related based on site history, the groundwater BHHRA, and/or the soil BHHRAs were considered for inclusion as COCs. The following subsections discuss in detail the specific basis for identification of each of the limestone bedrock COCs in each site area.

2.2.1 TNTA COCs

A total of 11 overburden/shale COCs were identified for TNTA. These include each of the eight limestone COCs (2,4-DNT, 2,6-DNT, TNT, 2ADNT, 4ADNT, 2-nitrotoluene, 4-nitrotoluene, and nitrobenzene), each of which had a groundwater concentration that exceeded the respective RGOs. The additional three overburden/shale COCs are 1,3-dinitrobenzene (1,3-DNB), 3-nitrotoluene, and toluene. Each of these three COCs had concentrations that exceeded the overburden/shale RGOs (Section 3.2), and each was determined to be site related based on former TNT manufacturing operations. The toluene concentration exceeded the risk-based screening concentration in only one sample; this sample also exceeded the RGO of 1,000 µg/L (based on the Ohio public drinking water standard). This sample was collected at Building Area 111 (mono house) using direct-push technology. Even though naturally occurring toluene is present regionally in the overburden/shale, the concentrations observed in the background overburden shale were in the low parts per billion range. Therefore, given the elevated concentration of toluene at this location and the past use of toluene for TNT manufacturing, toluene was identified as a COC for TNTA overburden/shale groundwater. The eight TNTA overburden/shale COCs that were identified as limestone bedrock COCs were also identified as

TNTA soil COCs; neither 1,3-DNB, 3-nitrotoluene, nor toluene was identified as a TNTA soil COC (IT Corporation, 2002).

2.2.2 TNTB COCs

Six TNTB overburden/shale COCs were identified. This includes all five of the TNTB limestone bedrock groundwater COCs (TNT, 2,4-DNT, 2,6-DNT, 2ADNT, and 4ADNT) and 1,3-DNB. Each of these COCs exceeded the respective overburden/shale RGOs. Each of these TNTB overburden/shale bedrock groundwater COCs was also identified as a TNTB soil COC, except 1,3-DNB.

2.2.3 TNTC COCs

Nine TNTC overburden/shale COCs were identified. These include all five of the TNTB limestone bedrock groundwater COCs (TNT, 2,4-DNT, 2,6-DNT, 2ADNT, and 4ADNT) and 1,3-DNB, 2-nitrotoluene, 3-nitrotoluene, and 4-nitrotoluene. Each of these COCs exceeded the respective overburden/shale RGOs. The five which are limestone COCs are also TNTC soil COCs. Neither 1,3-DNB nor any of the three nitrotoluene isomers are TNTC soil COCs.

2.2.4 PRRWP Area COCs

A total of 15 COCs were identified as PRRWP Area overburden/shale COCs. This includes all six of the COCs that were identified as PRRWP Area bedrock groundwater COCs (TNT, 2,4-DNT, 2,6-DNT, 2ADNT, 4ADNT, and nitrobenzene) and the following nine chemicals: 1,2,3-trinitrobenzene (1,3,5-TNB), 1,3-DNB, 2,4-dinitrophenol, 3-nitroaniline, 4,6-dinitro-2-methylphenol, 4-nitrophenol, dibenzofuran, fluorene, and nitrate. Neither TNT nor the ADNT isomers were detected in PRRWP Area overburden/shale groundwater, but these were identified as overburden/shale COCs because TNT is the lone soil COC at the PRRWP Area, and the ADNTs are breakdown products of TNT. The other 12 chemicals were identified as COCs because they had maximum concentrations in the overburden/shale groundwater that exceed RGOs.

4,6-Dinitro-2-methylphenol is an aromatic compound, but based on its structure and use, it may not be site related. This chemical has commonly been used as an herbicide and pesticide, though no use of it at PBOW has been identified. It has been included as a COC because of its high concentration (up to 20,000 µg/L), the fact that it is a nitroaromatic, and the likelihood that any remedial technology used to treat other nitroaromatics COCs would have to factor in the high concentrations of this compound. TNT was selected as a groundwater COC based on its status as a PRRWP Area soil COC and its prevalence and high concentrations found in PRRWP Area soil. The other groundwater COC, 2ADNT was selected because of its association with TNT

and 4ADNT. Although fluorene and dibenzofuran are not known to have been used or generated during TNT manufacturing and are not PRRWP soil COCs, polycyclic aromatic hydrocarbon in general are TNTB soil COCs. The PRRWP received wastewater from TNTB. Nitrate concentrations at concentrations exceeding the RGO were routinely detected in three of the four PRRWP Area wells.

2.2.5 WARWP Area COCs

A total of 13 COCs were identified as WARWP Area overburden/shale COCs. This includes all six which were also identified as limestone bedrock groundwater COCs and the following seven: 1,3,5-TNB, 1,3-DNB, TNT, 2ADNT, 4ADNT, 2,4-dinitrophenol, and 3-nitroaniline. Each of these COCs were detected at concentrations that exceed the RGOs in WARWP Area overburden/shale groundwater except for 2ADNT and 4ADNT. The ADNT isomers were not detected in WARWP overburden/shale groundwater, but are included as COCs because they are degradation products of TNT.

3.0 Derivation of Remedial Goal Options

RGOs were derived specifically for the limestone bedrock groundwater based primarily on risk-based calculations using the groundwater BHHRA (Section 3.1). Because the overburden/shale groundwater was not quantitatively evaluated in the BHHRA (Section 1.0), a different approach was taken for the derivation of overburden/shale RGOs (Section 3.2).

3.1 Limestone Bedrock Groundwater Remedial Goal Options

The limestone bedrock groundwater RGOs were derived such that residential use of groundwater at these levels would not exceed a total target-organ HI of 1 or an incremental lifetime cancer risk (ILCR) of 1E-5. Risk-based remediation concentrations (RBRC), presented in the groundwater BHHRA, were used in the derivation of the RGO values. The RBRCs are essentially chemical-specific risk-based values that have been back-calculated based on the groundwater BHHRA. Although the BHHRA lists a variety of RBRCs, only the residential cancer RBRCs associated with a chemical-specific ILCR of 1E-5 and the residential RBRCs associated with a chemical-specific HQ of 1 are discussed in this appendix.

Because most of the nitroaromatics and related compounds share a common target organ (erythrocyte), additive risk is an issue. Therefore, professional judgment was used in the derivation of RGOs to balance the noncancer hazards, as well as cancer risks, among the COCs to develop a set of RGOs that would serve to minimize any remediation effort and still meet

human health protectiveness criteria. Another consideration in the derivation of RGOs was use of the same values for a given COC across the five areas to best serve in the implementation of an overall remediation and/or monitoring program.

The five TNTB and TNTC COCs are also COCs for TNTA and the PRRWP Area (Table C-1). The RGOs for these five COCs were thus developed such that the same concentrations are used throughout and immediately downgradient of these four areas. Two of the five TNTB and TNTC COCs, 2,4-DNT and 2,6-DNT, are also COCs at the WARWP Area. RGOs were selected for the WARWP Area such that the values for 2,4-DNT and 2,6-DNT, 0.5 µg/L in each case, are the same as for the other four site areas. Also, nitrobenzene is a chemical of potential concern for TNTA, the PRRWP Area, and the WARWP Area. The same RGO for nitrobenzene (0.5 µg/L) was derived for each of these areas. Because the approach was taken to use the same RGO values at multiple PBOW sites, the derivation of RGOs for the COCs in each area also had to consider the ramifications of the RGO values on the other applicable areas. A master list of all the RGOs is provided as Table C-3. Brief discussions of how the RGOs were derived for each specific site area are provided in the following subsections. The residential groundwater use RBRCs discussed in the following paragraphs are presented in the groundwater BHHRA (Shaw, 2006). These RBRCs are based on an HQ of 1 and an ILCR of 1E-5. Table C-4 presents the RBRCs, adjustment factors used to derive the limestone bedrock groundwater RGOs such that risk meet OEPA risk criteria (HI of 1 and ILCR of 1E-5), and the resultant RGOs.

TNTB and TNTC RGOs. The five COCs for TNTB and TNTC (2,4-DNT, 2,6-DNT, TNT, 2ADNT, and 4ADNT) were selected based on soil contamination and/or impact to the overburden groundwater. Because the ILCR exceedance of the OEPA criterion (1E-5) associated with the DNT isomers will result at a much lower exposure concentration than will exceedance of the OEPA noncancer criterion (HI =1), concentrations associated with cancer effects were the starting point for the derivation of the RGOs. The residential cancer RBRC was multiplied by a factor of 0.5 for each of the DNTs. This resulted in an RGO of 0.5 µg/L for each DNT isomer (Table C-3). TNT is the only other carcinogenic COC for TNTB and TNTC; the RGO for TNT was determined primarily based on noncancer effects.

The noncancer-based RGOs were derived by multiplying the respective residential RBRCs (8, 3, and 3 µg/L) by a factor of 0.33 for TNT, 2ADNT, and 4ADNT. This resulted in an overall HI of 0.99 (rounded to 1). This results in respective RGOs for these three compounds of 3, 1, and 1 µg/L. The addition of the HQ values associated with the RGOs for the two DNT isomers (based on cancer effects) would contribute a value of 0.05; the resulting HI (1.0) would round to the OEPA criterion of 1. The noncancer-based RGO for TNT would result in an ILCR of 1E-6.

This would result in an overall ILCR of 1.1E-5 if all COCs were present at their RGOs; this values rounds to the OEPA criterion of 1E-5. Therefore, groundwater with concentrations at the set of RGOs for TNTB and TNTC would meet the OEPA criteria for both cancer risk and noncancer hazard.

TNTA RGOs. The RGOs for the five TNTB and TNTC COCs were also selected for TNTA. In addition, the following three COCs are associated with TNTA: 2-nitrotoluene, 4-nitrotoluene, and nitrobenzene. Of these, the two nitrotoluenes have associated cancer effects. The cancer effects of the two nitrotoluenes are dominant as compared with noncancer effects at the same concentrations. Therefore, a determination was made to multiply the residential noncancer RBRC for 2-nitrotoluene (2.8 µg/L) by a factor of 0.2 and multiply the noncancer RBRC for 4-nitrotoluene (38 µg/L) by a factor of 0.1, resulting in respective RGOs of 0.6 µg/L and 0.1 µg/L (Table C-4). This increases the overall ILCR for the COCs at their respective RGOs to 1.4E-5, assuming that all COCs are present at their RGOs; this meets the OEPA acceptable criterion of 1E-5.

With respect to noncancer effects, the noncancer RBRC for nitrobenzene (1.4 µg/L) was multiplied by a factor of 0.33, just as was done for TNT, 2ADNT, and 4ADNT, resulting in a nitrobenzene RGO of 0.5 µg/L. The cancer-based RGOs for the two nitrotoluene isomers add less than 0.03 to the total combined HI value of 1.4 for these eight COCs at their RGOs. This HI value meets the OEPA criterion of 1. Therefore, the set of RGOs for TNTA meet the OEPA criteria for both cancer risk and noncancer hazard.

PRRWP Area RGOs. The RGOs for the five TNTB and TNTC COCs were also selected for the PRRWP Area. A sixth COC, nitrobenzene, was also identified for the PRRWP Area. Nitrobenzene was also identified for TNTA as described above. Because nitrobenzene is not carcinogenic, the overall ILCR at the PRRWP RGOs is the same (1.0E-5) as at the TNTB and TNTC RGOs.

With respect to noncancer effects, the noncancer RBRC for nitrobenzene was multiplied by a factor of 0.33, just as was done for TNT, 2ADNT, and 4ADNT. This results in an overall HI of 1.3, which meets the OEPA criterion of 1. Therefore, the set of RGOs for the PRRWP Area meet the OEPA criteria for both cancer risk and noncancer hazard.

WARWP Area RGOs. The set of limestone bedrock groundwater COCs for the WARWP Area is substantially different from the other four site areas. Of the six COCs, only the DNT isomers and nitrobenzene are also COCs at any of the other four sites. Three of the WARWP

Area COCs have associated carcinogenic effects; these are 2,4-DNT, 2,6-DNT, and 3-nitroaniline. The cancer effects of 3-nitroaniline occur at a substantially higher concentration than adverse noncancer effects. Therefore, the same RGOs were used for 2,4-DNT and 2,6-DNT at the WARWP Area as were derived for the other four areas, and the focus of deriving the RGOs for the WARWP Area COCs was on noncancer effects.

Five of the six WARWP Area COCs affect the same target organ, the erythrocyte. The sixth COC, 4,6-dinitro-2-methylphenol, does not have specific adverse erythrocyte effects. Therefore, the target effect of 4,6-dinitro-2-methylphenol (cellular respiration) is not regarded as additive with that of the other five COCs. The RBRC (2 µg/L), itself, is selected as the RGO for 4,6-dinitro-2-methylphenol. For nitrobenzene, 3-nitroaniline, and nitrate, the RBRCs (1,4, 5, and 24,919 µg/L, respectively) were initially multiplied by a factor of 0.33, just as was done for nitrobenzene in the TNTB, TNTC, and the PRRWP Area COCs, to derive the RGOs. This resulted in respective values of 0.5, 2, and 8,330 µg/L for nitrobenzene, 3-nitroaniline, and nitrate. The RGO for nitrate was adjusted upward slightly from 8,223 µg/L to 10,000 µg/L (10 milligrams per liter [mg/L]) to match the Ohio public drinking water standard. As mentioned in the discussion of the TNTB and TNTC RGO derivation (Section 3.1), the combined noncancer contribution of the DNT isomers at the cancer-based RGO concentrations is negligible (HI of 0.05). Therefore, at the RGO concentrations, the combined HI value for the five COCs with potential erythrocyte effects at the RGO concentrations is 1.1, which meets the OEPA criterion of 1.

The two DNT isomers and nitrobenzene are the only carcinogenic COCs. The ILCR of nitrobenzene at the noncancer-based RGO is 5E-7, which is regarded as negligible. Because the RGO for each of the DNT isomers is 0.5 times the RBRC, the combined ILCR of the three carcinogenic RBRCs at the respective RGOs is 1.0E-5. This value meets the OEPA criterion of 1E-5.

3.2 Overburden/Shale Groundwater Remedial Goal Options

The limestone bedrock groundwater RGOs were also used as overburden/shale groundwater RGOs for the 11 COCs identified for both limestone bedrock and overburden/shale groundwater. These 11 COCs and corresponding RGOs are shown on the upper portion of Table C-3. Their derivations are described in Section 3.1.

For 9 of the additional 10 groundwater overburden/shale groundwater COCs (bottom portion of Table C-3), the groundwater RBSCs were selected as the RGOs. The RBSCs are conservative concentrations that consider the additive toxic effects of multiple COCs. The RGO for toluene,

the remaining overburden/shale COC, is the Ohio public drinking water standard of 1 mg/L (1,000 µg/L). As mentioned, this COC was detected at a concentration exceeding the RBSC only at one TNTA location, Building Area 111. Based on the RGOs of the COCs detected at that location, and their target organs and associated reference doses, toluene is unlikely to represent a human health threat even if chronically ingested at the RGO, assuming a residential drinking water use.

4.0 Use of Remedial Goal Options

As mentioned in Section 1.0, RGOs are intended for groundwater that may potentially be used as residential tap water, including use for bathing and drinking. The RGOs should not be used as cleanup values for overburden/shale groundwater if it is determined that this groundwater would not provide a suitable source of drinking water, even though it is connected with bedrock groundwater. Such use of these RGO values might falsely identify or exaggerate the need for remedial efforts.

The RGOs are conservatively selected to represent an average concentration of each COC to which a groundwater user may regularly be exposed over a chronic timeframe. Therefore, it is recommended that they be used as action levels to determine whether further action is required. Such action may include further sampling, evaluation, and/or remediation. For noncancer hazards, a chronic time frame would mean at least several years during early childhood, and a time frame for cancer risks is based on a 30-year exposure. Therefore, slight temporary exceedances of the RGO values may not necessarily result in an unacceptable cancer risk or an adverse noncancer health effect. Professional judgment may be used, together with state-of-the-practice risk assessment and toxicology technique, to determine whether or not a given exceedance may be cause for concern. Also, each RGO, except for 4,6-dinitro-2-methylphenol (see Section 3.1 of this appendix), was derived under the assumption that each of the other COCs is present at the RGO concentration. This is highly unlikely ever to be the case. Therefore, it is recommended that the overall risks be considered in the evaluation of any RGO exceedances. For instance, if 2,4-DNT were found to be present at two times the RGO, but no other COC is present, then the OEPA ILCR is not exceeded. Such an exceedance should specifically be monitored to ensure that risks or hazards do not increase to levels that exceed the OEPA criteria.

5.0 References

IT Corporation (IT), 2002, ***TNT Areas A and C, Remedial Investigation, Former Plum Brook Ordnance Works, Volume 2: Human Health Risk Assessment,*** Final, Sandusky, Ohio, November.

IT Corporation (IT), 2000a, ***TNT Area B Remedial Investigation, Former Plum Brook Ordnance Works, Volume 2: Human Health Risk Assessment,*** Final, Sandusky, Ohio, August.

IT Corporation (IT), 2000b, ***Risk Assessment and Direct-Push Investigation of Red Water Pond Areas,*** Former Plum Brook Ordnance Works, Final, Sandusky, Ohio, August.

Shaw Environmental, Inc. (Shaw), 2006, ***Baseline Human Health Risk Assessment of Groundwater***, Final, Former Plum Brook Ordnance Works, September.

Table C-1

Groundwater Contaminants of Concern
Limestone Bedrock Unit
TNT and Red Water Pond Areas
Former Plum Brook Ordnance Works, Sandusky, Ohio

TNT Area A	TNT Area B	TNT Area C	PRRWP Area	WARWP Area
Nitroaromatics	***Nitroaromatics***	***Nitroaromatics***	***Nitroaromatics***	***Nitroaromatics***
2,4,6-Trinitrotoluene	2,4,6-Trinitrotoluene	2,4,6-Trinitrotoluene	2,4,6-Trinitrotoluene	2,4-Dinitrotoluene
2,4-Dinitrotoluene	2,4-Dinitrotoluene	2,4-Dinitrotoluene	2,4-Dinitrotoluene	2,6-Dinitrotoluene
2,6-Dinitrotoluene	2,6-Dinitrotoluene	2,6-Dinitrotoluene	2,6-Dinitrotoluene	Nitrobenzene
2-Amino-4,6-dinitrotoluene	2-Amino-4,6-dinitrotoluene	2-Amino-4,6-dinitrotoluene	2-Amino-4,6-dinitrotoluene	
4-Amino-2,6-dinitrotoluene	4-Amino-2,6-dinitrotoluene	4-Amino-2,6-dinitrotoluene	4-Amino-2,6-dinitrotoluene	***SVOCs***
2-Nitrotoluene			Nitrobenzene	4,6-Dinitro-2-methylphenol
4-Nitrotoluene				3-Nitroaniline
Nitrobenzene				
				Wet Chemistry
				Nitrate

Notes:
SVOCs - Semi-volitale organic compounds
PRRWP - Pentolite Road Red Water Pond
WARWP - West Area Red Water Pond

Table C-2

Groundwater Contaminants of Concern
Overburden/Shale
TNT and Red Water Pond Areas
Former Plum Brook Ordnance Works, Sandusky, Ohio

TNT Area A	TNT Area B	TNT Area C	PRRWP Area	WARWP Area
Nitroaromatics	***Nitroaromatics***	***Nitroaromatics***	***Nitroaromatics***	***Nitroaromatics***
2,4,6-Trinitrotoluene	2,4,6-Trinitrotoluene	2,4,6-Trinitrotoluene	2,4,6-Trinitrotoluene	2,4-Dinitrotoluene
2,4-Dinitrotoluene	2,4-Dinitrotoluene	2,4-Dinitrotoluene	2,4-Dinitrotoluene	2,6-Dinitrotoluene
2,6-Dinitrotoluene	2,6-Dinitrotoluene	2,6-Dinitrotoluene	2,6-Dinitrotoluene	Nitrobenzene
2-Amino-4,6-dinitrotoluene	2-Amino-4,6-dinitrotoluene	2-Amino-4,6-dinitrotoluene	2-Amino-4,6-dinitrotoluene	*1,3,5-Trinitrobenzene*
4-Amino-2,6-dinitrotoluene	4-Amino-2,6-dinitrotoluene	4-Amino-2,6-dinitrotoluene	4-Amino-2,6-dinitrotoluene	*1,3-Dinitrobenzene*
2-Nitrotoluene	*1,3-Dinitrobenzene*	*1,3-Dinitrobenzene*	Nitrobenzene	*2,4,6-Trinitrotoluene*
4-Nitrotoluene		*2-Nitrotoluene*	*1,3,5-Trinitrobenzene*	*2-Amino-4,6-dinitrotoluene*
Nitrobenzene		*3-Nitrotoluene*	*1,3-Dinitrobenzene*	*4-Amino-2,6-dinitrotoluene*
1,3-Dinitrobenzene [a]		*4-Nitrotoluene*		*3-Nitroaniline*
3-Nitrotoluene			***SVOCs***	
			2,4-Dinitrophenol	***SVOCs***
VOCs			*3-Nitroaniline*	4,6-Dinitro-2-methylphenol
Toluene			*4,6-Dinitro-2-methylphenol*	3-Nitroaniline
			4-Nitrophenol	*2,4-Dinitrophenol*
			Dibenzofuran	
			Fluorene	***Wet Chemistry***
				Nitrate
			Wet Chemistry	
			Nitrate	

Notes:
SVOCs - Semi-volitale organic compounds
VOCs - Volatile organic compound
PRRWP - Pentolite Road Red Water Pond
WARWP - West Area Red Water Pond

[a] Analytes shown in italics are chemicals of concern (COCs) for overburden/shale groundwater only. Other chemicals are COCs in both the overburden/shale and limestone bedrock groundwater.

Table C-3

Remedial Goal Options for Bedrock Groundwater
TNT and Red Water Pond Areas
Plum Brook Ordnance Works, Sandusky, Ohio

Chemicals of Concern for Both Limestone Bedrock and Overburden/Shale Groundwater[a]	Remedial Goal Option (µg/L)
2,4,6-Trinitrotoluene	*3*
2,4-Dinitrotoluene	*0.5*
2,6-Dinitrotoluene	*0.5*
2-Amino-4,6-dinitrotoluene	*1*
4-Amino-2,6-dinitrotoluene	*1*
2-Nitrotoluene	*0.6*
4-Nitrotoluene	*4*
Nitrobenzene	*0.5*
4,6-Dinitro-2-methylphenol	2
3-Nitroaniline	2
Nitrate	10,000
Additional Chemicals of Concern for Overburden/Shale Groundwater Only[b]	**Remedial Goal Option (µg/L)**
1,3,5-Trinitrotoluene	109
1,3-Dinitrobenzene	0.4
3-Nitrotoluene	122
2,4-Dinitrophenol	7.3
4,6-Dinitro-2-methylphenol	0.4
4-Nitrophenol	4.9
3-Nitroaniline	1.1
Dibenzofuran	1.2
Fluorene	24
Toluene	1,000

Notes: µg/L = micrograms per liter; RGO = remedial goal option

[a] Remedial Goal Options (RGO) for the limestone bedrock chemicals of concern COC) were derived based on back-calculations from the groundwater risk assessment (Shaw, 2006) as described in Section 3.4 of the text. The RGO for nitrate equals the maximum contaminant level (MCL) for drinking water (EPA, 2006).

[b] RGOs for the additonal overburden/shale groundwater COCs are the risk-based screening concentrations found in the risk assessment (Shaw, 2006). The exception is the toluene RGO which equals the MCL (EPA, 2006).

Sources:

Shaw Environmental, Inc., 2006, *Baseline Human Health Risk Assesment of Groundwater* , Final, Plumbrook Ordnance Works, Sandusky, Ohio, September.

U.S. Environmental Protection Agency (EPA), 2006, *2006 Edition of the* Drinking Water Standards and Health Advisories, Office of Water, August, EPA 822-R-06-013.

Table C-4

Derivation of Remedial Goal Options from Risk-Based Remediation Criteria
TNT and Red Water Pond Areas
Delaware Limestone Bedrock Groundwater
Plum Brook Ordnance Works
Sandusky, Ohio

Chemical of Concern[a]	On-Site Resident RBRCs[b] (µg/L) Cancer: Target Incremental Lifetime Cancer Risk of 1.0E-5	On-Site Resident RBRCs[b] (µg/L) Noncancer: Target Hazard Index of 1[c]	Adjustment Factor Used to Derive RGO[d]	Remedial Goal Option[e] (µg/L)
Explosives				
2,4,6-Trinitrotoluene	22	8	0.33	3
2,4-Dinitrotoluene	1.0	30	0.5	0.5
2,6-Dinitrotoluene	1.0	15	0.5	0.5
2-Nitrotoluene	2.8	151	0.2	0.6
4-Nitrotoluene	38	150	0.1	4
2-Amino-4,6-dinitrotoluene	--	3.1	0.33	1
4-Amino-2,6-dinitrotoluene	--	3.1	0.33	1
Nitrobenzene	--	1.4	0.33	0.5
Semivolatile Organic Compounds				
4,6-Dinitro-2-methylphenol	--	2	1	2
3-Nitroaniline	31	5	0.33	2
Miscellaneous				
Nitrate[f]	--	24,919	0.33	10,000

RBRC = Risk-based remediation concentration; RGO = remedial goal option; µg/L - micrograms per liter
"--" indicates that no cancer and/or noncancer toxicity value is available, at least for the pathways represented by this receptor

[a] Chemicals of concern are identified as those with an incremental lifetime cancer risk greater than 1E-6, or that contribute a noncancer hazard quotient of at least 0.1 to a target organ-specific total hazard index that is greater than 1.

[b] RBRCs are derived by back-calculation, using the baseline human health risk assessment methodologies and assumptions, and the specified target hazard index and incremental lifetime cancer risk values (Shaw, 2006).

[c] For conservativeness, value is based on exposure during childhood.

[d] This is the factor by which the RBRC was multiplied to derive the RGO such that the combined incremental lifetime cancer risk and the hazard index in each site area meet the Ohio Environmental Protection Agency Criteria of 1E-5 and 1, respectively (refer to Section 3.1 of this appendix).

[e] For each COC this is the lesser of the cancer or noncancer RBRC, multiplied by the adjustment factor.

[f] The nitrate RGO was adjusted slightly to equal the Ohio prublic drinking water standard.

Reference: Shaw Environmental, Inc. (Shaw), 2006, *Baseline Human Health Risk Assessment of Groundwater,* Final, Former Plum Brook Ordnance Works, Sandusky, Ohio, September.

APPENDIX D

SAMPLE FEDERAL FACILITY LAND-USE CONTROL RECORD OF DECISION CHECKLIST WITH SUGGESTED LANGUAGE

APPENDIX D

SAMPLE FEDERAL FACILITY LAND-USE CONTROL RECORD OF DECISION CHECKLIST WITH SUGGESTED LANGUAGE

June 2005

SAMPLE FEDERAL FACILITY LAND USE CONTROL ROD CHECKLIST WITH SUGGESTED LANGUAGE[1]

(Navy/Army, DLA RODs, #s 1-9 below and RD/RAWP, #s 10-19 below /Air Force RODs, #s 1-19 below)

Where appropriate, Regions should consider including concepts and provisions in RODs, etc., similar to the samples provided below in order to ensure protective remedies:

_____1. Map/Figure showing boundaries of the land use controls

_____2. Document risk exposure assumptions and reasonably anticipated land uses, as well as any known prohibited uses which might not be obvious based on the reasonably anticipated land uses. (For example, where "unrestricted industrial" use is anticipated, list prohibited uses such as on-site company day-care centers, recreation areas, etc.)

_____3. Describe the risks necessitating the LUCs.

_____4. State the LUC performance objectives. We have had comments on these because several of the objectives have not been clear. The following are some examples of what we have been looking for:

1. Prevent access or use of the groundwater until cleanup levels are met.
2. Maintain the integrity of any current or future remedial or monitoring system such as monitoring wells, impermeable reactive barriers.
3. Maintain the 12 inch vegetative soil layer to limit ecological contact.
4. Prohibit the development and use of property for residential housing, elementary and secondary schools, child care facilities and playgrounds.

_____5. Generally describe the LUC, the logic for its selection and any related deed restrictions/notifications

_____6. Duration language: "Land Use Controls will be maintained until the concentration of hazardous substances in the soil and groundwater are at such levels to allow for unrestricted use and exposure."

_____7. Include language that the [military service] is responsible for implementing, maintaining, reporting on, and enforcing the land use controls. This may be modified to include another party should the site-specific circumstances warrant it.

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[1]While the checklist applies to land use controls, ROD reviews indicated a slight problem with the Declaration language which often states who selected the remedy. Where that language is included, please ensure that the military service and EPA select the remedy.

_____8. Where someone else will or the military service plans that someone else will ultimately be implementing, maintaining, reporting on, and enforcing land use controls, the following language should be included:

"Although the [military service] may later transfer [has transferred] these procedural responsibilities to another party by contract, property transfer agreement, or through other means, the [military service] shall retain ultimate responsibility for remedy integrity."

_____9. [**ONLY INCLUDE IN NON-AF RODS**] Refer to the remedial design (RD) or remedial action work plan (RAWP) for the implementation actions. Because this is a new idea (i.e., including the LUC implementation actions in either or both of these two primary documents), to ensure that the requirement is clear and enforceable, we developed the following language where it makes sense:

> "A LUC Remedial Design will be prepared as the land use component of the Remedial Design. Within 90 days of ROD signature, the [military service] shall prepare and submit to EPA for review and approval a LUC remedial design that shall contain implementation and maintenance actions, including periodic inspections." Another option is to refer to the enforceable schedule in the IAG for the RD or RAWP."

NAVY/ARMY/DLA RD or RAWP CHECKLIST AND AF ROD CHECKLIST CONTINUED

_____10. Commitment by military service to address any situation that may interfere with the effectiveness of LUC:

"Any activity that is inconsistent with the IC objectives or use restrictions, or any other action that may interfere with the effectiveness of the ICs will be addressed by the [military service] as soon as practicable, but in no case will the process be initiated later than___ days [10 days suggested] after the [military service] becomes aware of the breach."

_____11. Commitment by military service to notify EPA of and address any situation that may interfere with the effectiveness of LUC:

"The [military service] will notify EPA and [the state] as soon a practicable but no longer than ten days after discovery of any activity that is inconsistent with the IC objectives or use restrictions, or any other action that may interfere with the effectiveness of the ICs The [military service] will notify EPA and [the state] regarding how the [military service] has addressed or will address the breach within 10 days of sending EPA and [the state] notification of the breach."

_____12. Notification to EPA and the state regarding land use changes:

[For closing base]:[We are seeing in military service RODs language requiring the property transferee to notify EPA and the state prior to notifying the military service about possible land use changes. We have switched that around so that the military service reviews the proposal first. This should save EPA some resources.]

"Prior to seeking approval from the EPA and [the state] the recipient of the property must notify and obtain approval from the [military service] of any proposals for a land use change at a site inconsistent with the use restrictions and assumptions described in this ROD Amendment."

[For active base]:

"The [military service] shall notify EPA and state ____ days [45 days suggested] in advance of any proposed land use changes that are inconsistent with land use control objectives or the selected remedy."

_____13. Notification regarding transfers and federal-to-federal transfers:

"The [military service] will provide notice to EPA and [the state] at least six (6) months prior to any transfer or sale of [OUs at issue] so that EPA and [the state] can be involved in discussions to ensure that appropriate provisions are included in the transfer terms or conveyance documents to maintain effective ICs. If it is not possible for the facility to notify EPA and [the state] at least six months prior to any transfer or sale, then the facility will notify EPA and [the state] as soon as possible but no later than 60 days prior to the transfer or sale of any property subject to ICs. In addition to the land transfer notice and discussion provisions above, the [military service] further agrees to provide EPA and [the state] with similar notice, within the same time frames, as to federal-to-federal transfer of property. The [military service] shall provide a copy of executed deed or transfer assembly to EPA and [the state]."

_____14. Concurrence language: "The [military service] shall not modify or terminate Land Use Controls, implementation actions, or modify land use without approval by EPA and the [state]. The [military service] shall seek prior concurrence before any anticipated action that may disrupt the effectiveness of the LUCs or any action that may alter or negate the need for LUCs."

_____15. Monitoring and reporting language:

"Monitoring of the environmental use restrictions and controls will be conducted annually [or more or less frequently as may be determined to be necessary based upon site activities or conditions] by the [military service]. The monitoring results will be included in a separate report or as a section of another environmental report, if appropriate, and provided to the USEPA and the [the state]. The annual monitoring reports will be used in preparation of the Five Year Review to evaluate the effectiveness of the remedy.

The annual monitoring report, submitted to the regulatory agencies by the [military service], will evaluate the status of the ICs and how any IC deficiencies or inconsistent uses have been addressed. The annual evaluation will address whether the use restrictions and controls referenced above were communicated in the deed(s), whether the owners and state and local agencies were notified of the use restrictions and controls affecting the property, and whether use of the property has conformed with such restrictions and controls."

_____16. A comprehensive list of LUCs. If the description of the LUCs in #5 above is comprehensive, it could substitute for #16's listing of LUCs.

_____17. For active facilities, a description of the internal procedures for implementing the LUCs (e.g., orders, instructions, Base Master Plan) and a commitment by the [military service] to notify EPA in advance of any changes to the internal procedures that would affect the LUCs.

Generally, #s 18 and 19 apply at a BRAC installation, but they may have application elsewhere.

_____18. Other property transfer language:

a. "Deed Restrictions: "Each transfer of fee title from the United States will include a CERCLA 120(h)(3) covenant which will have a description of the residual contamination on the property and the environmental use restrictions, expressly prohibiting activities inconsistent with the performance measure goals and objectives.

The environmental restrictions are included in a section of the CERCLA 120(h)(3) covenant that the United States is required to include in the deed for any property that has had hazardous substances stored for one year or more, known to have been released or disposed of on the property. Each deed will also contain a reservation of access to the property for the [military service], USEPA, and [the State], and their respective officials, agents, employees, contractors, and subcontractors for purposes consistent with the [military service] Installation Restoration Program ("IRP") or the Federal Facility Agreement ("FFA"). The deed will contain appropriate provisions to ensure that the restrictions continue to run with the land and are enforceable by the [military service]."

b. "Lease Restrictions: " During the time between the adoption of this ROD and deeding of the property, equivalent restrictions are being implemented by lease terms, which are no less restrictive than the use restrictions and controls described above, in this ROD. These lease terms shall remain in place until the property is transferred by deed, at which time they will be superceded by the institutional controls described in this ROD."

c. "Notice: "Concurrent with the transfer of fee title from the [military service] to transferee, information regarding the environmental use restrictions and controls will be communicated in writing to the property owners and to appropriate state and local agencies to ensure such agencies can factor such conditions into their oversight and decision-making activities regarding the property."

_____ 19. Ensure that the document adequately describes pre-transfer LUCs, not just post-transfer LUCs.

APPENDIX E

ENGINEERING CALCULATIONS

APPENDIX E

ENGINEERING CALCULATIONS

Table E-1

Average Concentration of Nitroaromatics in Overburden Groundwater
Remedial Alternative GW-3 Target Areas for ISEB
TNT Area A Plume
Plum Brook Ordnance Works
Sandusky, Ohio

Sampling Locations and Corresponding Concentrations (µg/L)

	GW-1 Building 111 Mono House	GW-2 Building 112 Bi-Tri House	GW-3 Building 119 A.F. Rec.	GW-4 Building 116 Wash House	GW-5 Building 146 Wash House	GW-6 Building 126 Wash House	GW-8 Building 131 Mono House	GW-10 Building 185 Nitr. House	DP-21 Building 132 Bi-Tri House	Plume Area Weighted Average
Plume Area (ft2)	4900	0	15000	0	47000	16300	0	4900	0	
Chemical										
TNT		137		157	1125	32,400		50.9	4.1	**6597**
2,4-DNT	957	3.29	385.5		4.7	12.3	15.6	6900	9.5	507
2,6-DNT	377		385.5			12.3	15.3	6900	4.9	473
2-ADNT		16.1		139	295	217			4.3	197
4-ADNT		28.9		201	122	230			3.9	108
Total Dinitroaromatics										**1285**
2-NT	129		2510				115		24	435
3-NT			190					27.8		34
4-NT	86.3		1880				28.6	8.35	3.1	325
Total Mononitroaromatics										**794**
1,3-DNB			0.563		0.529	0.654				0
Nitrobenzene			5.37							1
Toluene	1350									75

Note: Values for TNT and the ADNTs in GW-5 are the geometric means of the combined concentrations of GW-5 and downgradient well location TNT-MW11.

Table E-2

Average Concentration of Nitroaromatics in Overburden Groundwater
Remedial Alternative GW-3 Target Areas for ISEB
TNT Area B
Plum Brook Ordnance Works
Sandusky, Ohio

	Sampling Locations and Estimated Concentrations (µg/L)										Plume Area Weighted Average
	Building 412 SG House	Building 417 WW Disp	Building 452 Bi-Tri House	Building 453 Fort. House	Building 456 Wash House	Building 459 AF Rec. Bldg.	Building 463 Fort. House	Building 466 Wash House	Building 469 AF Rec. Bldg.	Building 472 Bi-Tri House	
Plume Area (ft2)								16400			
Chemical											
TNT		9.3				34.5	5.8			217	**0**
2,4-DNT	13.8	12.7	3.7	2.8	5.1		144	185	5.6		185
2,6-DNT	5.6				5.6		447				0
2-ADNT										40.9	0
4-ADNT										204	0
Total Dinitroaromatics											**185**

* Building 472 (Bi-Tri House) added based on TNTB Remediation Report pit water samples

Table E-3

Average Concentrations of Nitroaromatics in Overburden Groundwater
Remedial Alternative GW-3 Target Areas for ISEB
TNT Area C
Plum Brook Ordnance Works
Sandusky, Ohio

Sampling Locations and Estimated Concentrations (µg/L)

	GW-2 Building 682 Bi-Tri House	GW-4 Building 603 Fort. House	GW-5 Building 616 Wash House	GW-6 Building 692 Bi-Tri House	GW-7 Building 693 Fort. House	GW-8 Building 683 Fort. House	GW-9 Building 681 Mono House	GW-10 Building 611 Mono House	Plume Area Weighted Average
Plume Area (ft2)	10000		16700			4900	4900		
Chemical									
TNT	1880	620	9720			20,100	3.9	9.7	**7661**
2,4-DNT	4610	215	4.8	2.9	6.9	37,600	442	4.05	6372
2,6-DNT	1330	169	4.8	2.3	0.9	1,060	122	3.95	525
2-ADNT		147	34.9	2.88	3.2		40.3	15.1	21
4-ADNT	436	59.4	48	3.27	2.7	419	17.4	21.1	200
Total Dinitroaromatics									**7118**
2-NT	258	4.73			0.791	236	2310	2.61	412
3-NT	16.1					18.4	182		31
4-NT	94.7					189	1290		224
Total Mononitroaromatics									**667**
1,3-DNB	0.802								

Table E-4

Average Concentration of Nitroaromatic Compounds in Overburden Groundwater
Pentolite Road Red Water Pond Area
Remedial Alternative GW-3 Target Areas for ISEB
Plum Brook Ordnance Works
Sandusky, Ohio

Sampling Locations and Estimated Concentrations (µg/L)

	DP-1	DP-3	DP-6	DP-7	DP-8	DP-10	DP-11	DP-12	DP-13	DP-14	DP-15	DP-16	DP-17	DP-18	DP-19	MW-7	MW-8	MW-9	Average
Chemical																			
2,4-DNT	20	9200	31	0.82	2.8	4100	380	2.3	2.4	13	80	35	8.9	2.4	19	1800	2400	120	1012
2,6-DNT	3.3	550	5.1			400						10	1.7			140	190		72
2,4-Dinitrophenol	8.3	5800				5900						22					6000	48	988
4,6-Dinitro-2-methylphenol		2300				1700					830					12000	20000	280	2062
1,3-DNB		4800	10	0.42	1.2	2100	840	1.3	1.6				6.4	1.1		2000	2100	170	668
1,3,5-TNB							600									2800	2400	71	326
Total Dinitroaromatics																			**5128**
4-Nitrophenol		290				210						5				11	42		31
3-Nitroaniline	88																160	450	39
Nitrobenzene																13	14		1.5
Total Mononitroaromatics																			**71**
Dibenzofuran																6.5	620		35
Fluorene																28	44		4
Nitrate		450,000					350,000									190,000	1.0E+06	110,000	116667

Table E-5

Average Concentrations of Nitroaromatics in Overburden Groundwater
Remedial Alternative GW-3 Target Areas for ISEB
West Area Red Water Pond Area
Plum Brook Ordnance Works
Sandusky, Ohio

Sampling Locations and Estimated Concentrations (µg/L)

	DP-4	DP-8	DP-9	DP-11	DP-12	DP-13	DP-15	DP-16	DP-17	IT-MW2	WA-MW2	Average
Chemical												
TNT				7.1								7.1
2,4-DNT		2.3	60	1.8	2	950	1.1	60	52	47	55	111.9
2,6-DNT			6.3			56		15	18	8.9	4.1	9.85
4,6-Dinitro-2-methylphenol			24							12		3.27
2,4-Dintrophenol											7.6	7.6
1,3-DNB		0.74	8.6		0.69	270				19	23	29.28
1,3,5-TNB		9.4	7.2			680		40	32			69.87
Total Dinitroaromatics												**239**
3-NT										36		3.27
Nitrobenzene										2.5	3.7	0.56
3-Nitroaniline	3.2		5.1	2.1		15		43	49	3.3	330	40.97
Total Mononitroaromatics												**45**
Nitrate											62000	5636

Table E-6

Competing Electron Acceptors in Overburden/Weathered Shale Groundwater
Plum Brook Ordnace Works
Sandusky, Ohio

Area	Dissolved O_2[a] (ppm)	Sulfate (mg/L)	Nitrate (mg/L)	Iron (unfiltered) (mg/L)
TNTA	0.97	344	ND	38.8
TNTB	0.97	355	0.042[b]	24.8
TNTC	0.97	718	0.4	6.48
PRRWP	0.97	5263	253/419[c]	21.2
WARWP	0.97	721	12.6/24.7[d]	3.9

Notes:
Results are the average concentrations taken from the groundwater risk assessment, except as noted.
[a] Dissolved oxygen results are from the background wells and two MK-MW17 wells, all of which are screened in the shale and were collected using low-flow.
[b] The nitrate concentration used for TNTB was the single detection (MK-MW16 in 2002) collected among the overburden wells associated with TNTB.
[c] First value indicates the average concentration associated with the overall PRRWP Area; the second value is the average concentration associated with the PRRWP area most highly contaminated with nitroaromatics.
[d] First value indicates the average concentration associated with the overall WARWP Area; the second value is the average concentration associated with the WARWP area most highly contaminated with nitroaromatics.

Soil Bulk Density: 1.7 g/cm3 106.1 lbs/ft3
This value is based on a default of 48.14 kg/ft3 that Song-Kai used.

Fraction of organic carbon: 0.01 (recommended default).

Table E-7

Emulsified Edible Oil Design Software
Remedial Alternative GW-3 Target Areas for ISEB
TNT Area A
Plum Brook Ordnance Works
Sandusky, Ohio

(Page 1 of 2)

EOS Remediation, Inc.

Emulsified Edible Oil Design Software
for EOS® Family of Bioremediation Products

Version 2.06 Rev. Date: November 28, 2006
www.EOSRemediation.com

Help

Site Name:	Plum Brook Ornance Works
Location:	Sandusky, Ohio
Project No.:	GW-3 TNTA

Step 1: Select a Substrate from the EOS® Family of Bioremediation Products

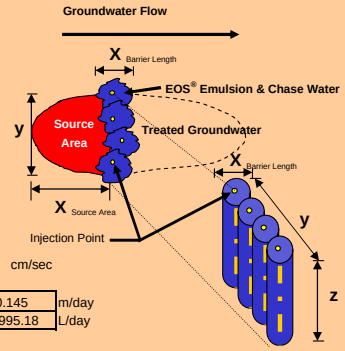
Substrate Selected (pick from drop down list): EOS 400

For Product Literature Click Here

Step 2: EOS® Consumption During Contaminant Biodegradation / Biotransformation

Section A: Treatment Area Dimensions

Length of treatment area parallel to groundwater flow, "x"	10	ft	3.0	m
Width of treatment area perpendicular to groundwater flow, "y"	297	ft	90.5	m
Minimum depth to contamination	8	ft	2.4	m
Maximum depth of contamination	28	ft	8.5	m
Treatment thickness, "z"	20	ft	6.1	m
Treatment zone cross-sectional area = y * z	5,940	ft^2	551.8	m^2



Section B: Groundwater Flow Rate / Site Data

Soil Characteristics

Nominal Soil Type (pick from drop down list)	Enter Site Data			
Hydraulic Characteristics				
Total Porosity (accept default or enter n)	0.35	(decimal)		
Effective Porosity (accept default or enter n_e)	0.20	(decimal)		
Hydraulic Conductivity (accept default or enter K)	10.45	ft/day	3.7E-03	cm/sec
Hydraulic Gradient (accept default or enter i)	9.10E-03	ft/ft		
Non-reactive Transport Velocity (V_x) = K * i / n_e	0.48	ft/day	0.145	m/day
Groundwater flow rate through treatment zone (Q)	4225.18	gallons/day	15995.18	L/day

Section C: Calculated Contact Length (x) = C_t * V_x

Contact time (C_t) between oil and contaminants (accept default or enter C_t)	21	typical values 60 to 180 days, see comment	
Calculated Contact Length (x) = Ct * V_x	10.0	ft	
Treatment zone volume	59,400	ft^3	1,682 m^2
Treatment zone groundwater volume (volume * effective porosity)	88,862	gallons	336,404 L

Section D: Design Lifespan For One Application

	0.058	year(s)	typical values 5 to 10 years	
Estimated total groundwater volume treated over design life	178,310	gallons	675,022	L

Section E: Electron Acceptors

Inputs		Typical Value	GW Conc. (mg/L)	MW (g/mole)	e^- equiv./ mole	Stoichmetry *Contaminant/H_2 (wt/wt H_2)*	Hydrogen Demand *(g H_2)*
Dissolved Oxygen (DO)		0 to 8	1	32.0	4	7.94	85.04752448
Nitrate Nitrogen (NO_3^- - N)		1 to 10		62.0	5	12.30	
Sulfate (SO_4^{2-})		10 to 500	344	96.1	8	11.91	19491.80579
Tetrachloroethene (PCE), C_2Cl_4				165.8	8	20.57	
Trichloroethene (TCE), C_2HCl_3				131.4	6	21.73	
cis-1,2-dichloroethene (c-DCE), $C_2H_2Cl_2$				96.9	4	24.05	
Vinyl Chloride (VC), C_2H_3Cl				62.5	2	31.00	
Carbon tetrachloride, CCl_4				153.8	8	19.08	
Chloroform, $CHCl_3$				119.4	6	19.74	
sym-tetrachloroethane, $C_2H_2Cl_4$				167.8	8	20.82	
1,1,1-Trichloroethane (TCA), CH_3CCl_3				133.4	6	22.06	
1,1-Dichloroethane (DCA), CH_2CHCl_2				99.0	4	24.55	
Chloroethane, C_2H_5Cl				64.9	2	32.18	
Perchlorate, ClO_4^-				99.4	8	12.33	
Hexavalent Chromium, Cr[VI]				52.0	3	17.20	
User added	Trinitrotoluene		6.60	227	18	12.51	356.0622739
User added	Dinitrotoluene & Aminodinitrotoluene		1.29	190	12	15.71	55.43100248
User added	Nitrotoluene		0.79	137	6	22.65	23.53927876

Table E-7

Emulsified Edible Oil Design Software
Remedial Alternative GW-3 Target Areas for ISEB
TNT Area A
Plum Brook Ordnance Works
Sandusky, Ohio

Section F: Additional Hydrogen Demand and Carbon Losses

Generation (Potential Amount Formed)	Typical Value	GW Conc. (mg/L)	MW (g/mole)	e^- equiv./ mole	Stoichmetry *Contaminant / H_2 (wt/wt H_2)*	Hydrogen Demand *(g H_2)*	DOC Released *(moles)*
Estimated Amount of $Fe2^+$ Formed	10 to 100	10	55.8	1	55.41	121.829113	
Estimated Amount of Manganese (Mn^{2+}) Formed		5	54.9	2	27.25	123.8404532	
Estimated Amount of CH_4 Formed	5 to 20	10	16.0	8	1.99	3392.740237	
Target Amount of DOC to Release	60 to 100	100	12.0				5620.03

Calculations assume:
1.) all reactions go to completion during passage through emulsified edible oil treated zone; and,
2.) perfect reaction stoichiometry.

EOS® Requirement Calculations Based on Hydrogen Demand and Carbon Losses

Stoichiometric Hydrogen Demand	52	pounds
DOC Released	321	pounds

EOS® Requirement Based on Hydrogen Demand and Carbon Loss

2 drums

Step 3: EOS® Requirement Based on Oil Entrapment by Aquifer Material

Soil Characteristics

Density of Sediment (accept default or enter site specific value)	106.0	lbs / ft3
Effective Thickness (typically less than 40%)	0.30	
Weight of sediment to be treated	1,888,920	lbs
Adsorptive Capacity of Soil (accept default or enter site specific value)	0.0035	lbs EOS® / lbs sediment

For Additional Information on Effective Thickness, Click Here

Oil Retention by Sediment[1]
- Fine sand with some clay 0.001 to 0.002 lbs EOS® / lbs soil
- Sand with higher silt/clay content 0.002 to 0.004 lbs EOS® / lbs soi

[1]Default values provided based on laboratory studies completed by NCSU

For Additional Data, Click Here

EOS® Requirement Based on Oil Entrapment by Aquifer Material

16 drums

Summary – How much EOS® do you need?

Suggested Quantity of EOS® for Your Project 16 drums

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†Exclusive license agreement with Solutions-IES under U.S. Patent # 6,398,960 and several international patents pending.
††EOS® is a registered trademark of EOS Remediation, Inc.

Table E-8

Emulsified Edible Oil Design Software
Remedial Alternative GW-3 Target Areas for ISEB
TNT Area B
Plum Brook Ordnance Works
Sandusky, Ohio

EOS Remediation, Inc.

Emulsified Edible Oil Design Software
for EOS® Family of Bioremediation Products

Version 2.06 Rev. Date: November 28, 2006
www.EOSRemediation.com

Help

Site Name:	Plum Brook Ornance Works
Location:	Sandusky, Ohio
Project No.:	GW-3 TNTB

Step 1: Select a Substrate from the EOS® Family of Bioremediation Products

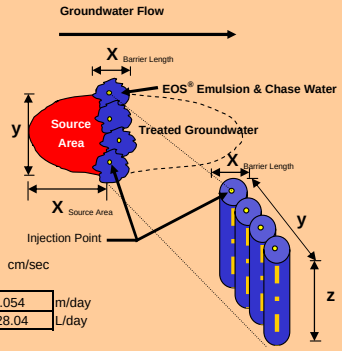
Substrate Selected (pick from drop down list): EOS 400

For Product Literature Click Here

Step 2: EOS® Consumption During Contaminant Biodegradation / Biotransformation

Section A: Treatment Area Dimensions

Length of treatment area parallel to groundwater flow, "x"	10	ft	3.0	m
Width of treatment area perpendicular to groundwater flow, "y"	128	ft	39.0	m
Minimum depth to contamination	5	ft	1.5	m
Maximum depth of contamination	6	ft	1.8	m
Treatment thickness, "z"	1	ft	0.3	m
Treatment zone cross-sectional area = y * z	128	ft^2	11.9	m^2



Section B: Groundwater Flow Rate / Site Data

Soil Characteristics

Nominal Soil Type (pick from drop down list)	Enter Site Data			
Hydraulic Characteristics				
Total Porosity (accept default or enter n)	0.35	(decimal)		
Effective Porosity (accept default or enter n_e)	0.20	(decimal)		
Hydraulic Conductivity (accept default or enter K)	7.85	ft/day	2.8E-03	cm/sec
Hydraulic Gradient (accept default or enter i)	4.50E-03	ft/ft		
Non-reactive Transport Velocity (V_x) = K * i / n_e	0.18	ft/day	0.054	m/day
Groundwater flow rate through treatment zone (Q)	33.82	gallons/day	128.04	L/day

Section C: Calculated Contact Length (x) = C_t * V_x

Contact time (C_t) between oil and contaminants (accept default or enter C_t)	56	typical values 60 to 180 days, see comment
Calculated Contact Length (x) = Ct * V_x	9.9	ft

Treatment zone volume	1,280	ft^3	36	m^2
Treatment zone groundwater volume (volume * effective porosity)	1,915	gallons	7,249	L

Section D: Design Lifespan For One Application	0.153	year(s)	typical values 5 to 10 years	
Estimated total groundwater volume treated over design life	3,804	gallons	14,399	L

Section E: Electron Acceptors

Inputs		Typical Value	GW Conc. (mg/L)	MW (g/mole)	e^- equiv./ mole	Stoichmetry *Contaminant/H_2 (wt/wt H_2)*	Hydrogen Demand (g H_2)
Dissolved Oxygen (DO)		0 to 8	1	32.0	4	7.94	1.814207945
Nitrate Nitrogen (NO_3^- - N)		1 to 10		62.0	5	12.30	
Sulfate (SO_4^{2-})		10 to 500	355	96.1	8	11.91	429.0889925
Tetrachloroethene (PCE), C_2Cl_4				165.8	8	20.57	
Trichloroethene (TCE), C_2HCl_3				131.4	6	21.73	
cis-1,2-dichloroethene (c-DCE), $C_2H_2Cl_2$				96.9	4	24.05	
Vinyl Chloride (VC), C_2H_3Cl				62.5	2	31.00	
Carbon tetrachloride, CCl_4				153.8	8	19.08	
Chloroform, $CHCl_3$				119.4	6	19.74	
sym-tetrachloroethane, $C_2H_2Cl_4$				167.8	8	20.82	
1,1,1-Trichloroethane (TCA), CH_3CCl_3				133.4	6	22.06	
1,1-Dichloroethane (DCA), CH_2CHCl_2				99.0	4	24.55	
Chloroethane, C_2H_5Cl				64.9	2	32.18	
Perchlorate, ClO_4^-				99.4	8	12.33	
Hexavalent Chromium, Cr[VI]				52.0	3	17.20	
User added	Trinitrotoluene			227	18	12.51	
User added	Dinitrotoluene & Aminodinitrotoluene		0.185	190	12	15.71	0.169574341
User added	Nitrotoluene			137	6	22.65	

Table E-8

Emulsified Edible Oil Design Software
Remedial Alternative GW-3 Target Areas for ISEB
TNT Area B
Plum Brook Ordnance Works
Sandusky, Ohio

Section F: Additional Hydrogen Demand and Carbon Losses

Generation (Potential Amount Formed)	Typical Value	GW Conc. (mg/L)	MW (g/mole)	e^- equiv./ mole	Stoichmetry *Contaminant / H_2 (wt/wt H_2)*	Hydrogen Demand *(g H_2)*	DOC Released *(moles)*
Estimated Amount of $Fe2^+$ Formed	10 to 100	10	55.8	1	55.41	2.598821613	
Estimated Amount of Manganese (Mn^{2+}) Formed		5	54.9	2	27.25	2.64172691	
Estimated Amount of CH_4 Formed	5 to 20	10	16.0	8	1.99	72.37290364	
Target Amount of DOC to Release	60 to 100	100	12.0				119.88

Calculations assume:
1.) all reactions go to completion during passage through emulsified edible oil treated zone; and,
2.) perfect reaction stoichiometry.

EOS® Requirement Calculations Based on Hydrogen Demand and Carbon Losses

Stoichiometric Hydrogen Demand	1	pounds
DOC Released	7	pounds

EOS® Requirement Based on Hydrogen Demand and Carbon Loss

1 drums

Step 3: EOS® Requirement Based on Oil Entrapment by Aquifer Material

Soil Characteristics

Density of Sediment (accept default or enter site specific value)	106.0	lbs / ft3
Effective Thickness (typically less than 40%)	0.30	
Weight of sediment to be treated	40,704	lbs
Adsorptive Capacity of Soil (accept default or enter site specific value)	0.0035	lbs EOS® / lbs sediment

For Additional Information on Effective Thickness, Click Here

Oil Retention by Sediment[1]
- Fine sand with some clay 0.001 to 0.002 lbs EOS® / lbs soil
- Sand with higher silt/clay content 0.002 to 0.004 lbs EOS® / lbs soi

[1]Default values provided based on laboratory studies completed by NCSU

For Additional Data, Click Here

EOS® Requirement Based on Oil Entrapment by Aquifer Material

1 drums

Summary – How much EOS® do you need?

Suggested Quantity of EOS® for Your Project 1 drums

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†Exclusive license agreement with Solutions-IES under U.S. Patent # 6,398,960 and several international patents pending.
††EOS® is a registered trademark of EOS Remediation, Inc.

Table E-9

Emulsified Edible Oil Design Software
Remedial Alternative GW-3 Target Areas for ISEB
TNT Area C
Plum Brook Ordnance Works
Sandusky, Ohio

(Page 1 of 2)

EOS Remediation, Inc.

Emulsified Edible Oil Design Software
for EOS® Family of Bioremediation Products

Version 2.06 Rev. Date: November 28, 2006
www.EOSRemediation.com

Help

Site Name:	Plum Brook Ornance Works
Location:	Sandusky, Ohio
Project No.:	GW-3 TNTC

Step 1: Select a Substrate from the EOS® Family of Bioremediation Products

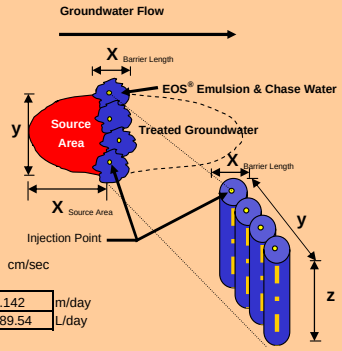
Substrate Selected (pick from drop down list): EOS 400

For Product Literature Click Here

Step 2: EOS® Consumption During Contaminant Biodegradation / Biotransformation

Section A: Treatment Area Dimensions

Length of treatment area parallel to groundwater flow, "x"	10	ft	3.0	m
Width of treatment area perpendicular to groundwater flow, "y"	230	ft	70.1	m
Minimum depth to contamination	6	ft	1.8	m
Maximum depth of contamination	16	ft	4.9	m
Treatment thickness, "z"	10	ft	3.0	m
Treatment zone cross-sectional area = y * z	2,300	ft^2	213.7	m^2



Section B: Groundwater Flow Rate / Site Data

Soil Characteristics

Nominal Soil Type (pick from drop down list)	Enter Site Data			
Hydraulic Characteristics				
Total Porosity (accept default or enter n)	0.35	(decimal)		
Effective Porosity (accept default or enter n_e)	0.20	(decimal)		
Hydraulic Conductivity (accept default or enter K)	8.5	ft/day	3.0E-03	cm/sec
Hydraulic Gradient (accept default or enter i)	1.10E-02	ft/ft		
Non-reactive Transport Velocity (V_x) = K * i / n_e	0.47	ft/day	0.142	m/day
Groundwater flow rate through treatment zone (Q)	1608.57	gallons/day	6089.54	L/day

Section C: Calculated Contact Length (x) = C_t * V_x

Contact time (C_t) between oil and contaminants (accept default or enter C_t)		21	typical values 60 to 180 days, see comment	
Calculated Contact Length (x) = Ct * V_x		9.8	ft	
Treatment zone volume	23,000	ft^3	651	m^2
Treatment zone groundwater volume (volume * effective porosity)	34,408	gallons	130,257	L

Section D: Design Lifespan For One Application	0.058	year(s)	typical values 5 to 10 years	
Estimated total groundwater volume treated over design life	68,462	gallons	259,173	L

Section E: Electron Acceptors

Inputs		Typical Value	GW Conc. (mg/L)	MW (g/mole)	e^- equiv./ mole	Stoichmetry *Contaminant/H_2 (wt/wt H_2)*	Hydrogen Demand *(g H_2)*
Dissolved Oxygen (DO)		0 to 8	1	32.0	4	7.94	32.65378422
Nitrate Nitrogen (NO_3^- - N)		1 to 10	0.4	62.0	5	12.30	8.425801109
Sulfate (SO_4^{2-})		10 to 500	718	96.1	8	11.91	15620.31972
Tetrachloroethene (PCE), C_2Cl_4				165.8	8	20.57	
Trichloroethene (TCE), C_2HCl_3				131.4	6	21.73	
cis-1,2-dichloroethene (c-DCE), $C_2H_2Cl_2$				96.9	4	24.05	
Vinyl Chloride (VC), C_2H_3Cl				62.5	2	31.00	
Carbon tetrachloride, CCl_4				153.8	8	19.08	
Chloroform, $CHCl_3$				119.4	6	19.74	
sym-tetrachloroethane, $C_2H_2Cl_4$				167.8	8	20.82	
1,1,1-Trichloroethane (TCA), CH_3CCl_3				133.4	6	22.06	
1,1-Dichloroethane (DCA), CH_2CHCl_2				99.0	4	24.55	
Chloroethane, C_2H_5Cl				64.9	2	32.18	
Perchlorate, ClO_4^-				99.4	8	12.33	
Hexavalent Chromium, Cr[VI]				52.0	3	17.20	
User added	Trinitrotoluene		7.66	227	18	12.51	158.6655482
User added	Dinitrotoluene & Aminodinitrotoluene		7.12	190	12	15.71	117.4667242
User added	Nitrotoluene		0.67	137	6	22.65	7.665009635

Section F: Additional Hydrogen Demand and Carbon Losses

Table E-9

Emulsified Edible Oil Design Software
Remedial Alternative GW-3 Target Areas for ISEB
TNT Area C
Plum Brook Ordnance Works
Sandusky, Ohio

Generation (Potential Amount Formed)	Typical Value	GW Conc. (mg/L)	MW (g/mole)	e^- equiv./ mole	Stoichmetry *Contaminant / H_2 (wt/wt H_2)*	Hydrogen Demand *(g H_2)*	DOC Released *(moles)*
Estimated Amount of $Fe2^+$ Formed	10 to 100	10	55.8	1	55.41	46.7759831	
Estimated Amount of Manganese (Mn^{2+}) Formed		5	54.9	2	27.25	47.54823212	
Estimated Amount of CH_4 Formed	5 to 20	10	16.0	8	1.99	1302.634125	
Target Amount of DOC to Release	60 to 100	100	12.0				2157.80

Calculations assume:
1.) all reactions go to completion during passage through emulsified edible oil treated zone; and,
2.) perfect reaction stoichiometry.

EOS® Requirement Calculations Based on Hydrogen Demand and Carbon Losses

Stoichiometric Hydrogen Demand	38	pounds
DOC Released	123	pounds

EOS® Requirement Based on Hydrogen Demand and Carbon Loss

2 drums

Step 3: EOS® Requirement Based on Oil Entrapment by Aquifer Material

Soil Characteristics

Density of Sediment (accept default or enter site specific value)	106.0	lbs / ft3
Effective Thickness (typically less than 40%)	0.30	
Weight of sediment to be treated	731,400	lbs
Adsorptive Capacity of Soil (accept default or enter site specific value)	0.0035	lbs EOS® / lbs sediment

For Additional Information on Effective Thickness, Click Here

Oil Retention by Sediment[1]
- Fine sand with some clay 0.001 to 0.002 lbs EOS® / lbs soil
- Sand with higher silt/clay content 0.002 to 0.004 lbs EOS® / lbs soi

[1]Default values provided based on laboratory studies completed by NCSU

For Additional Data, Click Here

EOS® Requirement Based on Oil Entrapment by Aquifer Material

7 drums

Summary – How much EOS® do you need?

Suggested Quantity of EOS® for Your Project 7 drums

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†Exclusive license agreement with Solutions-IES under U.S. Patent # 6,398,960 and several international patents pending.
††EOS® is a registered trademark of EOS Remediation, Inc.

Table E-10

Emulsified Edible Oil Design Software
Remedial Alternative GW-3 Target Areas for ISEB
West Area Red Water Pond Area
Plum Brook Ordnance Works
Sandusky, Ohio

EOS Remediation, Inc.

Emulsified Edible Oil Design Software
for EOS® Family of Bioremediation Products

Version 2.06 Rev. Date: November 28, 2006
www.EOSRemediation.com

Help

Site Name:	Plum Brook Ornance Works
Location:	Sandusky, Ohio
Project No.:	GW-3 WARWP

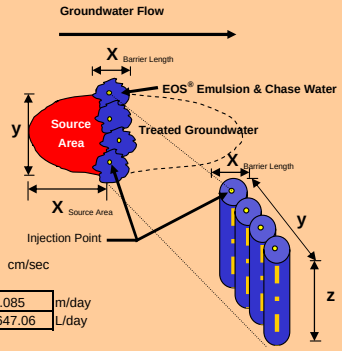
Step 1: Select a Substrate from the EOS® Family of Bioremediation Products

Substrate Selected (pick from drop down list): EOS 400
For Product Literature Click Here

Step 2: EOS® Consumption During Contaminant Biodegradation / Biotransformation

Section A: Treatment Area Dimensions

Length of treatment area parallel to groundwater flow, "x"	10	ft	3.0	m
Width of treatment area perpendicular to groundwater flow, "y"	566	ft	172.5	m
Minimum depth to contamination	6	ft	1.8	m
Maximum depth of contamination	19	ft	5.8	m
Treatment thickness, "z"	13	ft	4.0	m
Treatment zone cross-sectional area = y * z	7,358	ft^2	683.6	m^2



Section B: Groundwater Flow Rate / Site Data

Soil Characteristics				
Nominal Soil Type (pick from drop down list)	Enter Site Data			
Hydraulic Characteristics				
Total Porosity (accept default or enter n)	0.35	(decimal)		
Effective Porosity (accept default or enter n_e)	0.20	(decimal)		
Hydraulic Conductivity (accept default or enter K)	10.75	ft/day	3.8E-03	cm/sec
Hydraulic Gradient (accept default or enter i)	5.20E-03	ft/ft		
Non-reactive Transport Velocity (V_x) = K * i / n_e	0.28	ft/day	0.085	m/day
Groundwater flow rate through treatment zone (Q)	3076.62	gallons/day	11647.06	L/day

Section C: Calculated Contact Length (x) = C_t * V_x

Contact time (C_t) between oil and contaminants (accept default or enter C_t)	35		typical values 60 to 180 days, see comment
Calculated Contact Length (x) = Ct * V_x	9.8	ft	

Treatment zone volume	73,580	ft^3	2,084	m^2
Treatment zone groundwater volume (volume * effective porosity)	110,076	gallons	416,711	L

Section D: Design Lifespan For One Application	0.096	year(s)	typical values 5 to 10 years	
Estimated total groundwater volume treated over design life	217,880	gallons	824,824	L

Section E: Electron Acceptors

Inputs		Typical Value	GW Conc. (mg/L)	MW (g/mole)	e^- equiv./ mole	Stoichmetry *Contaminant/H_2 (wt/wt H_2)*	Hydrogen Demand *(g H_2)*
Dissolved Oxygen (DO)		0 to 8	1	32.0	4	7.94	103.9213923
Nitrate Nitrogen (NO_3^- - N)		1 to 10	24.7	62.0	5	12.30	1655.844704
Sulfate (SO_4^{2-})		10 to 500	721	96.1	8	11.91	49919.72421
Tetrachloroethene (PCE), C_2Cl_4				165.8	8	20.57	
Trichloroethene (TCE), C_2HCl_3				131.4	6	21.73	
cis-1,2-dichloroethene (c-DCE), $C_2H_2Cl_2$				96.9	4	24.05	
Vinyl Chloride (VC), C_2H_3Cl				62.5	2	31.00	
Carbon tetrachloride, CCl_4				153.8	8	19.08	
Chloroform, $CHCl_3$				119.4	6	19.74	
sym-tetrachloroethane, $C_2H_2Cl_4$				167.8	8	20.82	
1,1,1-Trichloroethane (TCA), CH_3CCl_3				133.4	6	22.06	
1,1-Dichloroethane (DCA), CH_2CHCl_2				99.0	4	24.55	
Chloroethane, C_2H_5Cl				64.9	2	32.18	
Perchlorate, ClO_4^-				99.4	8	12.33	
Hexavalent Chromium, Cr[VI]				52.0	3	17.20	
User added	Trinitrotoluene		0.0071	227	18	12.51	0.468040736
User added	Dinitro-aromatics		0.239	190	12	15.71	12.54885795
User added	Mononitro-aromatics		0.045	137	6	22.65	1.638407224

Section F: Additional Hydrogen Demand and Carbon Losses

Table E-10

Emulsified Edible Oil Design Software
Remedial Alternative GW-3 Target Areas for ISEB
West Area Red Water Pond Area
Plum Brook Ordnance Works
Sandusky, Ohio

Generation (Potential Amount Formed)	Typical Value	GW Conc. (mg/L)	MW (g/mole)	e^- equiv./ mole	Stoichmetry *Contaminant / H_2 (wt/wt H_2)*	Hydrogen Demand *(g H_2)*	DOC Released *(moles)*
Estimated Amount of $Fe2^+$ Formed	10 to 100	10	55.8	1	55.41	148.8656033	
Estimated Amount of Manganese (Mn^{2+}) Formed		5	54.9	2	27.25	151.323303	
Estimated Amount of CH_4 Formed	5 to 20	10	16.0	8	1.99	4145.661984	
Target Amount of DOC to Release	60 to 100	100	12.0				6867.24

Calculations assume:
1.) all reactions go to completion during passage through emulsified edible oil treated zone; and,
2.) perfect reaction stoichiometry.

EOS® Requirement Calculations Based on Hydrogen Demand and Carbon Losses

Stoichiometric Hydrogen Demand	124	pounds
DOC Released	392	pounds

EOS® Requirement Based on Hydrogen Demand and Carbon Loss

4 drums

Step 3: EOS® Requirement Based on Oil Entrapment by Aquifer Material

Soil Characteristics

Density of Sediment (accept default or enter site specific value)	106.0	lbs / ft3
Effective Thickness (typically less than 40%)	0.30	
Weight of sediment to be treated	2,339,844	lbs
Adsorptive Capacity of Soil (accept default or enter site specific value)	0.0035	lbs EOS® / lbs sediment

For Additional Information on Effective Thickness, Click Here

Oil Retention by Sediment[1]
- Fine sand with some clay 0.001 to 0.002 lbs EOS® / lbs soil
- Sand with higher silt/clay content 0.002 to 0.004 lbs EOS® / lbs soi

[1]Default values provided based on laboratory studies completed by NCSU

For Additional Data, Click Here

EOS® Requirement Based on Oil Entrapment by Aquifer Material

20 drums

Summary – How much EOS® do you need?

Suggested Quantity of EOS® for Your Project 20 drums

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††EOS® is a registered trademark of EOS Remediation, Inc.

Table E-11

Emulsified Edible Oil Design Software
Remedial Alternative GW-3 Target Areas for ISEB
Pentolite Road Red Water Pond Area
Plum Brook Ordnance Works
Sandusky, Ohio

EOS Remediation, Inc.

Emulsified Edible Oil Design Software
for EOS® Family of Bioremediation Products

Version 2.06 Rev. Date: November 28, 2006
www.EOSRemediation.com

Help

Site Name:	Plum Brook Ornance Works
Location:	Sandusky, Ohio
Project No.:	GW-3 PRRWP

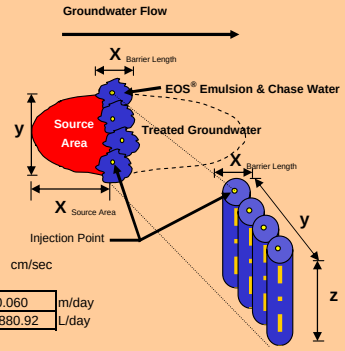
Step 1: Select a Substrate from the EOS® Family of Bioremediation Products

Substrate Selected (pick from drop down list): EOS 400
For Product Literature Click Here

Step 2: EOS® Consumption During Contaminant Biodegradation / Biotransformation

Section A: Treatment Area Dimensions

Length of treatment area parallel to groundwater flow, "x"	10	ft	3.0	m
Width of treatment area perpendicular to groundwater flow, "y"	608	ft	185.3	m
Minimum depth to contamination	6	ft	1.8	m
Maximum depth of contamination	31	ft	9.4	m
Treatment thickness, "z"	25	ft	7.6	m
Treatment zone cross-sectional area = y * z	15,200	ft^2	1,412.1	m^2



Section B: Groundwater Flow Rate / Site Data

Soil Characteristics

Nominal Soil Type (pick from drop down list)	Enter Site Data			
Hydraulic Characteristics				
Total Porosity (accept default or enter *n*)	0.35	(decimal)		
Effective Porosity (accept default or enter n_e)	0.20	(decimal)		
Hydraulic Conductivity (accept default or enter *K*)	10.6	ft/day	3.7E-03	cm/sec
Hydraulic Gradient (accept default or enter *i*)	3.70E-03	ft/ft		
Non-reactive Transport Velocity (V_x) = K * i / n_e	0.20	ft/day	0.060	m/day
Groundwater flow rate through treatment zone (Q)	4459.16	gallons/day	16880.92	L/day

Section C: Calculated Contact Length (x) = C_t * V_x

Contact time (C_t) between oil and contaminants (accept default or enter C_t)	50		typical values 60 to 180 days, see comment
Calculated Contact Length (x) = Ct * V_x	9.8	ft	

Treatment zone volume	152,000	ft^3	4,304	m^2
Treatment zone groundwater volume (volume * effective porosity)	227,392	gallons	860,832	L

Section D: Design Lifespan For One Application	0.137	year(s)	typical values 5 to 10 years	
Estimated total groundwater volume treated over design life	450,372	gallons	1,704,962	L

Section E: Electron Acceptors

Inputs		Typical Value	GW Conc. (mg/L)	MW (g/mole)	e^- equiv./ mole	Stoichmetry *Contaminant/H_2 (wt/wt H_2)*	Hydrogen Demand *(g H_2)*
Dissolved Oxygen (DO)		0 to 8	1	32.0	4	7.94	214.8120122
Nitrate Nitrogen (NO_3^- - N)		1 to 10	419	62.0	5	12.30	58061.77117
Sulfate (SO_4^{2-})		10 to 500	5263	96.1	8	11.91	753223.5488
Tetrachloroethene (PCE), C_2Cl_4				165.8	8	20.57	
Trichloroethene (TCE), C_2HCl_3				131.4	6	21.73	
cis-1,2-dichloroethene (c-DCE), $C_2H_2Cl_2$				96.9	4	24.05	
Vinyl Chloride (VC), C_2H_3Cl				62.5	2	31.00	
Carbon tetrachloride, CCl_4				153.8	8	19.08	
Chloroform, $CHCl_3$				119.4	6	19.74	
sym-tetrachloroethane, $C_2H_2Cl_4$				167.8	8	20.82	
1,1,1-Trichloroethane (TCA), CH_3CCl_3				133.4	6	22.06	
1,1-Dichloroethane (DCA), CH_2CHCl_2				99.0	4	24.55	
Chloroethane, C_2H_5Cl				64.9	2	32.18	
Perchlorate, ClO_4^-				99.4	8	12.33	
Hexavalent Chromium, Cr[VI]				52.0	3	17.20	
User added	Trinitrotoluene			227	18	12.51	
User added	Dinitro-aromatics		5.13	190	12	15.71	556.7718559
User added	Mononitro-aromatics		0.07	137	6	22.65	5.268184633

Table E-11

Emulsified Edible Oil Design Software
Remedial Alternative GW-3 Target Areas for ISEB
Pentolite Road Red Water Pond Area
Plum Brook Ordnance Works
Sandusky, Ohio

Section F: Additional Hydrogen Demand and Carbon Losses

Generation (Potential Amount Formed)	Typical Value	GW Conc. (mg/L)	MW (g/mole)	e^- equiv./ mole	Stoichmetry *Contaminant / H_2 (wt/wt H_2)*	Hydrogen Demand *(g H_2)*	DOC Released *(moles)*
Estimated Amount of $Fe2^+$ Formed	10 to 100	10	55.8	1	55.41	307.7145052	
Estimated Amount of Manganese (Mn^{2+}) Formed		5	54.9	2	27.25	312.7947239	
Estimated Amount of CH_4 Formed	5 to 20	10	16.0	8	1.99	8569.342396	
Target Amount of DOC to Release	60 to 100	100	12.0				14195.01

Calculations assume:
1.) all reactions go to completion during passage through emulsified edible oil treated zone; and,
2.) perfect reaction stoichiometry.

EOS® Requirement Calculations Based on Hydrogen Demand and Carbon Losses

Stoichiometric Hydrogen Demand	1,809	pounds
DOC Released	810	pounds

EOS® Requirement Based on Hydrogen Demand and Carbon Loss

40 drums

Step 3: EOS® Requirement Based on Oil Entrapment by Aquifer Material

Soil Characteristics

Density of Sediment (accept default or enter site specific value)	106.0	lbs / ft3
Effective Thickness (typically less than 40%)	0.30	
Weight of sediment to be treated	4,833,600	lbs
Adsorptive Capacity of Soil (accept default or enter site specific value)	0.0035	lbs EOS® / lbs sediment

For Additional Information on Effective Thickness, Click Here

Oil Retention by Sediment[1]
- Fine sand with some clay 0.001 to 0.002 lbs EOS® / lbs soil
- Sand with higher silt/clay content 0.002 to 0.004 lbs EOS® / lbs soi

[1]Default values provided based on laboratory studies completed by NCSU

For Additional Data, Click Here

EOS® Requirement Based on Oil Entrapment by Aquifer Material

41 drums

Summary – How much EOS® do you need?

Suggested Quantity of EOS® for Your Project 41 drums

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Table E-12

ISEB Injection Configuration in Overburden/Shale Groundwater
Remedial Alternative GW-3
Plum Brook Ordnance Works
Sandusky, Ohio

Site	Plume Area A_p (ft^2)	Plume Length/ Width L_p/W_p (ft)	No. of DP Pts./ Barrier I_r	Hydraulic Cond. K (ft/day)	Hydraulic Gradient i (ft/ft)	Seepage Velocity v_x (ft/day)	Seepage Velocity v_x (ft/yr)	Contact Time C_t (days)	GW Flow Distance D_x (ft)	Mass of Soil M_s (lbs)	Mass Oil Adsorbed M_a (lbs)	Mass H_2 Demand M_{H2} (lbs)	Mass DOC Released M_{DOC} (lbs)	Mass Oil for Treatment M_b (lbs)	Mass Ratio M_a/M_b	Distance betw/ Barriers D_b (ft)	Flush Duration R_t (yr)	Barriers per Plume B_p	Fractional Coverage of Plume F	DP Injection Points I_p	Mass of Oil Emulsion M_p (lbs)
TNTA	88100	297	30	10.45	9.10E-03	0.48	174	21	9.98	1888920	6611	52	321	794	8.33	83	0.48	4	0.13	120	26444
TNTB	16400	128	13	7.85	4.50E-03	0.18	64	56	9.89	40704	142	1	7	16	8.88	88	1.38	2	0.16	26	284
TNTC	52900	230	23	8.50	1.10E-02	0.47	171	21	9.82	731400	2560	38	123	468	5.47	54	0.32	5	0.22	115	12800
WARWP	320000	566	57	10.75	5.20E-03	0.28	102	35	9.78	2339844	8189	124	392	1519	5.39	53	0.52	11	0.19	627	90079
PRRWP	370000	608	61	10.60	3.70E-03	0.20	72	50	9.805	4833600	16918	1809	810	17255	0.98	10	0.14	61	1.00	3721	1031998
Total	847400																			4609	1161605

A_p = Area of plume (see Table 3-3)
L_p (W_p) = Length (also width) of plume (calculated as if plume geometry is a square), $L_p = A_p^{0.5}$
X_b = Barrier length (in direction of groundwater flow) — X_b = 10 feet
D_i = Distance between injection points — D_i = 10 feet
DP = direct push (injection points)
I_r = Number of injection points per barrier (perpendicular to direction of groundwater flow), $I_r = W_p/D_i$
K = Hydraulic conductivity
i = Hydraulic gradient
n_e = Effective porosity — n_e = 0.2
v_x = Seepage velocity, $v_x = (K*i)/n_e$
C_t = Contact time between oil and contaminants (see EOS spreadsheet)
D_x = distance that groundwater flows during contact time (C_t), $D_x = v_x*C_t$
M_s = Mass of soil in one barrier (see EOS spreadsheet)
H_s = pounds H_2 released per pound substrate — H_s = 0.11
z_e = Effective vertical height of treatment zone — z_e = 0.30
R_e = Effective retension of vegetable oil on soil (adsorptive capacity) — R_e = 0.0035
M_a = Mass of undiluted vegetable oil emulsion adsorbed to soil in injection zone, $M_a = M_s*R_e$
M_{H2} = Mass of hydrogen required for biodegradation (see EOS spreadsheet)
M_{DOC} = Target mass of dissolved organic carbon released (see EOS spreadsheet)
M_b = Mass of undiluted vegetable oil emulsion required for biodegradation, $M_b = (M_{H2}/H_s)+M_{DOC}$
D_b = Distance between barriers (parallel to direction of groundwater flow), $D_b*(M_a/M_b)$
B_p = Number of barriers in plume, $B_p = L_p/(X_b+D_b)$
I_p = Number of injection points per plume, $I_p = B_p*I_r$
M_p = Total mass of undiluted vegetable oil emulsion required for plume

Reference:
Solutions-IES (2006), ***Protocol for Enhanced In Situ Bioremediation Using Emulsified Edible Oil***, prepared for the Environmental Security Technology Certification Program (ESTCP), May.

Table E-13

Average Concentration of Nitroaromatics in Overburden Groundwater
Remedial Alternative GW-4 Target Areas for ISEB
TNT Area A
Plume Brook Ordnance Works
Sandusky, Ohio

Sampling Locations and Corresponding Concentrations (µg/L)

	GW-1 Building 111 Mono House	GW-2 Building 112 Bi-Tri House	GW-3 Building 119 A.F. Rec.	GW-4 Building 116 Wash House	GW-5 Building 146 Wash House	GW-6 Building 126 Wash House	GW-8 Building 131 Mono House	GW-10 Building 185 Nitr. House	DP-21 Building 132 Bi-Tri House	Plume Area Weighted Average
Plume Area (ft2)	4900	4900	15000	15500	47000	16300	4900	4900	4900	
Chemical										
TNT		137		157	1125	32,400		50.9	4.1	**4940**
2,4-DNT	957	3.29	385.5		4.7	12.3	15.6	6900	9.5	379
2,6-DNT	377		385.5			12.3	15.3	6900	4.9	353
2-ADNT		16.1		139	295	217			4.3	166
4-ADNT		28.9		201	122	230			3.9	108
Total Dinitroaromatics										**1006**
2-NT	129		2510				115		24	329
3-NT			190					27.8		25
4-NT	86.3		1880				28.6	8.35	3.1	244
Total Mononitroaromatics										**598**
1,3-DNB			0.563		0.529	0.654				0
Nitrobenzene			5.37							1
Toluene	1350									56

Note: Values for TNT and the ADNTs in GW-5 are the geometric means of the combined concentrations of GW-5 and downgradient well location TNT-MW11.

Table E-14

Average Concentration of Nitroaromatics in Overburden Groundwater
Remedial Alternative GW-4 Target Areas for ISEB
TNT Area B
Plum Brook Ordnance Works
Sandusky, Ohio

	Sampling Locations and Estimated Concentrations (µg/L)										Plume Area Weighted Average
	Building 412 SG House	Building 417 WW Disp	Building 452 Bi-Tri House	Building 453 Fort. House	Building 456 Wash House	Building 459 AF Rec. Bldg.	Building 463 Fort. House	Building 466 Wash House	Building 469 AF Rec. Bldg.	Building 472 Bi-Tri House	
Plume Area (ft2)	8100	38700	5800	4900	14000		16600	16400		4900	
Chemical											
TNT		9.3				34.5	5.8			217	**14**
2,4-DNT	13.8	12.7	3.7	2.8	5.1		144	185	5.6		56
2,6-DNT	5.6				5.6		447				69
2-ADNT										40.9	2
4-ADNT										204	9
Total Dinitroaromatics											**136**

* Building 472 (Bi-Tri House) added based on TNTB Remediation Report pit water samples

Table E-15

Average Concentration of Nitroaromatics in Overburden Groundwater
Remedial Alternative GW-4 Target Areas for ISEB
TNT Area C
Plum Brook Ordnance Works
Sandusky, Ohio

Sampling Locations and Estimated Concentrations (µg/L)

	GW-2 Building 682 Bi-Tri House	GW-4 Building 603 Fort. House	GW-5 Building 616 Wash House	GW-6 Building 692 Bi-Tri House	GW-7 Building 693 Fort. House	GW-8 Building 683 Fort. House	GW-9 Building 681 Mono House	GW-10 Building 611 Mono House	Plume Area Weighted Average
Plume Area (ft2)	10000	4900	16700	9000	4900	4900	4900	4900	
Chemical									
TNT	1880	620	9720			20,100	3.9	9.7	**4696**
2,4-DNT	4610	215	4.8	2.9	6.9	37,600	442	4.05	3882
2,6-DNT	1330	169	4.8	2.3	0.9	1,060	122	3.95	333
2-ADNT		147	34.9	2.88	3.2		40.3	15.1	27
4-ADNT	436	59.4	48	3.27	2.7	419	17.4	21.1	129
Total Dinitroaromatics									**4371**
2-NT	258	4.73			0.791	236	2310	2.61	251
3-NT	16.1					18.4	182		19
4-NT	94.7					189	1290		136
Total Mononitroaromatics									**406**
1,3-DNB	0.802								
Nitrate									

Table E-16

Average Concentration of Nitroaromatics in Overburden Groundwater
Remedial Alternative GW-4 Target Areas for ISEB
West Area Red Water Pond Area
Plum Brook Ordnance Works
Sandusky, Ohio

Sampling Locations and Estimated Concentrations (µg/L)

	DP-4	DP-8	DP-9	DP-11	DP-12	DP-13	DP-15	DP-16	DP-17	IT-MW2	WA-MW2	Average
Chemical												
TNT				7.1								7.1
2,4-DNT		2.3	60	1.8	2	950	1.1	60	52	47	55	111.9
2,6-DNT			6.3			56		15	18	8.9	4.1	9.85
4,6-Dinitro-2-methylphenol			24							12		3.27
2,4-Dintrophenol											7.6	7.6
1,3-DNB		0.74	8.6		0.69	270				19	23	29.28
1,3,5-TNB		9.4	7.2			680		40	32			69.87
Total Dinitroaromatics												**239**
3-NT										36		3.27
Nitrobenzene										2.5	3.7	0.56
3-Nitroaniline	3.2		5.1	2.1		15		43	49	3.3	330	40.97
Total Mononitroaromatics												**45**
Nitrate											62000	5636

Table E-17

Average Concentration of Nitroaromatics in Overburden Groundwater
Remedial Alternative GW-4 Target Areas for ISEB
Pentolite Road Red Water Pond Area
Plum Brook Ordnance Works
Sandusky, Ohio

Sampling Locations and Estimated Concentrations (µg/L)

	DP-1	DP-3	DP-6	DP-7	DP-8	DP-10	DP-11	DP-12	DP-13	DP-14	DP-15	DP-16	DP-17	DP-18	DP-19	MW-7	MW-8	MW-9	Average
Chemical																			
2,4-DNT	20	9200	31	0.82	2.8	4100	380	2.3	2.4	13	80	35	8.9	2.4	19	1800	2400	120	1012
2,6-DNT	3.3	550	5.1			400						10	1.7			140	190		72
2,4-Dinitrophenol	8.3	5800				5900						22					6000	48	988
4,6-Dinitro-2-methylphenol		2300				1700					830					12000	20000	280	2062
1,3-DNB		4800	10	0.42	1.2	2100	840	1.3	1.6				6.4	1.1		2000	2100	170	668
1,3,5-TNB							600									2800	2400	71	326
Total Dinitroaromatics																			**5128**
4-Nitrophenol		290				210						5				11	42		31
3-Nitroaniline	88																160	450	39
Nitrobenzene																13	14		1.5
Total Mononitroaromatics																			**71**
Dibenzofuran																6.5	620		35
Fluorene																28	44		4
Nitrate		450,000					350,000									190,000	1.0E+06	110,000	116667

Table E-18

Emulsified Edible Oil Design Software
Remedial Alternative GW-3 Target Areas for ISEB
TNT Area A
Plum Brook Ordnance Works
Sandusky, Ohio

(Page 1 of 2)

EOS Remediation, Inc.

Emulsified Edible Oil Design Software
for EOS® Family of Bioremediation Products

Version 2.06 Rev. Date: November 28, 2006
www.EOSRemediation.com

Help

Site Name:	Plum Brook Ornance Works
Location:	Sandusky, Ohio
Project No.:	GW-4 TNTA

Step 1: Select a Substrate from the EOS® Family of Bioremediation Products

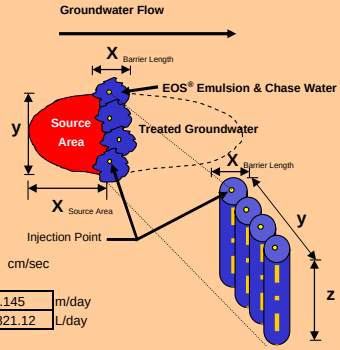
Substrate Selected (pick from drop down list): EOS 400

For Product Literature Click Here

Step 2: EOS® Consumption During Contaminant Biodegradation / Biotransformation

Section A: Treatment Area Dimensions

Length of treatment area parallel to groundwater flow, " x"	10	ft	3.0	m
Width of treatment area perpendicular to groundwater flow, " y"	344	ft	104.9	m
Minimum depth to contamination	8	ft	2.4	m
Maximum depth of contamination	24	ft	7.3	m
Treatment thickness, "z"	16	ft	4.9	m
Treatment zone cross-sectional area = y * z	5,504	ft^2	511.3	m^2



Section B: Groundwater Flow Rate / Site Data

Soil Characteristics				
Nominal Soil Type (pick from drop down list)	Enter Site Data			
Hydraulic Characteristics				
Total Porosity (accept default or enter *n*)	0.35	(decimal)		
Effective Porosity (accept default or enter n_e)	0.20	(decimal)		
Hydraulic Conductivity (accept default or enter *K*)	10.45	ft/day	3.7E-03	cm/sec
Hydraulic Gradient (accept default or enter *i*)	9.10E-03	ft/ft		
Non-reactive Transport Velocity (V_x) = K * i / n_e	0.48	ft/day	0.145	m/day
Groundwater flow rate through treatment zone (Q)	3915.05	gallons/day	14821.12	L/day

Section C: Calculated Contact Length (x) = C_t * V_x

Contact time (C_t) between oil and contaminants (accept default or enter C_t)		21	typical values 60 to 180 days, see comment	
Calculated Contact Length (x) = Ct * V_x		10.0	ft	
Treatment zone volume	55,040	ft^3	1,559	m^2
Treatment zone groundwater volume (volume * effective porosity)	82,340	gallons	311,712	L

Section D: Design Lifespan For One Application	0.058	year(s)	typical values 5 to 10 years	
Estimated total groundwater volume treated over design life	165,222	gallons	625,475	L

Section E: Electron Acceptors

Inputs		Typical Value	GW Conc. (mg/L)	MW (g/mole)	e^- equiv./ mole	Stoichmetry *Contaminant/H_2 (wt/wt H_2)*	Hydrogen Demand *(g H_2)*
Dissolved Oxygen (DO)		0 to 8	1	32.0	4	7.94	78.80497891
Nitrate Nitrogen (NO_3^- - N)		1 to 10		62.0	5	12.30	
Sulfate (SO_4^{2-})		10 to 500		96.1	8	11.91	
Tetrachloroethene (PCE), C_2Cl_4			344	165.8	8	20.57	10461.69877
Trichloroethene (TCE), C_2HCl_3				131.4	6	21.73	
cis-1,2-dichloroethene (c-DCE), $C_2H_2Cl_2$				96.9	4	24.05	
Vinyl Chloride (VC), C_2H_3Cl				62.5	2	31.00	
Carbon tetrachloride, CCl_4				153.8	8	19.08	
Chloroform, $CHCl_3$				119.4	6	19.74	
sym-tetrachloroethane, $C_2H_2Cl_4$				167.8	8	20.82	
1,1,1-Trichloroethane (TCA), CH_3CCl_3				133.4	6	22.06	
1,1-Dichloroethane (DCA), CH_2CHCl_2				99.0	4	24.55	
Chloroethane, C_2H_5Cl				64.9	2	32.18	
Perchlorate, ClO_4^-				99.4	8	12.33	
Hexavalent Chromium, Cr[VI]				52.0	3	17.20	
User added	Trinitrotoluene		4.94	227	18	12.51	246.9454079
User added	Dinitrotoluene & Aminodinitrotoluene		1.006	190	12	15.71	40.05465391
User added	Nitrotoluene		0.598	137	6	22.65	16.51046196

Section F: Additional Hydrogen Demand and Carbon Losses

Table E-18

Emulsified Edible Oil Design Software
Remedial Alternative GW-3 Target Areas for ISEB
TNT Area A
Plum Brook Ordnance Works
Sandusky, Ohio

(Page 2 of 2)

Generation (Potential Amount Formed)	Typical Value	GW Conc. (mg/L)	MW (g/mole)	e^- equiv./ mole	Stoichmetry *Contaminant / H_2 (wt/wt H_2)*	Hydrogen Demand *(g H_2)*	DOC Released *(moles)*
Estimated Amount of $Fe2^+$ Formed	10 to 100	10	55.8	1	55.41	112.8867741	
Estimated Amount of Manganese (Mn^{2+}) Formed		5	54.9	2	27.25	114.7504805	
Estimated Amount of CH_4 Formed	5 to 20	10	16.0	8	1.99	3143.710819	
Target Amount of DOC to Release	60 to 100	100	12.0				5207.52

Calculations assume:
1.) all reactions go to completion during passage through emulsified edible oil treated zone; and,
2.) perfect reaction stoichiometry.

EOS® Requirement Calculations Based on Hydrogen Demand and Carbon Losses

Stoichiometric Hydrogen Demand	31	pounds
DOC Released	297	pounds

EOS® Requirement Based on Hydrogen Demand and Carbon Loss

2 drums

Step 3: EOS® Requirement Based on Oil Entrapment by Aquifer Material

Soil Characteristics

Density of Sediment (accept default or enter site specific value)	106.0	lbs / ft3
Effective Thickness (typically less than 40%)	0.30	
Weight of sediment to be treated	1,750,272	lbs
Adsorptive Capacity of Soil (accept default or enter site specific value)	0.0035	lbs EOS® / lbs sediment

For Additional Information on Effective Thickness, Click Here

Oil Retention by Sediment[1]
- Fine sand with some clay 0.001 to 0.002 lbs EOS® / lbs soil
- Sand with higher silt/clay content 0.002 to 0.004 lbs EOS® / lbs soi

[1]Default values provided based on laboratory studies completed by NCSU

For Additional Data, Click Here

EOS® Requirement Based on Oil Entrapment by Aquifer Material

15 drums

Summary – How much EOS® do you need?

Suggested Quantity of EOS® for Your Project 15 drums

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†Exclusive license agreement with Solutions-IES under U.S. Patent # 6,398,960 and several international patents pending.
††EOS® is a registered trademark of EOS Remediation, Inc.

Table E-19

Emulsified Edible Oil Design Software
Remedial Alternative GW-3 Target Areas for ISEB
TNT Area B
Plum Brook Ordnance Works
Sandusky, Ohio

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EOS Remediation, Inc.

Emulsified Edible Oil Design Software
for EOS® Family of Bioremediation Products

Version 2.06 Rev. Date: November 28, 2006
www.EOSRemediation.com

Help

Site Name:	Plum Brook Ornance Works
Location:	Sandusky, Ohio
Project No.:	GW-4 TNTB

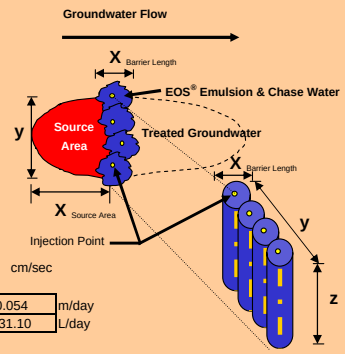
Step 1: Select a Substrate from the EOS® Family of Bioremediation Products

Substrate Selected (pick from drop down list): EOS 400
For Product Literature Click Here

Step 2: EOS® Consumption During Contaminant Biodegradation / Biotransformation

Section A: Treatment Area Dimensions

Length of treatment area parallel to groundwater flow, "x"	10	ft	3.0	m
Width of treatment area perpendicular to groundwater flow, "y"	331	ft	100.9	m
Minimum depth to contamination	6	ft	1.8	m
Maximum depth of contamination	7	ft	2.1	m
Treatment thickness, "z"	1	ft	0.3	m
Treatment zone cross-sectional area = y * z	331	ft^2	30.8	m^2



Section B: Groundwater Flow Rate / Site Data

Soil Characteristics					
Nominal Soil Type (pick from drop down list)	Enter Site Data				
Hydraulic Characteristics					
Total Porosity (accept default or enter *n*)	0.35	(decimal)			
Effective Porosity (accept default or enter n_e)	0.20	(decimal)			
Hydraulic Conductivity (accept default or enter *K*)	7.85	ft/day	2.8E-03	cm/sec	
Hydraulic Gradient (accept default or enter *i*)	4.50E-03	ft/ft			
Non-reactive Transport Velocity (V_x) = K * i / n_e	0.18	ft/day			0.054 m/day
Groundwater flow rate through treatment zone (Q)	87.46	gallons/day			331.10 L/day

Section C: Calculated Contact Length (x) = C_t * V_x

Contact time (C_t) between oil and contaminants (accept default or enter C_t)	56		typical values 60 to 180 days, see comment
Calculated Contact Length (x) = Ct * V_x	9.9	ft	

Treatment zone volume	3,310	ft^3	94	m^2
Treatment zone groundwater volume (volume * effective porosity)	4,952	gallons	18,746	L

Section D: Design Lifespan For One Application

	0.153	year(s)	typical values 5 to 10 years	
Estimated total groundwater volume treated over design life	9,836	gallons	37,236	L

Section E: Electron Acceptors

Inputs		Typical Value	GW Conc. (mg/L)	MW (g/mole)	e^- equiv./ mole	Stoichmetry *Contaminant/H_2 (wt/wt H_2)*	Hydrogen Demand *(g H_2)*
Dissolved Oxygen (DO)		0 to 8	1	32.0	4	7.94	4.691428358
Nitrate Nitrogen (NO_3^- - N)		1 to 10		62.0	5	12.30	
Sulfate (SO_4^{2-})		10 to 500	355	96.1	8	11.91	1109.597317
Tetrachloroethene (PCE), C_2Cl_4				165.8	8	20.57	
Trichloroethene (TCE), C_2HCl_3				131.4	6	21.73	
cis-1,2-dichloroethene (c-DCE), $C_2H_2Cl_2$				96.9	4	24.05	
Vinyl Chloride (VC), C_2H_3Cl				62.5	2	31.00	
Carbon tetrachloride, CCl_4				153.8	8	19.08	
Chloroform, $CHCl_3$				119.4	6	19.74	
sym- tetrachloroethane, $C_2H_2Cl_4$				167.8	8	20.82	
1,1,1-Trichloroethane (TCA), CH_3CCl_3				133.4	6	22.06	
1,1-Dichloroethane (DCA), CH_2CHCl_2				99.0	4	24.55	
Chloroethane, C_2H_5Cl				64.9	2	32.18	
Perchlorate, ClO_4^-				99.4	8	12.33	
Hexavalent Chromium, Cr[VI]				52.0	3	17.20	
User added	Trinitrotoluene		0.014	227	18	12.51	0.041663281
User added	Dinitrotoluene & Aminodinitrotoluene		0.136	190	12	15.71	0.322363114
User added	Nitrotoluene			137	6	22.65	

Table E-19

Emulsified Edible Oil Design Software
Remedial Alternative GW-3 Target Areas for ISEB
TNT Area B
Plum Brook Ordnance Works
Sandusky, Ohio

Section F: Additional Hydrogen Demand and Carbon Losses

Generation (Potential Amount Formed)	Typical Value	GW Conc. (mg/L)	MW (g/mole)	e^- equiv./ mole	Stoichmetry *Contaminant / H_2 (wt/wt H_2)*	Hydrogen Demand *(g H_2)*	DOC Released *(moles)*
Estimated Amount of $Fe2^+$ Formed	10 to 100	10	55.8	1	55.41	6.720390266	
Estimated Amount of Manganese (Mn^{2+}) Formed		5	54.9	2	27.25	6.831340682	
Estimated Amount of CH_4 Formed	5 to 20	10	16.0	8	1.99	187.1518055	
Target Amount of DOC to Release	60 to 100	100	12.0				310.01

Calculations assume:
1.) all reactions go to completion during passage through emulsified edible oil treated zone; and,
2.) perfect reaction stoichiometry.

EOS® Requirement Calculations Based on Hydrogen Demand and Carbon Losses

Stoichiometric Hydrogen Demand	3	pounds
DOC Released	18	pounds

EOS® Requirement Based on Hydrogen Demand and Carbon Loss

1 drums

Step 3: EOS® Requirement Based on Oil Entrapment by Aquifer Material

Soil Characteristics

Density of Sediment (accept default or enter site specific value)	106.0	lbs / ft3
Effective Thickness (typically less than 40%)	0.30	
Weight of sediment to be treated	105,258	lbs
Adsorptive Capacity of Soil (accept default or enter site specific value)	0.0035	lbs EOS® / lbs sediment

For Additional Information on Effective Thickness, Click Here

Oil Retention by Sediment[1]
- Fine sand with some clay 0.001 to 0.002 lbs EOS® / lbs soil
- Sand with higher silt/clay content 0.002 to 0.004 lbs EOS® / lbs soi

[1]Default values provided based on laboratory studies completed by NCSU

For Additional Data, Click Here

EOS® Requirement Based on Oil Entrapment by Aquifer Material

1 drums

Summary – How much EOS® do you need?

Suggested Quantity of EOS® for Your Project 1 drums

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†Exclusive license agreement with Solutions-IES under U.S. Patent # 6,398,960 and several international patents pending.
††EOS® is a registered trademark of EOS Remediation, Inc.

Table E-20

Emulsified Edible Oil Design Software
Remedial Alternative GW-3 Target Areas for ISEB
TNT Area C
Plum Brook Ordnance Works
Sandusky, Ohio

(Page 1 of 2)

EOS Remediation, Inc.

Emulsified Edible Oil Design Software
for EOS® Family of Bioremediation Products

Version 2.06 Rev. Date: November 28, 2006
www.EOSRemediation.com

Help

Site Name:	Plum Brook Ornance Works
Location:	Sandusky, Ohio
Project No.:	GW-4 TNTC

Step 1: Select a Substrate from the EOS® Family of Bioremediation Products

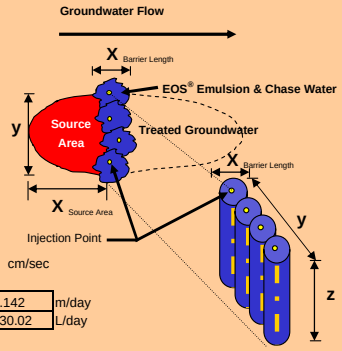
Substrate Selected (pick from drop down list): EOS 400

For Product Literature Click Here

Step 2: EOS® Consumption During Contaminant Biodegradation / Biotransformation

Section A: Treatment Area Dimensions

Length of treatment area parallel to groundwater flow, "x"	10	ft	3.0	m
Width of treatment area perpendicular to groundwater flow, "y"	245	ft	74.7	m
Minimum depth to contamination	8	ft	2.4	m
Maximum depth of contamination	23	ft	7.0	m
Treatment thickness, "z"	15	ft	4.6	m
Treatment zone cross-sectional area = y * z	3,675	ft^2	341.4	m^2



Section B: Groundwater Flow Rate / Site Data

Soil Characteristics					
Nominal Soil Type (pick from drop down list)	Enter Site Data				
Hydraulic Characteristics					
Total Porosity (accept default or enter *n*)	0.35	(decimal)			
Effective Porosity (accept default or enter n_e)	0.20	(decimal)			
Hydraulic Conductivity (accept default or enter *K*)	8.5	ft/day	3.0E-03	cm/sec	
Hydraulic Gradient (accept default or enter *i*)	1.10E-02	ft/ft			
Non-reactive Transport Velocity (V_x) = K * i / n_e	0.47	ft/day		0.142	m/day
Groundwater flow rate through treatment zone (Q)	2570.22	gallons/day		9730.02	L/day

Section C: Calculated Contact Length (x) = C_t * V_x

Contact time (C_t) between oil and contaminants (accept default or enter C_t)	21		typical values 60 to 180 days, see comment
Calculated Contact Length (x) = Ct * V_x	9.8	ft	

Treatment zone volume	36,750	ft^3	1,041	m^2
Treatment zone groundwater volume (volume * effective porosity)	54,978	gallons	208,129	L

Section D: Design Lifespan For One Application	0.058	year(s)	typical values 5 to 10 years	
Estimated total groundwater volume treated over design life	109,390	gallons	414,113	L

Section E: Electron Acceptors

Inputs		Typical Value	GW Conc. (mg/L)	MW (g/mole)	e^- equiv./ mole	Stoichmetry *Contaminant/H_2 (wt/wt H_2)*	Hydrogen Demand *(g H_2)*
Dissolved Oxygen (DO)		0 to 8	1	32.0	4	7.94	52.17506826
Nitrate Nitrogen (NO_3^- - N)		1 to 10	0.4	62.0	5	12.30	13.46296482
Sulfate (SO_4^{2-})		10 to 500	718	96.1	8	11.91	24958.55433
Tetrachloroethene (PCE), C_2Cl_4				165.8	8	20.57	
Trichloroethene (TCE), C_2HCl_3				131.4	6	21.73	
cis-1,2-dichloroethene (c-DCE), $C_2H_2Cl_2$				96.9	4	24.05	
Vinyl Chloride (VC), C_2H_3Cl				62.5	2	31.00	
Carbon tetrachloride, CCl_4				153.8	8	19.08	
Chloroform, $CHCl_3$				119.4	6	19.74	
sym-tetrachloroethane, $C_2H_2Cl_4$				167.8	8	20.82	
1,1,1-Trichloroethane (TCA), CH_3CCl_3				133.4	6	22.06	
1,1-Dichloroethane (DCA), CH_2CHCl_2				99.0	4	24.55	
Chloroethane, C_2H_5Cl				64.9	2	32.18	
Perchlorate, ClO_4^-				99.4	8	12.33	
Hexavalent Chromium, Cr[VI]				52.0	3	17.20	
User added	Trinitrotoluene		4.696	227	18	12.51	155.4216312
User added	Dinitrotoluene & Aminodinitrotoluene		4.371	190	12	15.71	115.2245918
User added	Nitrotoluene		0.406	137	6	22.65	7.421529932

Table E-20

Emulsified Edible Oil Design Software
Remedial Alternative GW-3 Target Areas for ISEB
TNT Area C
Plum Brook Ordnance Works
Sandusky, Ohio

(Page 2 of 2)

Section F: Additional Hydrogen Demand and Carbon Losses

Generation (Potential Amount Formed)	Typical Value	GW Conc. (mg/L)	MW (g/mole)	e^- equiv./ mole	Stoichmetry *Contaminant / H_2 (wt/wt H_2)*	Hydrogen Demand *(g H_2)*	DOC Released *(moles)*
Estimated Amount of $Fe2^+$ Formed	10 to 100	10	55.8	1	55.41	74.73988603	
Estimated Amount of Manganese (Mn^{2+}) Formed		5	54.9	2	27.25	75.97380566	
Estimated Amount of CH_4 Formed	5 to 20	10	16.0	8	1.99	2081.382786	
Target Amount of DOC to Release	60 to 100	100	12.0				3447.78

Calculations assume:
1.) all reactions go to completion during passage through emulsified edible oil treated zone; and,
2.) perfect reaction stoichiometry.

EOS® Requirement Calculations Based on Hydrogen Demand and Carbon Losses

Stoichiometric Hydrogen Demand	61	pounds
DOC Released	197	pounds

EOS® Requirement Based on Hydrogen Demand and Carbon Loss

2 drums

Step 3: EOS® Requirement Based on Oil Entrapment by Aquifer Material

Soil Characteristics

Density of Sediment (accept default or enter site specific value)	106.0	lbs / ft3
Effective Thickness (typically less than 40%)	0.30	
Weight of sediment to be treated	1,168,650	lbs
Adsorptive Capacity of Soil (accept default or enter site specific value)	0.0035	lbs EOS® / lbs sediment

For Additional Information on Effective Thickness, Click Here

Oil Retention by Sediment[1]
- Fine sand with some clay 0.001 to 0.002 lbs EOS® / lbs soil
- Sand with higher silt/clay content 0.002 to 0.004 lbs EOS® / lbs soi

[1]Default values provided based on laboratory studies completed by NCSU

For Additional Data, Click Here

EOS® Requirement Based on Oil Entrapment by Aquifer Material

10 drums

Summary – How much EOS® do you need?

Suggested Quantity of EOS® for Your Project 10 drums

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Table E-21

Emulsified Edible Oil Design Software
Remedial Alternative GW-3 Target Areas for ISEB
West Area Red Water Pond Area
Plum Brook Ordnance Works
Sandusky, Ohio

(Page 1 of 2)

EOS Remediation, Inc.

Emulsified Edible Oil Design Software for EOS® Family of Bioremediation Products

Version 2.06 Rev. Date: November 28, 2006
www.EOSRemediation.com

Help

Site Name:	Plum Brook Ornance Works
Location:	Sandusky, Ohio
Project No.:	GW-4 WARWP

Step 1: Select a Substrate from the EOS® Family of Bioremediation Products

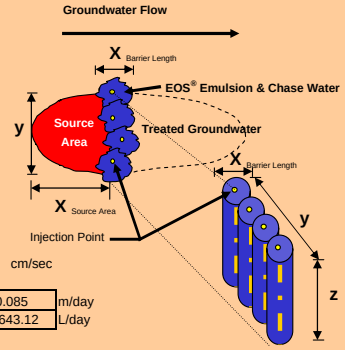
Substrate Selected (pick from drop down list): EOS 400

For Product Literature Click Here

Step 2: EOS® Consumption During Contaminant Biodegradation / Biotransformation

Section A: Treatment Area Dimensions

Length of treatment area parallel to groundwater flow, "x"	10	ft	3.0	m
Width of treatment area perpendicular to groundwater flow, "y"	663	ft	202.1	m
Minimum depth to contamination	6	ft	1.8	m
Maximum depth of contamination	19	ft	5.8	m
Treatment thickness, "z"	13	ft	4.0	m
Treatment zone cross-sectional area = y * z	8,619	ft^2	800.7	m^2



Section B: Groundwater Flow Rate / Site Data

Soil Characteristics				
Nominal Soil Type (pick from drop down list)	Enter Site Data			
Hydraulic Characteristics				
Total Porosity (accept default or enter n)	0.35	(decimal)		
Effective Porosity (accept default or enter n_e)	0.20	(decimal)		
Hydraulic Conductivity (accept default or enter K)	10.75	ft/day	3.8E-03	cm/sec
Hydraulic Gradient (accept default or enter i)	5.20E-03	ft/ft		
Non-reactive Transport Velocity (V_x) = K * i / n_e	0.28	ft/day	0.085	m/day
Groundwater flow rate through treatment zone (Q)	3603.88	gallons/day	13643.12	L/day

Section C: Calculated Contact Length (x) = C_t * V_x

Contact time (C_t) between oil and contaminants (accept default or enter C_t)	35	typical values 60 to 180 days, see comment
Calculated Contact Length (x) = Ct * V_x	9.8	ft

Treatment zone volume	86,190	ft^3	2,441	m^2
Treatment zone groundwater volume (volume * effective porosity)	128,940	gallons	488,126	L

Section D: Design Lifespan For One Application	0.096	year(s)	typical values 5 to 10 years	
Estimated total groundwater volume treated over design life	255,220	gallons	966,181	L

Section E: Electron Acceptors

Inputs		Typical Value	GW Conc. (mg/L)	MW (g/mole)	e^- equiv./ mole	Stoichmetry *Contaminant/H_2 (wt/wt H_2)*	Hydrogen Demand *(g H_2)*
Dissolved Oxygen (DO)		0 to 8	1	32.0	4	7.94	121.7312422
Nitrate Nitrogen (NO_3^- - N)		1 to 10	12.6	62.0	5	12.30	989.4418885
Sulfate (SO_4^{2-})		10 to 500	721	96.1	8	11.91	58474.87129
Tetrachloroethene (PCE), C_2Cl_4				165.8	8	20.57	
Trichloroethene (TCE), C_2HCl_3				131.4	6	21.73	
cis-1,2-dichloroethene (c-DCE), $C_2H_2Cl_2$				96.9	4	24.05	
Vinyl Chloride (VC), C_2H_3Cl				62.5	2	31.00	
Carbon tetrachloride, CCl_4				153.8	8	19.08	
Chloroform, $CHCl_3$				119.4	6	19.74	
sym- tetrachloroethane, $C_2H_2Cl_4$				167.8	8	20.82	
1,1,1-Trichloroethane (TCA), CH_3CCl_3				133.4	6	22.06	
1,1-Dichloroethane (DCA), CH_3CHCl_2				99.0	4	24.55	
Chloroethane, C_2H_5Cl				64.9	2	32.18	
Perchlorate, ClO_4^-				99.4	8	12.33	
Hexavalent Chromium, Cr[VI]				52.0	3	17.20	
User added	Trinitrotoluene		0.0071	227	18	12.51	0.548252665
User added	Dinitro-aromatics		0.239	190	12	15.71	14.69945728
User added	Mononitro-aromatics		0.045	137	6	22.65	1.919194328

Table E-21

Emulsified Edible Oil Design Software
Remedial Alternative GW-3 Target Areas for ISEB
West Area Red Water Pond Area
Plum Brook Ordnance Works
Sandusky, Ohio

(Page 2 of 2)

Section F: Additional Hydrogen Demand and Carbon Losses

Generation (Potential Amount Formed)	Typical Value	GW Conc. (mg/L)	MW (g/mole)	e^- equiv./ mole	Stoichmetry *Contaminant / H_2 (wt/wt H_2)*	Hydrogen Demand *(g H_2)*	DOC Released *(moles)*
Estimated Amount of $Fe2^+$ Formed	10 to 100	10	55.8	1	55.41	174.3779064	
Estimated Amount of Manganese (Mn^{2+}) Formed		5	54.9	2	27.25	177.2568019	
Estimated Amount of CH_4 Formed	5 to 20	10	16.0	8	1.99	4856.137625	
Target Amount of DOC to Release	60 to 100	100	12.0				8044.13

Calculations assume:
1.) all reactions go to completion during passage through emulsified edible oil treated zone; and,
2.) perfect reaction stoichiometry.

EOS® Requirement Calculations Based on Hydrogen Demand and Carbon Losses

Stoichiometric Hydrogen Demand	143	pounds
DOC Released	459	pounds

EOS® Requirement Based on Hydrogen Demand and Carbon Loss

5 drums

Step 3: EOS® Requirement Based on Oil Entrapment by Aquifer Material

Soil Characteristics

Density of Sediment (accept default or enter site specific value)	106.0	lbs / ft3
Effective Thickness (typically less than 40%)	0.30	
Weight of sediment to be treated	2,740,842	lbs
Adsorptive Capacity of Soil (accept default or enter site specific value)	0.0035	lbs EOS® / lbs sediment

For Additional Information on Effective Thickness, Click Here

Oil Retention by Sediment[1]
- Fine sand with some clay 0.001 to 0.002 lbs EOS® / lbs soil
- Sand with higher silt/clay content 0.002 to 0.004 lbs EOS® / lbs soi

[1]Default values provided based on laboratory studies completed by NCSU

For Additional Data, Click Here

EOS® Requirement Based on Oil Entrapment by Aquifer Material

23 drums

Summary – How much EOS® do you need?

Suggested Quantity of EOS® for Your Project 23 drums

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Table E-22

Emulsified Edible Oil Design Software
Remedial Alternative GW-3 Target Areas for ISEB
Pentolite Road Red Water Pond Area
Plum Brook Ordnance Works
Sandusky, Ohio

EOS Remediation, Inc.

Emulsified Edible Oil Design Software
for EOS® Family of Bioremediation Products

Version 2.06 Rev. Date: November 28, 2006
www.EOSRemediation.com

Help

Site Name:	Plum Brook Ornance Works
Location:	Sandusky, Ohio
Project No.:	GW-4 PRRWP

Step 1: Select a Substrate from the EOS® Family of Bioremediation Products

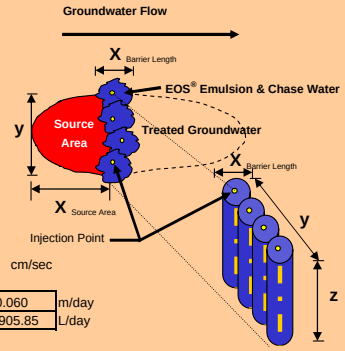
Substrate Selected (pick from drop down list): EOS 400

For Product Literature Click Here

Step 2: EOS® Consumption During Contaminant Biodegradation / Biotransformation

Section A: Treatment Area Dimensions

Length of treatment area parallel to groundwater flow, "x"	10	ft	3.0	m
Width of treatment area perpendicular to groundwater flow, "y"	825	ft	251.5	m
Minimum depth to contamination	6	ft	1.8	m
Maximum depth of contamination	31	ft	9.4	m
Treatment thickness, "z"	25	ft	7.6	m
Treatment zone cross-sectional area = y * z	20,625	ft^2	1,916.1	m^2



Section B: Groundwater Flow Rate / Site Data

Soil Characteristics

Nominal Soil Type (pick from drop down list)	Enter Site Data			
Hydraulic Characteristics				
Total Porosity (accept default or enter n)	0.35	(decimal)		
Effective Porosity (accept default or enter n_e)	0.20	(decimal)		
Hydraulic Conductivity (accept default or enter K)	10.6	ft/day	3.7E-03	cm/sec
Hydraulic Gradient (accept default or enter i)	3.70E-03	ft/ft		
Non-reactive Transport Velocity (V_x) = K * i / n_e	0.20	ft/day	0.060	m/day
Groundwater flow rate through treatment zone (Q)	6050.67	gallons/day	22905.85	L/day

Section C: Calculated Contact Length (x) = C_t * V_x

Contact time (C_t) between oil and contaminants (accept default or enter C_t)	50	typical values 60 to 180 days, see comment	
Calculated Contact Length (x) = Ct * V_x	9.8	ft	
Treatment zone volume	206,250	ft^3	5,840 m^2
Treatment zone groundwater volume (volume * effective porosity)	308,550	gallons	1,168,070 L

Section D: Design Lifespan For One Application

	0.137	year(s)	typical values 5 to 10 years	
Estimated total groundwater volume treated over design life	611,114	gallons	2,313,477	L

Section E: Electron Acceptors

Inputs		Typical Value	GW Conc. (mg/L)	MW (g/mole)	e^- equiv./ mole	Stoichmetry *Contaminant/H_2 (wt/wt H_2)*	Hydrogen Demand *(g H_2)*
Dissolved Oxygen (DO)		0 to 8	1	32.0	4	7.94	291.4801153
Nitrate Nitrogen (NO_3^- - N)		1 to 10	253	62.0	5	12.30	47571.53305
Sulfate (SO_4^{2-})		10 to 500	5263	96.1	8	11.91	1022054.98
Tetrachloroethene (PCE), C_2Cl_4				165.8	8	20.57	
Trichloroethene (TCE), C_2HCl_3				131.4	6	21.73	
cis-1,2-dichloroethene (c-DCE), $C_2H_2Cl_2$				96.9	4	24.05	
Vinyl Chloride (VC), C_2H_3Cl				62.5	2	31.00	
Carbon tetrachloride, CCl_4				153.8	8	19.08	
Chloroform, $CHCl_3$				119.4	6	19.74	
sym-tetrachloroethane, $C_2H_2Cl_4$				167.8	8	20.82	
1,1,1-Trichloroethane (TCA), CH_3CCl_3				133.4	6	22.06	
1,1-Dichloroethane (DCA), CH_2CHCl_2				99.0	4	24.55	
Chloroethane, C_2H_5Cl				64.9	2	32.18	
Perchlorate, ClO_4^-				99.4	8	12.33	
Hexavalent Chromium, Cr[VI]				52.0	3	17.20	
User added	Trinitrotoluene			227	18	12.51	
User added	Dinitro-aromatics		5.13	190	12	15.71	755.4881269
User added	Mononitro-aromatics		0.07	137	6	22.65	7.148441319

Table E-22

Emulsified Edible Oil Design Software
Remedial Alternative GW-3 Target Areas for ISEB
Pentolite Road Red Water Pond Area
Plum Brook Ordnance Works
Sandusky, Ohio

Section F: Additional Hydrogen Demand and Carbon Losses

Generation (Potential Amount Formed)	Typical Value	GW Conc. (mg/L)	MW (g/mole)	e^- equiv./ mole	Stoichmetry *Contaminant / H_2 (wt/wt H_2)*	Hydrogen Demand *(g H_2)*	DOC Released *(moles)*
Estimated Amount of $Fe2^+$ Formed	10 to 100	10	55.8	1	55.41	417.5402414	
Estimated Amount of Manganese (Mn^{2+}) Formed		5	54.9	2	27.25	424.4336303	
Estimated Amount of CH_4 Formed	5 to 20	10	16.0	8	1.99	11627.80835	
Target Amount of DOC to Release	60 to 100	100	12.0				19261.32

Calculations assume:
1.) all reactions go to completion during passage through emulsified edible oil treated zone; and,
2.) perfect reaction stoichiometry.

EOS® Requirement Calculations Based on Hydrogen Demand and Carbon Losses

Stoichiometric Hydrogen Demand	2,386	pounds
DOC Released	1,100	pounds

EOS® Requirement Based on Hydrogen Demand and Carbon Loss

53 drums

Step 3: EOS® Requirement Based on Oil Entrapment by Aquifer Material

Soil Characteristics

Density of Sediment (accept default or enter site specific value) 106.0 lbs / ft3

Effective Thickness (typically less than 40%) 0.30

For Additional Information on Effective Thickness, Click Here

Weight of sediment to be treated 6,558,750 lbs

Adsorptive Capacity of Soil (accept default or enter site specific value) 0.0035 lbs EOS® / lbs sediment

Oil Retention by Sediment[1]
- Fine sand with some clay 0.001 to 0.002 lbs EOS® / lbs soil
- Sand with higher silt/clay content 0.002 to 0.004 lbs EOS® / lbs soi

[1]Default values provided based on laboratory studies completed by NCSU

For Additional Data, Click Here

EOS® Requirement Based on Oil Entrapment by Aquifer Material

55 drums

Summary – How much EOS® do you need?

Suggested Quantity of EOS® for Your Project 55 drums

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Table E-23

ISEB Injection Configuration in Overburden/Shale Groundwater
Remedial Alternative GW-4
Plum Brook Ordnance Works
Sandusky, Ohio

Site	Plume Area A_p (ft^2)	Plume Length/ Width L_p/W_p (ft)	No. of DP Pts./ Barrier I_r	Hydraulic Cond. K (ft/day)	Hydraulic Gradient i (ft/ft)	Seepage Velocity v_x (ft/day)	Seepage Velocity v_x (ft/yr)	Contact Time C_t (days)	GW Flow Distance D_x (ft)	Mass of Soil M_s (lbs)	Mass Oil Adsorbed M_a (lbs)	Mass H_2 Demand M_{H2} (lbs)	Mass DOC Released M_{DOC} (lbs)	Mass Oil for Treatment M_b (lbs)	Mass Ratio M_a/M_b	Distance betw/ Barriers D_b (ft)	Flush Duration R_t (yr)	Barriers per Plume B_p	Fractional Coverage of Plume F	DP Injection Points I_p	Mass of Oil Emulsion M_p (lbs)
TNTA	118300	344	34	10.45	9.10E-03	0.48	174	21	9.98	1750272	6126	31	297	579	10.58	106	0.61	4	0.12	136	24504
TNTB	109400	331	33	7.85	4.50E-03	0.18	64	56	9.89	105258	368	3	18	45	8.13	80	1.25	5	0.15	165	1840
TNTC	60200	245	25	8.50	1.10E-02	0.47	171	21	9.82	1168650	4090	61	197	752	5.44	53	0.31	5	0.20	125	20450
WARWP	440000	663	66	10.75	5.20E-03	0.28	102	35	9.78	2740842	9593	143	459	1759	5.45	53	0.52	13	0.20	858	124709
PRRWP	680000	825	83	10.60	3.70E-03	0.20	72	50	9.81	6558750	22956	2386	1100	22791	1.01	10	0.14	83	1.00	6889	1905348
Total	1407900																			8173	2076851

A_p = Area of plume (see Table 3-3)
L_p (W_p) = Length (also width) of plume (calculated as if plume geometry is a square), $L_p = A_p^{0.5}$
X_b = Barrier length (in direction of groundwater flow) — X_b = 10 feet
D_i = Distance between injection points — D_i = 10 feet
DP = direct push (injection points)
I_r = Number of injection points per barrier (perpendicular to direction of groundwater flow), $I_r = W_p/D_i$
K = Hydraulic conductivity
i = Hydraulic gradient
n_e = Effective porosity — n_e = 0.2
v_x = Seepage velocity, $v_x = (K*i)/n_e$
C_t = Contact time between oil and contaminants (see EOS spreadsheet)
D_x = distance that groundwater flows during contact time (C_t), $D_x = v_x*C_t$
M_s = Mass of soil in one barrier (see EOS spreadsheet)
H_s = pounds H_2 released per pound substrate — H_s = 0.11
z_e = Effective vertical height of treatment zone — z_e = 0.30
R_e = Effective retension of vegetable oil on soil (adsorptive capacity) — R_e = 0.0035
M_a = Mass of undiluted vegetable oil emulsion adsorbed to soil in injection zone, $M_a = M_s*R_e$
M_{H2} = Mass of hydrogen required for biodegradation (see EOS spreadsheet)
M_{DOC} = Target mass of dissolved organic carbon released (see EOS spreadsheet)
M_b = Mass of undiluted vegetable oil emulsion required for biodegradation, $M_b = (M_{H2}/H_s)+M_{DOC}$
D_b = Distance between barriers (parallel to direction of groundwater flow), $D_x*(M_a/M_b)$

Table E-24

Characterization of Influent Groundwater
WARWP and PRRWP Groundwater Treatment Systems
Plum Brook Ordnance Works, Sandusky, Ohio

	West Area Red Water Pond						Pentolite Road Red Water Pond					
Flow Rate (gpm) =	6						10.5					
	Concentration (µg/L)			**Mass Rate (lb/day)**			**Concentration (µg/L)**			**Mass Rate (lb/day)**		
Chemical Parameter	**Minimum**	**Maximum**	**Average**	**Minimum**	**Maximum**	**Average**	**Minimum**	**Maximum**	**Average**	**Minimum**	**Maximum**	**Average**
2,4,6-Trinitrotoluene	-	-	-	-	-	-	-	-	-	-	-	-
2,4-Dinitrotoluene	16	19	12				0.58	1.5	1.02	0.00007	0.00019	0.00013
2,6-Dinitrotoluene	-	-	-	-	-	-	0.59	1.4	1.03	0.00007	0.00018	0.00013
2-Amino-4,6-dinitrotoluene	-	-	-	-	-	-	-	0.19	0.19	-	0.00002	0.00002
4-Amino-2,6-dinitrotoluene	-	-	-	-	-	-	-	-	-	-	-	-
Nitrobenzene	-	5.8	5.8	-	0.00042	0.00042	-	-	-	-	-	-
4,6-Dinitro-2-methylphenol	-	28	28	-	0.00202	0.00202	-	-	-	-	-	-
3-Nitroanaline	-	150	150	-	0.01082	0.01082	-	-	-	-	-	-
Nitrate	22000	79300	31326	1.6	5.7	2.3	-	-	-	-	-	-
Iron	164	923	480	0.01182	0.06655	0.03461	31600	257000	110567	4.0	32.4	14.0
TSS	11000	54000	31250	0.79	3.9	2.3	65000	499000	254667	8.2	63.0	32.1
TOC	160000	937000	476000	11.54	67.6	34.3	2600	3700	3267	0.33	0.47	0.41
Benzene	-	1.1	< 1.1	-	0.00008	<0.00008	60	130	87	0.008	0.016	0.011
Toluene	-	-	-	-	-	-	76	100	86	0.010	0.013	0.011
Ethylbenzene	-	-	-	-	-	-	73	120	89	0.009	0.015	0.011
Xylene	-	-	-	-	-	-	370	560	463	0.047	0.071	0.058

RESPONSE TO COMMENTS

RESPONSE TO COMMENTS

Response to Comments
Draft Feasibility Study for Groundwater
TNT and Red Water Pond Areas
Plum Brook Ordnance Works, Sandusky Ohio
Report Dated March 1, 2007
Responses Submitted October 22, 2007

Comments by John Weaver, Geologist, Ohio Environmental Protection Agency.

Comment 1: **Shaw Environmental, Inc. (Shaw) states in Section 1.4.3 of the March 1, 2007 Draft Feasibility Study for Groundwater TNT and Red Water Pond Areas (FS) that current and future human health risks at the five areas of concern (AOCs) [TNT Areas A, B, and C and the Red Water Pond Areas (RWPA)] were not evaluated for the soil to ground water pathway as part of this feasibility study. This pathway has been modeled and evaluated as part of the ground water baseline human health risk assessment (BHHRA). As noted in Section 1.8 of the FS, Ohio EPA's cancer and noncancer criterion (1x10-5 and 1, respectively) were exceeded onsite (at each AOC) and at the property boundary for a residential-use scenario. For clarification, the Red Water Pond Areas (RWPA) consists of the Pentolite Road and West Area red water pond areas.**

Response 1: The text will be clarified to state that the separate soil, sediment, and surface water BHHRAs did not evaluate the soil-to-groundwater pathway, but that the groundwater BHHRA did evaluate this pathway.

Comment 2: **In order to adequately evaluate the treatment options for ground water occurring at the five AOCs, Ohio EPA has gleaned the following facts/conclusions from the FS.**

<u>Overburden/Olentangy-Ohio Shale</u>

Uppermost ground water zone monitored at NPBS. Ground water occurs within discontinuous lenses and layers of more permeable sand/gravel, at the glacial till/shale interface, and within the shale. These two zones are treated as a single hydrostratigraphic unit as they are hydraulically connected.

Occurrence of ground water is seasonal where limited amounts are observed during periods of low precipitation. Ground water flow is variable across NPBS with flow to the northwest-north-northeast.

Shaw and USACE, in conjunction with Ohio EPA, have previously concluded that the overburden/shale ground water zone beneath NPBS at NPBS as a non-potable source of water due to its low yield, discontinuous nature of more saturated, permeable lenses, and overall

drinking water quality. While risks associated with ground water occurring in the overburden/shale will not be quantitatively evaluated using a residential scenario, it will be addressed in a qualitative manner as described in Sections 1.3 and 3.1.3.1 of the Shaw March 2006 document entitled, 'Baseline Human Health Risk Assessment'. Specifically, Shaw will perform modeling to determine the potential impact of any nitroaromatic contamination in the overburden/shale zone on the limestone bedrock zone beneath NPBS.

Shaw has calculated two sets of estimated areas and volumes of ground water contamination in the overburden/shale at each AOC. The estimates are based upon the zone being used and not being used as a drinking water source.

<u>Bedrock (Delaware Limestone)</u>

Lowermost (deepest) ground water zone monitored at NPBS.

Contains traces of naturally-occurring hydrocarbons and hydrogen sulfide. Shaw has concluded that this zone is locally undesirable for potable purposes due to its drinking water quality and the availability of municipal sources.

Ground water flows through fracture and bedding planes and solution cavities and to the north-northeast across NPBS.

Shaw concludes that based upon an evaluation of geochemical parameter analytical data, conditions in the Delaware Limestone are favorable for natural attenuation of nitroaromatic contamination.

Shaw has calculated estimated areas and volumes of ground water contamination in the Delaware Limestone at each AOC. The estimates are based upon the zone being used as a drinking water source.

<u>Miscellaneous</u>

The majority of residences in Erie County, including NPBS, receive their potable water from municipal supplies whose primary source is surface water (Lake Erie).

The main ground water source in Erie County is the regional bedrock aquifer (Delaware Limestone).

Six private potable wells have been identified within 1-mile downgradient of NPBS. The nearest well is to the northeast and approximately 850 feet away.

The remedial action objectives (RAOs) for both overburden/shale and Delaware Limestone ground water at the five AOCs are: (1) to prevent onsite human (residential) exposure to constituents of concern (COCs) above remedial goal options (RGOs) and (2), prevent offsite and downgradient human (residential) exposure to COCs above RGOs. Shaw has developed RGOs for those COCs identified in the two ground water zones. COC selection was based upon risk contribution, COCs identified in soils that could leach, and COCs/breakdown products observed in overlying soils and the overburden/shale.

Modeling data indicates that the overburden/shale zone would impact the Delaware Limestone above RGOs.

Ground water analytical data indicates that several COCs exceed corresponding RGOs in the Delaware Limestone ground water zone.

Shaw has identified four remedial alternatives for the treatment of ground water as follows:

a. Alternative GW-1 - No Further Action
No further remedial action or monitoring would be implemented for contaminated ground water. Shaw concluded that this would not be effective as it would not protect human health.

b. Alternative GW-2 - Ground Water Monitoring and Institutional Controls

This alternative consists of long term monitoring to assess ground water quality and the implementation of institutional controls to restrict the use of all ground water. This alternative would be implemented and enforced via a land-use control implementation plan. Additional monitoring well installation would be necessary in support of this alternative. Shaw has concluded that this alternative would prevent human exposure to impacted ground water and would provide an early-warning system if offsite drinking water was threatened.

c. Alternative GW-3 - In Situ Enhanced Bioremediation/Pump and Treat for Mitigation/Protection of the Delaware Limestone Bedrock Aquifer

This alternative involves the limited injection of emulsified vegetable oil into the overburden/shale ground water zone to enhance anaerobic degradation, pumping and treating of

ground water in the limestone aquifer, long term monitoring to assess ground water quality, and the implementation of institutional controls to restrict the use of all ground water. Shaw has concluded that this alternative would prevent human exposure to impacted ground water, would provide an early-warning system if offsite drinking water was threatened, and provide active remediation of COCs to below RGOs.

d. Alternative GW-4 - In Situ Enhanced Bioremediation/Pump and Treat for Mitigation/Protection of the Overburden/Shale and Bedrock Aquifers

This alternative is exactly the same as proposed in Alternative GW-3, with the exception that the overburden/shale ground water zone would be treated to unrestricted use. With Alternative GW-3, injection of treatment substrates into the overburden/shale ground water zone would continue only until the underlying Delaware Limestone was protected. Restoration of the overburden/shale ground water zone under Alternative GW-3 to unrestricted use would not be performed.

Ohio EPA is unclear as to why the FS does not contain a recommendation for implementation of one of the remedial alternatives noted above.

Response 2: It is the policy of USACE Legal Counsel to not recommend an alternative until the Proposed Plan. USACE notes that the summary provided is correct.

Comment 3: **Ohio EPA DDAGW is of the opinion that funding for several of the recommendations for additional work at NPBS (Section 7.4 of the FS) would be better spent on the actual implementation of one of the remedial alternatives discussed in Comment 2 above.**

Response 3: Comment noted.

Comments by Bonnie Buthker, Risk Assessor, Ohio Environmental Protection Agency

Comment 1: **<u>Screening of remedial options</u>. A table summarizing the results of the preliminary screening of process options should be included in the FS. Though the text discusses this information in detail, it is very difficult to quickly view which options were evaluated and which were retained.**

Response 1: A summary table will be prepared for the technology screening process as suggested in the comment.

Comment 2: **<u>Discussion of Legal Controls to prevent use of ground water</u>. To be clearer and consistent with other Feasibility Studies, the institutional controls that can prevent use of the ground water should be discussed first. The discussion should also focus on the types of legal controls that could be implemented. For institutional controls to be effective, many layers of use controls and notifications of use restrictions should be used. Local zoning ordnances, land use plans, or controls that NASA that could implement should also be discussed, since these mechanisms (in addition to use of Ohio's Environmental Covenant Law) will factor into the effectiveness and implementability of this response option.**

Response 2: The text in Sections 5.2.1, 5.3.1 and 5.4.1 will be reorganized to present the institutional control element first in the description of remedial Alternatives GW-2 through GW-4. Some examples of the types of institutional controls that could be implemented at the site will be added to the discussion. This topic will be expanded in the final FS report.

Comment 3: **A table summarizing the results of the preliminary screening of process options should be included in the FS. Though the text discusses this information in detail, it is very difficult to quickly view which options were evaluated and which were retained.**

Response 3: A summary table will be prepared for the technology screening process as suggested in the comment.

Comment 4: **<u>Monitored Natural Attenuation option</u>. The FS report indicates that the ground water data collected to date was not adequate to determine if natural attenuation would be effective to address the explosive contamination present at POTW. In addition, the text also states that "applying MNA to TNT-contaminated sites is challenging ..." USACE does not have evidence that MNA is effective to address TNT, nor is there site specific data to demonstrate that MNA is currently occurring in ground water at PBOW. Without more supportive evidence that MNA is effective, this process option should be screened out.**

Response 4: U.S. Army Corps of Engineers policy (Engineer Regulation 1110-1-8157) requires that natural attenuation is considered as a remedial action alternative (see comment #4 from Sam Bass, USACE-CX). Therefore, monitored natural attenuation with institutional controls will be developed as an additional remedial alternative in the FS.

Comment 5: **The organization of the text makes it very difficult for the reader to determine which in-situ versus ex-situ treatment options were considered in the FS. In addition, some other types of process options**

are interspersed within this discussion, which makes it even more confusing for the reader. For example, the discussion on phytoremediation is between the discussion of in-situ enhanced bioremediation and in-situ chemical oxidation. Use restrictions are mentioned between this and a type of in-situ bioremediation (Apatite II). This section needs to be reorganized so that there is a logical flow of the type of process options that were evaluated in the FS.

Response 5: The text in this chapter will be reorganized to group similar general response actions together as suggested in the comment.

Comment 6: **In the preamble to the National Contingency Plan (U.S.EPA's Ground Water Policy), it discusses that, for Class III ground water (water that is unsuitable for human consumption due to contamination that is not site related), the remediation approach should be tailored to returning the ground water to its designated use. Alternatives for Class III Ground water should be relatively limited and focus on preventing adverse spread of significant contamination or source control to prevent exposure to waste materials or contamination. There is naturally occurring petroleum and hydrogen sulfide contamination present in the bedrock aquifer at PBOW. If the explosives contamination was not present, it is unlikely that this ground water would be suitable for human consumption. In addition, source removals will minimize the probability of additional explosives contamination leaching to ground water. This discussion should be added to the text, since it also demonstrates why active remediation to address the ground water may not be appropriate for PBOW.**

Response 6: USACE agrees with the reviewer that this groundwater is unsuitable for human consumption. These statements concerning usability of the GW and reference to the NCP Preamble will be incorporated into the revised text as appropriate. See also the response to Sam Bass, USACE CX, Comment No. 2.

Comment 7: **The text of the FS indicates that all alternatives (other than the No Action Alternative) are equally effective in addressing the contamination present at POTW. However, Table 6-1 does not indicate this. This inconsistency could confuse the reader. Please clarify if all alternatives are equally effective, or if one is more effective than the others evaluated (e.g., shorter timeframe to remediation, less residuals that have to be managed, etc.) This information is essential to determine the net benefit (if there is any) to active remediation versus long-term monitoring prior to selection of the preferred alternative for the ground water.**

Response 7: Section 6.3 (long-term effectiveness) of the comparative analysis discusses how the remedial alternatives differ with respect to this criterion,

including the magnitude of residual risk remaining at the site. Section 6.4 (reduction of toxicity, mobility and volume through treatment) compares the amount of treatment employed under each alternative, although a discussion of treatment residuals will be added to the text in this section. Section 6.5 (short-term effectiveness) compares the time for each alternative to attain RGOs. With the exception of treatment residuals management, the discussion of each of these criteria in the text is consistent with the presentation in Table 6-1.

Comment 8: **Costs for alternatives are supposed to be evaluated over a 30 year period, not 150 years as was done in this FS. Please revise appropriately.**

Response 8: Although past EPA guidance limited the evaluation of present value costs to a 30 year duration, the most recent CERCLA cost estimation guidance (EPA, 2000) states that "a blanket use of the 30-year period of analysis is not recommended". A longer 150-year analysis period is used in the FS because groundwater modeling projects that the concentrations of COC in groundwater will remain above RGOs for at least this long. The longer 150-year analysis period is therefore considered to be appropriate in these circumstances and in accordance with current EPA guidance.

Reference: U.S. Environmental Protection Agency (EPA) and U.S. Army Corps of Engineers USACE), 2000, A Guide to Developing and Documenting Cost Estimates During the Feasibility Study, EPA 540-R-00-002, OSWER 9355.0-75, July.

Comments received from James Raab, Ohio Department of Natural Resources, dated May 29, 2007.

Comment 1: **The report refers to the limestone bedrock as the Delaware Limestone. The Delaware is just the uppermost limestone formation and is typically less than 50 feet thick. The Columbus Limestone lies beneath the Delaware Limestone and is typically more water bearing than the Delaware Limestone.**

Response 1: Comment noted. Review of the drilling logs for PBOW indicates that most wells were completed within 50 feet of encountering limestone bedrock. The additional information regarding the Columbus Limestone provided during review of this document will be incorporated.

Comment 2: **The direction of ground water flow in the carbonate aquifer is to the north. The Division of Water has constructed a historical potentiometric surface map. This map can be accessed at http://www.dnr.state.oh.us/water/gwpsurface/PSurfPDFs/ErieBed_Psurf.pdf. This map was created using existing water well records.**

Response 2: The groundwater map referenced was reviewed and provides good information on general direction of groundwater flow on a regional basis. However, these maps are constructed based on few data points collected over long time frames. The data presented in the FS is based on site wells measured over a short (24 hour) period and thus reflect more localized flow patterns, Groundwater flow is to the northeast, presumably influenced by groundwater removal activities as well as local hydrogeology.

Comment 3: **The presence of the Wagner quarry north of the PBOW means that the quarry could be capturing most of the ground water that flows beneath the site. I have talked with the inspector for the Division of Mineral Resources Management and he indicated that maps showing the extent of the dewatering at the quarry have not been developed. Even if the area of influence due to pumping at the quarry extends 1000 feet beyond the quarry property, the quarry sump would capture most of the ground water coming from beneath the PBOW site. I recommend that the proposed monitor wells be installed along the northern edge of the PBOW property and extend towards the quarry to better define the effect that the quarry might be having on the direction and rate of ground water flow. The limestone monitor wells should be deep enough so they are completed below the bottom of the Delaware Limestone.**

Response 3: It is agreed that the quarry may impact PBOW either from drawdown or groundwater capture. Based on monitoring well installation and sampling in areas between the PBOW site and the quarry, contamination is not migrating off site. Because of this, further downgradient well installation and sampling is not warranted for DOD related contamination. Also, note that nuisance odors associated with naturally occurring sulfate in this area have resulted in the abandonment of wells BED-MW22 and BED-MW27. However, due to concerns expressed by the RAB and it's consultant, the USACE is interested in obtaining water quality data from the quarry to ensure there is no unacceptable exposure to DOD-related contaminants to human or ecological receptors. It should be noted that there have been issues with obtaining samples from the quarry in the past due to the necessity for obtaining signed right-of-entry forms. Given the very low concentrations of nitroaromatics detected in groundwater near the downgradient, on-site boundary and lack of detections in downgradient off-site wells, concentrations of nitroaromatics in quarry water are expected to be negligible. Therefore, the USACE does not consider the collection of water samples from the quarry to be imperative for site management decisions, should issues with quarry water sampling continue.

Comment 4: **I am aware of one karst feature mapped in Perkins Township by the Erie County Soil and Water District, but there are extensive karst**

features in the Columbus Limestone on the western side of Erie County and eastern Sandusky and Seneca Counties. Ground water flow through fractures or voids should not be ruled out at this site. The existence of fractures or voids should be logged during the installation of any monitor wells.

Response 4: Comment noted. Groundwater flow is undoubtedly through fractures and bedding planes in the shale and limestone units. During drilling, rock cores are logged for lithology as well as fractures and voids at the site. To date, these logging activities associated with the USACE investigations have not resulted in the documentation of karst features on PBOW. However, because of the identification of karst features in the proximity of PBOW this information has been included in past reports.

Comments received from Mark Bohne, Chairman, Restoration Advisory Board via email on June 1, 2007.

Comment 1: **The study lacks any data about de-watering from either activities at Plum Brook NASA or Wagner Quarries. Throughout the research RAB members have raised questions about the possible affect(s) of dewatering, yet the topic is not fully developed in the document. Information supplied by Ohio DNR concerning groundwater removals at Wagner Quarries and NASA information about dewatering by NASA from the Test Reactor and Pump-and-Treat sites should be included in the report text and Feasibility Study research. The information should be included in the report for future reference in the event the affects need to be addressed in the future.**

Response 1: The issues regarding the dewatering will be included in the revised document. This will include information related to the dewatering activities at both the Wagner Quarry and onsite Reactor Sumps as well as the active PBOW pump and treat system. It should be noted that no baseline groundwater contours were created prior to the existence of the Wagner Quarry; therefore, the extent to which the quarry may affect groundwater in the vicinity of PBOW cannot be ascertained without additional investigation. However, the USACE feels that the data collected to date on PBOW are sufficient to select a preferred alternative. In addition, as noted in responses to other review comments, the USACE made extensive efforts to investigate the potential for offsite migration of contamination. These investigations included wells installation and groundwater sampling of new monitoring wells in addition to sampling private wells in the area. To date, contamination has not been detected in the areas between the PBOW boundary and the quarry, nor has it been detected in wells downgradient of the West Area Redwater Pond. Because of the lack of offsite contamination, no further investigation in downgradient areas is warranted at this time. Further, DERP-FUDS funding cannot be used to address drawdown issues related to the quarry

since there has been no Department of Defense contamination detected in this area.

Comment 2: **Recommendations from Ohio DNR (James Raab) that are expressed in a letter dated May 31, 2007 (attached) should also be addressed in the report.**

Response 2: Comment noted. Please note that formal responses to Ohio DNR's comments have been prepared and are also included in the feasibility study.

Comment 3: **Petroleum "fingerprinting" research should be developed (I was under the impression this was already performed) and included in the report. Reports of prior events by NASA (toluene spills, etc.) should also be included (if not also explored.)**

Also, could it be possible that NASA operations at the rocket engine test site (B3?) may have contributed to hydrocarbon releases in liquid form due to heating and melting of the shale during past testing? What is the location of that test site to the wells producing refinable oil deposits?

Response 3: The information on the fingerprinting will be included as well as information on the reported spills at the site. The NASA operations at the rocket engine test facility were designed to minimize any heating. Please see the responses to J. Weatherington-Rice's comments concerning this issue.

Comment 4: **Dye testing could be performed on-site by using developed wells, the Nuclear Test Reactor sump, the pump-and-treat sump and the sump at Wagner Quarry. The NASA systems are responsible for some dewatering (even if dwarfed by removal at Wagner Quarry), so valid data could be obtained by running the tests. Ohio DNR personnel, Erie Soil and Water personnel, and or NASA personnel could be used to perform the tests. All it would take is some inter-agency cooperation.**

Response 4: Comment noted. Further discussion with the USACE, NASA, Ohio EPA and the RAB are necessary to determine a path forward on this issue. Currently, the data quality objectives for this exercise are not clearly defined.

Comment 5: **My purpose here is clear. The Restoration Advisory Board doesn't want a "definitive" study that "locks-in" future remediation activities because the study is too restrictive. The Army Corps has always been receptive to reacting to events as they arise (soil removal activities at TNT B are a great example.) What we know now about groundwater**

flow, may change in the future as remediation activities progress. When faced with changes due to modifications to dewatering or soil removal activities, remediation activities may also need to be modified. If all variables are properly presented in the Feasibility Study, then future generations can use the study to recommend modifications to remediation activities.

Response 5: Comment noted. The potential effects of water use by outside entities, the potential for petroleum to be from anthropogenic sources and the potential impacts from these uncertainties on the remedial alternatives will be addressed in the revised report.

Comments received from Julie Weatherington-Rice, Geologist, Bennett & Williams, Inc., (TAPP Contractor), dated May 1, 2007.

Comment 1: **The Delaware Limestone in Erie County where it is measured and quarried in the two active Hanson quarries, the one west of Route 4, just south of I-80 in southwestern Erie County and here at the Wagner Quarry ranges in thickness from 40 feet at the southwestern quarry to as thin at 15 feet in the southern end of the Wagner Quarry. The Delaware Limestone is relegated to Bench 1 in the Wagner Quarry. There is no naturally occurring petroleum in the Delaware Limestone.**

Response 1: Agreed. The text will be corrected to more accurately reflect site geology. Review of site geology indicates the Delaware may be up to approximately 50 feet thick on PBOW. However, from a groundwater perspective, all wells are installed into the first water bearing fracture in the limestone bedrock. The fact that we see petroleum in some of the PBOW wells indicate that these wells are installed in the Columbus and that the upper zones of the limestone (i.e., the Delaware) may produce little or no water, at least on portions of the PBOW site.

Comment 2: **The underlying Columbus Limestone at the Wagner Quarry ranges in thickness from 59 feet to 83 feet in the southern portion of the quarry. It is located on the bottom of Bench 1 through Bench 3. This is the formation with naturally occurring petroleum. The naturally occurring petroleum is sporadic in occurrence. It is extremely thick in nature, more on the order of tar or asphalt. It moves very slowly out of the Columbus Limestone, taking a year or more to stain the face of the quarry walls after a new face has been blasted.**

Response 2: Comment noted. The observations at the Wagner Quarry can be useful; however, site-specific data obtained from PBOW monitoring wells, such as petroleum fingerprinting analysis and a review of the boring logs, will be used to evaluate the nature of the observed petroleum. The observations to date show sporadic detections of petroleum on PBOW.

Not all wells installed within the limestone have shown petroleum which may be the result of the sporadic distribution or that they are screened in the Delaware Limestone.

The observation of the high viscous petroleum within the quarry, while interesting, represents a completely different environment than that on PBOW. In the quarry, the limestone has been dewatered. Residual petroleum from seeps in the quarry face will have the lighter more volatile components (e.g., BTEX) evaporate leaving behind a heavier oil residue. This phenomenon is well documented in the literature, particularly from large oil spills in both marine and terrestrial environments. This evaporation occurs quite rapidly and can produce the tar-like substances seen in the quarry. On PBOW, the petroleum is found in saturated zones within deeper borings. Under these saturated conditions, volatilization is not possible due to the fact there is no direct exposure to the atmosphere. Thus, there is a plausible explanation based on readily observed differences in the two environments. Regardless, NASA is currently evaluating analytical data to determine the source of the petroleum.

Comment 3: **The entire Bench 4 and 5 are the upper portions of the Detroit River Dolostone (dolomite) formation. This formation continues to well below the bottom of Bench 5. The sump in the southeastern corner of the quarry that provides the dewatering point for the whole quarry is fully contained in the Detroit River Formation.** ***The top of the Detroit River Dolostone has a marked strong hydrogen sulfide order. There is some elemental sulfur present with depth on Bench 5.***

Response 3: Comment Noted.

Comment 4: **The entire Wagner Quarry is passively dewatered by just one small sump area in the southeast corner of the quarry. The surface elevation of the sump is maintained at approximately 460 feet above mean sea level (amsl). There is a pumping system that raises water from the sump and discharges it into a tributary to Pipe Creek where it then flows into Sandusky Bay and Lake Erie. The quarry's current average pumping rate is more than one million gallons per day. Pumping rates and volumes are reported annually to the Ohio Department of Natural Resources (ODNR), Division of Water. The annual pumping rates for 1990 through 2004 are listed on Table 1.**

Response 4: Comment noted.

Comment 5: **The quarry walls are intersected with hundreds, if not thousands, of vertical joints aligning with the regional jointing patterns for this part of Ohio. We measured one joint on the top of Bench 3 (floor of the quarry at Bench 2) as having a direction of N 450 E. The perpendicular jointing set will be approximately N 450 W. While the**

quarrying operation tends to enlarge the joint widths, the joint faces, where viewed face on, are case-hardened on the joint surfaces, which indicates that they have been open and active for a very long period of time. The ease of the dewatering operation indicates an extremely high velocity for the ground-water flow rate along the secondary fracture joints and bedding planes in all three of the carbonate formations exposed at the quarry.

Response 5: Comment noted. The observations of fracture orientation within the quarry are consistent with findings of the fracture trace study completed as part of the 1997 Sitewide Groundwater Investigation by SAIC as provided in the Remedial Investigation report. Undoubtedly there are areas that have extensive fracturing which facilitates groundwater movement. However, investigations have found that this is not consistent across the site. For example, wells installed in the PBOW Burning Grounds produced only limited amounts of water. Similarly, some offsite wells on the north and northwest sides of PBOW produced only limited amounts of water. Typically the boring logs describe the limestone units in these areas as "massive" with few observed fractures. Regardless, it is thought that there may be a more well-developed set of fractures and joints in the central portion of PBOW which results in the observed groundwater trough shown on contour maps.

Comment 6: **The quarry has been in operation since 1912. There is additional space on the current property and only the southeastern portion of the quarry has been quarried to the bottom of Bench 5. There is a significant amount of rock reserve at the quarry. It is anticipated that the quarry will be in operation for many more years to come. As the quarry deepens over the larger portion of its footprint, it may well be necessary to increase the dewatering pumping rate to maintain a dry hole for the rock excavation. The quarry is currently operating within all the requirements of the ODNR Division of Water in terms of water withdrawal reporting. Since it is a pre-existing water withdrawal user, the quarry operation has the right of first withdrawal.**

Response 6: Comment noted. As noted in other comments regarding this issue, to date DOD-related contamination has not been detected in off site monitoring wells or private wells. Because of this, further investigation for DOD contamination is not warranted at this time.

Comment 7: **Since the Wagner Quarry is down gradient from the Plum Brook site, it is anticipated that the longest 'tail" of the dewatering capture zone will be to the south-southwest, back into the Plum Brook site. The dewatering cone will follow the dominant jointing patterns and will probably not involve much matrix flow. This dewatering cone**

probably explains most, if not all, of the ground water trench found at PBOW in the earlier Shaw ground water reports.

Response 7: The available data does not support the extension of the groundwater trough observed on PBOW to the Wagner Quarry. Monitoring wells were specifically installed along the perimeter of PBOW and in offsite areas to address this concern. Groundwater levels at the northeast portion of PBOW show that the trough is truncated and does not extend to the quarry. This information will be considered during further evaluation of the FS. However, it is not anticipated that this will affect the selection of a preferred alternative for this site.

Comment 8: **There is no off-site Plum Brook Ordnance Works (PBOW) monitoring well on the Hanson Wagner Quarry property. Blake Silkwood reported that someone approached him some years ago about placing a monitoring well on the Wagner Quarry property. Mr. Silkwood indicated that company policy required a "hold harmless" clause for the well installation and future access. For some unknown reason, whoever discussed the issue with Mr. Silkwood was unable and/or unwilling to provide this standard Ohio agreement so no monitoring well was installed. In addition, the sump is not identified as a surface sampling location for Plum Brook. Therefore, the quality of the ground water moving from the PBOW into the Wagner Quarry sump is unknown and the quarry staff members that come into contact with the sump water have not been evaluated for possible risk factors. In addition, the NPDES permit for dewatering the quarry would not require monitoring for TNT breakdown products, as none were made on the quarry site, so no one is conducting a sampling program for the discharge water flowing into Pipe Creek. When Shaw and/or other contractors and/or Army Corps of Engineers are ready to discuss future monitoring efforts on the Wagner Quarry property, Mr. Silkwood can be reached at (419) 483-4390 of by e-mail at Blake.Silkwood@Hanson.biz.**

Response 8: For purposes of clarification, the USACE sought to collect surface water samples from the quarry in early 2004, once it was apparent that no agreement could be reached for the installation of a monitoring well. The USACE drafted a right of entry agreement and submitted it to Wagner Quarry for the purpose of sampling water from the quarry only. Wagner Quarry attorneys insisted that a standard U.S. Government clause, which is required to disclose the rights of the property owner and the responsibility of the U.S. Government, be stricken before a right of entry could be granted to sample this water. Because this was a U.S. Government disclosure issue, the USACE could not delete this clause. Right of entry was thus not granted by Wagner Quarry to sample the quarry water. While the "standard Ohio agreement" for obtaining right of

entry works for state agencies, this in no way supersedes Army requirements for the access by their contractors.

Specific Comments on the Report

Comment : **With this review, I have tried to anticipate the locations in this Feasibility Study where the dewatering efforts at the Wagner Quarry would come into play. Neither the dewatering efforts at the NASA Reactor or the Wagner Quarry are incorporated into this current version of the Feasibility Study. This review should provide a template for the revision of the feasibility study process and help develop an acceptable set of options for the ground water clean-up at Plum Brook.**

Response : A General Statement by USACE Regarding the Reviewer's Perspective on Wagner Quarry: The dewatering activities of the Wagner Quarry are indirectly incorporated into the feasibility study through the site-wide groundwater model. While it has been accurately identified that the model boundaries do not encompass the Wagner Quarry, the drawdown in bedrock water levels are indeed incorporated into the model. Water withdrawal from the Reactor sumps was simulated in the groundwater model along with the groundwater extraction from the active pump and treat system on PBOW. The Army feels the options for addressing groundwater contamination at this site are appropriate for the conditions at PBOW. Further, the intent of the statement ". . . help develop an acceptable set of options . . ." at the end of the paragraph is unclear since the reviewer has not specifically addressed any technical issues with the alternatives presented.

As stated in the response to Comment No. 8 above, the USACE requested a right of entry to sample the Wagner Quarry water. For apparent legal reasons, the Wagner Quarry attorneys denied this request. Therefore, no analytical data exist for the quarry water as to whether PBOW-related contaminants are present. Nor were any studies done to evaluate what effect, if any, the presence of the quarry may have on groundwater transport at PBOW. No pre-quarry baseline groundwater elevations exist in the area to evaluate in making a determination as to what degree the quarry may influence groundwater flow at PBOW. However, the groundwater analytical data and water level measurements collected on site and downgradient from the site, to date, in the direction of the quarry support the position that 1) the effect of the quarry on groundwater flow at PBOW (which is a minimum of 0.8 mile away) may be minimal and 2) detectable levels of PBOW contaminants are not migrating off site.

The assertion in several of the reviewer's comments that the quarry "controls" groundwater transport at PBOW are not supported by any analytical data or water level measurements. The USACE understands the conditions that the reviewer believes could be present between PBOW and the quarry; however, without data, her statements concerning the massive impact of groundwater

flow by the quarry are only opinions based on assumptions. The USACE maintains that the existing analytical data should be reviewed and given proper weight before assumptions regarding groundwater flow are presented. Only after this review should statements concerning groundwater flow be made; assumptions and opinions should be reasonably identified as such.

Comment: **<u>Executive Summary</u>. No specific comments and/or corrections were made to the Executive Summary as this is a shortened portion of the full text. Comments and/or corrections made in the full body of the text that affect the information in the Executive Summary should have those corrections brought forward.**

Response: Comment noted.

Comment 1: **<u>Section 1.4.1 Nature and Extent of Soil Contamination</u>. This is a good summary of conditions at the site. (page 1-11)**

Response 1: Comment noted.

Comment 2: **<u>Section 1.7 Groundwater Modeling and Fate-and-Transport Modeling (For additional comments see Appendix A discussions)</u>. Measurable impacts on the underlying carbonates are also a function of how actively portions of Plum Brook are being dewatered. (1-33)**

Response 2: The effect of the quarry is implicitly incorporated in the groundwater model through site boundary conditions which simulate observed head in the areas off of PBOW.

Comment 3: **<u>Section 1.8, Groundwater Risks</u>. Workers at the Wagner Quarry are also part of the "at risk" population of workers who could be impacted by ground water contamination at Plum Brook. This population needs to be added to the evaluated groups. (page 1-35)**

Response 3: An attempt was made to install three wells downgradient of the site between PBOW and the quarry. Water was not produced at locations BED-MW32 and BED-MW34, but was produced as BED-MW33 (refer to Figure 2-1 of the FS). No nitroaromatics were detected in this well, nor were any nitroaromatics detected in off-site private well PR-008, which is located approximately 840 feet north of the PBOW facility boundary, between PBOW and the quarry. Only abandoned well BED-MW27, located inside the facility boundary had low but detectable concentrations of nitroaromatics (maximum of 1.4 µg/L 2,4-DNT and 1.5 µg/L 2,6-DNT). This well was abandoned due to a nuisance odor from hydrogen sulfate; because it exhibited sulfate concentrations (>1,000 mg/L) this groundwater is clearly not fit for potable use.

The information on groundwater concentrations is reiterated above to make the point that contaminants have not been detected in off-site groundwater, and concentrations at the property boundary do not suggest that groundwater may be migrating off-site at appreciable concentrations. The USACE has tried to obtain analytical data from the quarry water and still agrees that sampling the water would be appropriate. However, the presence of the quarry would locally depress the water table and would draw groundwater from all directions, not just from the direction of PBOW. The USACE is of the opinion that the resulting quarry water is extremely unlikely to contain detectable levels of PBOW-related contaminants for the following reason: 1) Even the highest concentrations collected along the PBOW property boundary are quite low (maximum of 2.6 µg/L combined DNTs during any single sampling event) and 2) this concentration would be highly diluted by the drawing effect of water from all directions in the vicinity of the quarry and would be considerably less than the reporting limits (typically 0.4 µg/L combined). Such miniscule concentrations, if this is the case, would not represent an unacceptable risk to humans even if the water were used for potable purposes. Also, even at the maximum detected concentrations at BED-MW27 (located over 1 mile upgradient of the quarry), worker exposure would result in de minimis levels of risk.

Comment 4: **The Wagner Quarry sump is discharged to a tributary of Pipe Creek. This discharge becomes a ground water to surface water transport path which allows contaminated ground water to move to environmental receptors. This transport path has not been previously identified or investigated and needs to be for completion of the Remedial investigation process for the site. (page 1-36)**

Response 4: It is not established that the quarry water is contaminated (See response to previous Comment No. 3). Even if the extremely conservative assumption were to be made that the quarry water contains concentrations of 2,4-DNT and 2,6-DNT equal to the maximum groundwater concentrations detected in on-site boundary well BED-MW27 (1.4 µg/L and 1.5 µg/L, respectively), these concentrations are orders of magnitude less than the OEPA Lake Erie Basin Aquatic Life Criteria for 2,4-DNT (790 µg/l) and 2,6-DNT (1,500 µg/L) (OEPA, 2007) and would not pose a hazard to aquatic life. However, the existing data from site investigations do not suggest that this exposure pathway is complete.

Reference: OEPA, 2005, *Lake Erie Basin Aquatic Life and Human Health Tier I Criteria, Tier II Values, and Screening Values,* Division of Surface Water, July 27.

Comment 5: **<u>Section 2.2.2 Local Geology</u>. The designation of the thickness of the Delaware Limestone and it's characteristics in the Shaw report are at odds with the stratigraphic column and site visit information from the**

Wagner Quarry. The descriptions for the carbonate wells need to be corrected based on local, field-identified formational data. (See information presented on Figures 3 and 4.) Once natural petroleum products are intersected, the wells have penetrated the Columbus Limestone. The strong hydrogen sulfide gases and elemental sulfur are more typical of the Detroit River Dolostone. (page 2-2)

Response 5: Agreed. Further evaluation will be completed on the Delaware Limestone and underlying units to ensure our discussions are consistent with off-site observations. However, the reference to the Delaware producing petroleum and hydrogen sulfide was based on discussions with Ohio DNR.

Comment 6: **<u>Section 2.2.3 Local Soils</u>. The soils section is badly out of date. It should be updated to incorporate soils changes in the February 2002 Interim Report and the Erie SSURGO DDS 2.1 Soil Survey available from the Erie Soil & Water Conservation District. (page 2-3)**

Response 6: The section will be deleted from the report since this is a groundwater evaluation and surface soils are not pertinent to this study. Future reports will include the updated soils discussion as appropriate.

Comment 7: **<u>Section 2.2.4.2 General Site Hydrogeology</u>. The direction of flow in the underlying carbonate bedrock to the north northeast is the direction of flow that would be expected as a reflection of the dewatering sump at the Wagner Quarry. Flow is controlled by travel along the directions of regional jointing and the static water levels are controlled by how close or how far the measuring points are from the active dewatering cone of the quarry. There is an additional, smaller complication from the dewatering sump of the NASA Reactor that also needs to be considered but the quarry dewatering effort is so large and the elevation of the sump so deep that this system may overwhelm any other system that has an impact on the site. (page 2-4)**

Response 7: This comment is speculative with respect to the dewatering at the quarry and at the NASA reactor. The reactor pumps an average of only about 2 gpm; this would have little impact on flow, except for a very localized area. Undoubtedly the groundwater flow is controlled by the fracture within the limestone bedrock. It is well known that the dominant fracture orientation is northeast to southwest based on earlier groundwater studies at this site. See also General Response to the Reviewer's Comments Regarding Wagner Quarry.

Comment 8: **<u>Section 2.4 Site Conceptual Model</u>. While regional ground water recharge flow can be viewed in an "averaged" approach, contaminant transport is the "fastest route". The second paragraph describes a hydrogeologic setting that is poorly represented by the MODFLOW**

ground water flow model which assigns averaged input values for each grid cell. There are much better fractured rock models which allow for multiple vertical and horizontal hydraulic conductivities that should have been used to model the setting at Plum Brook. The modeling results could have been more believable. (page 2-5)

Response 8: The intent of the groundwater modeling was to evaluate the potential for contamination from the overburden/shale to migrate down into the deeper bedrock and to provide a relative timeframe for that to occur. This would allow prioritization of source area remediation to address the worst sites first due to limits in funding for this site. This of course is dependent on the selection of a preferred alternative which may or may not include active remediation. The limitations and resulting uncertainties of using MODLOW to simulate fracture-dominated systems are well recognized by the authors of this report. While models are available to simulate fracture-dominated systems, extensive additional data is required including the density of fracture networks as well as the size of the fractures. Regardless, there is sufficient data available currently to select a remedy for this site and additional modeling is not needed.

Comment 9: **<u>Section 2.5.2 Groundwater Use</u>. I cannot find the well referenced as "the nearest private well to PBOW is approximately 840 feet northeast" on Figure 1-2. Please add it to the figure. (page 2-6)**

Response 9: Reference will be changed to Figure 2-1.

Comment 10: **This section discusses six known private wells within a mile down gradient from PBOW, most, if not all, missing on Figure 1-2, but fails to mention the Wagner Quarry which is considerably less than one mile down gradient from Plum Brook and is actively dewatering at least portions of Plum Brook on a continuous basis. The Wagner Quarry needs to be added to the text and its dewatering cone needs to be factored into any ground water flow model created for the Plum Brook site. The top of water level in the sump is approximately 460 feet amsl which is as much as 200 feet lower in elevation than some of the static water levels recorded at the far edges of the site. (page 2-7)**

Response 10: The elevation of the limestone groundwater at the far northeast boundary well BED-MW22 is approximately 592 feet amsl. This well is approximately 0.8 mile (4200 feet) from the nearest point of the quarry. Well BED-MW33 is located northeast of well BED-MW22 and is approximately 1500 feet closer to the quarry. The elevation measurements of the limestone groundwater at this well ranges from approximately 539 to 551 feet amsl. It is noted that most of the wells on PBOW vary in measurement by less than 3 feet among measurement events. This includes far northern on-site well BED-MW22. It is possible that the markedly larger differences between measurements at BED-MW33 are

associated with dewatering at the quarry. Note that BED-MW33 is 1500 feet closer to the quarry than BED-MW22, and had a groundwater elevation that is 50 feet lower. If the location of BED-MW33 could be moved along the approximate contour such that it was at the midpoint between BED-MW22 and the nearest point of the quarry, it would be approximately 2,500 feet from BED-MW33 and about 1,700 feet from the quarry. The change in elevation of 50 feet from BED-MW22 to BED-MW33 along this path equals a change in elevation of 20 feet per 1000 feet laterally. Thus, in the 1,700-foot distance from BED-MW33 to the edge of the quarry, a change in elevation of approximately 34 feet would be expected. This would result in an expected groundwater elevation of approximately 510 feet amsl in the vicinity of the nearest (southwestern) portion of the quarry. The discrepancy between this value and the measured level of 460 feet in the quarry is 50 feet. The decrease in groundwater elevation from the "moved" location of BED-MW33 to the quarry is about 85 feet over this 1700-foot distance, or about 50 feet per 1000 feet laterally. This value is 2.5 times greater than that from BED-MW22 to BED-MW33. This indicates that the influence of the quarry within 1,700 feet is far greater than any influence of the quarry between BED-MW22 and BED-MW-33.

As mentioned at the beginning of the previous paragraph, the fluctuations in elevations at BED-MW33 suggest a markedly greater influence at the BEWD-MW33 location than what is observed at the PBOW boundary. Therefore, the influence of the quarry on site groundwater elevations appears to be minimal compared to the influence within 1700 feet of the quarry and may be negligible. As would be expected, the steepest hydraulic gradients were observed near the quarry, and dissipate in the upgradient (southwest) direction.

Comment 11: **<u>Section 2.6 Groundwater Quality Overburden/Shale</u>. The reported background chloride level of 34,600 mg/L in the shale is extremely high for these shale formations and should be investigated to determine if there is a possible man-made contamination reaching the well. These numbers at shallow depths are more typical of wells that have been contaminated by highway de-icing activities. In addition, the dissolved solids level of 43,800 mg/L is unusually high for these formations. (page 2-7)**

Response 11: The comment is noted. However, the background well in question (BED-MW20) likely represents natural conditions at the site. During sampling of this well, natural gas (methane) was likely present based on LEL readings collected during sampling. Further, this well is in close proximity to a former natural gas well at the site. As such, it is not unreasonable to expect higher concentrations of dissolved solids as well as high detections of chloride.

Comment 12: **<u>Delaware Limestone Bedrock</u>. Once natural occurring petroleum is reached, the well has entered the Columbus Limestone. By observations at the Wagner Quarry, there is no naturally occurring petroleum in the Delaware Limestone. Any natural petroleum encountered in drilling should be very thick and viscous. Typically it's seen as asphalt staining on the rock cores. Other types and consistencies of petroleum products encountered in drilling are probably NOT from natural sources and should be collected and fingerprinted for source of origin. Any escaped man-made hydrocarbons should be remediated as part of the Plum Brook clean-up activity. (page 2-8)**

Response 12: **N**ASA is currently fingerprinting the petroleum sampled on PBOW. The asphalt like description of petroleum at the Wagner Quarry is interesting, but may not be pertinent to PBOW (as discussed in the response to reviewer's general comment No. 2). Discussions with Ohio DNR were the basis for suggesting the petroleum observed on PBOW was likely naturally occurring. Any petroleum discovered to be from anthropogenic sources will be addressed per OEPA regulations.

Comment 13: **This is the first reference to "sellite (sodium sulfate) and its disposal that I remember seeing. What was it used for? (page 2-8)**

Response 13: Text will be added that sodium *sulfite* was used as a rinsing agent to purify TNT.

Comment 14: **<u>Section 2.7 Potential for Natural Attenuation of Nitroaromatics</u>. This section fails to list "dewatering and dilution" as another, and very likely major cause of the removal of nitroaromatics in the Delaware Limestone and underlying formations. (page 2-8, 2-9)**

Response 14: The analytical data and groundwater measurements do not suggest this. A steep hydraulic gradient that would be associated with an intensive dewatering effect was not observed. However, since dilution is a part of natural attenuation, it will be included in the text. See also the general statement by the USACE regarding the reviewer's perspective on the Wagner Quarry.

Comment 15: **<u>Section 3.2 Site-Specific Considerations</u>. This section states that "neither the overburden/shale nor the Delaware limestone bedrock is a desirable source of groundwater for human consumption." This statement significantly misrepresents the critical importance of the Delaware and underlying Columbus limestones as major private water well resources and/or public ground water supplies from Lake Erie to the Ohio River. In addition, the shales are also used heavily as private water well resources in rural areas from Lake Erie to the Ohio River; although their yields are greatly reduced when viewed against**

the yields found in the Columbus and Delaware limestones and their water quality is diminished. If water quality is significantly impacted at Plum Brook, manmade sources are probable contributors. Please rewrite this section to remove the unsupported bias against the water quality of the Columbus and Delaware limestones. (page 3-1)

Response 15: Disagree. The water quality discussions are based on observed conditions at this site. There is some disagreement between the reviewer and the authors of this report concerning the source of the petroleum. Regardless, the wells produce extreme amounts of hydrogen sulfide that cannot be tied to anything but natural sources. Natural sources for both the petroleum and the hydrogen sulfide were noted in the reviewers comments. Further, while the Delaware and Columbus units may be sources of potable water in areas from Lake Erie to the Ohio River, most of that is not pertinent to this discussion. What is important is to look at the portion of the aquifers downgradient of the site. Specifically, is groundwater used as a source of potable water for current and future residents? The findings from the years of study at this site suggest that Lake Erie will be used as the source for potable water into the future.

Comment 16: **The report in this section mixes the properties of the Delaware Limestone, the Columbus Limestone, and the Detroit River Dolostone. It is important to know which formation has been reached when assigning properties. This needs to be rewritten correctly. (page 3-2)**

Response 16: Further evaluation of historical boring logs will be completed to determine if the contact between the two units can be clearly distinguished and the text revised accordingly.

Comment 17: **<u>Section 3.4 Remedial Goal Options, Delaware Limestone</u>. The table referenced at the end of the 2nd paragraph should be Table 3-2. (page 3-3)**

Response 17: Actually, Table 3-1 should be referenced; revision will be made accordingly.

Comment 18: **<u>Section 3.6 Areal Extent of Contaminated Groundwater</u>. Bottom of page. Are the remediation areas of TNT-A subject to change as removals begin like TNT-B and TNT-C? If so, what does that do to the ground water remediation areas? (page 3-7)**

Response 18: The removals were performed for TNTB and PRRWP. Remedial actions will be performed at TNTA and TNTC. The assumptions to estimate the contaminated areas of soil were revised for TNTA and TNTC so that the resulting area for remediation of TNTA was only slightly less than the area actually remediated for TNTB, and the estimated area for TNTC is over 50 percent greater than the TNTB area. Therefore, it is unlikely that the actual

areas of soil to be remediated will be substantially larger than those which are estimated.

Comment 19: **<u>Section 3.7 Volumes of Contaminated Groundwater – assumptions page 3-10</u>. Migration into the competent shale will depend on fracture flow. Identification of the migration will depend on where the sampling points are located and how wide the diameter of the sampling points. If the points are small, they can miss the migration routes. Therefore, what were these assumptions based on? (page 3-10)**

Response 19: The volumes of contaminated groundwater contain some uncertainty due to the limited data available for the site which is why there are recommendations for additional delineation sampling prior to any active remediation (if that option is ultimately selected). The volumes assume that most of the contamination is retained in the overburden and weathered upper zones of the shale. The site data support this in that wells installed in competent shale near overburden sources of contamination are "clean" with respect to nitroaromatics. Further, wells installed in the underlying limestone bedrock through contaminated intervals of the overburden show no contamination either where the shale units are present. This does not preclude the possibility of some contamination existing within fractured and fissile bedding planes of the shale. The lateral extent of contamination was based on direct observations at this site, the completed soil remediation at TNTB, and observations at other TNT manufacturing facilities. The reviewer touches on a major concern at this site, that of fracture controlled flow and contaminant migration. The concern is that if this is indeed the case, current remediation strategies will either be ineffective (e.g. pump and treat) or prohibitively expensive (e.g. ISEB). For example, pump and treating of contaminated groundwater would be difficult if not impossible due to the intermittent nature of groundwater within the shale unit. Further, diffusion into the rock itself and the tendency for nitroaromatics to strongly sorb to the organic shales would lead to excessively long times required for remediation. The other option would be ISEB which is very effective in unconsolidated sediments, albeit injection points may need to be very closely spaced to allow the contact time necessary for remediation. That said, there is not a cost effective method for injection of compounds necessary for ISEB in a bedrock setting.

Comment 20: **We have contaminated carbonates below the shale so why is the shale assumed to be capable of preventing contamination from reaching the carbonates? (page 3-10)**

Response 20: The text clearly states that the carbonate contamination is likely the result of leaching of contaminants where the shale is thin or absent. This is particularly the case in the West Area and Pentolite Road Redwater Ponds.

Comment 21: **How does the dewatering at the site by the NASA Reactor and the Wagner Quarry come into play in these assumptions? (page 3-10)**

Response 21: These assumptions relate to the overburden/shale groundwater. Neither the reactor nor the quarry should affect the overburden/shale to a significant degree. Experience at the site suggests that seasonal variations are the significant influence to overburden/shale groundwater levels at the site. Therefore, if ISEB is selected as a remedial technology at the site, it will be necessary to implement this during a wet season/year since it requires saturated conditions.

Comment 22: **The "very low concentrations of nitroaromatics" in the "Delaware Limestone" also suggests that they have been pumped away. Was this remediation by off-site pumping route taken into consideration here? (page 3-10, 3-11)**

Response 22: The section referenced is for the overburden/shale units. The analytical data and groundwater measurements do not suggest that significant contamination is getting to the limestone bedrock. A steep hydraulic gradient that would be associated with an intensive pumping effect was not observed. The remedial alternative discussed (ISEB) would effectively treat the overburden/shale groundwater in a relatively short (months) time period. See also the General Statement regarding the reviewer's perspective on the Wagner Quarry.

Comment 23: **<u>Section 3.7.1 Volumes in Overburden/Shale for Protection of the Delaware Limestone Bedrock Groundwater</u>. I do not feel confident with this methodology and approach. I don't see the Wagner Quarry pumping volumes and rates being part of this set of calculations. (page 3-11)**

Response 23: These assumptions are based on on-site drinking water use of the overburden/shale. The remedial alternative discussed (ISEB) only addresses treating this unit.

Comment 24: **<u>Section 3.8.1 Location-Specific Applicable or Relevant or Appropriate Requirements Special Areas</u>. The report states that the "National Wetlands inventory maps of PBOW do not show wetlands areas on the installation". Has the Erie Soil & Water Conservation District been asked to assist with the wetlands survey review for the sites? Some of the settings, especially the Red Water ponds lend themselves to wetlands development and delineations. (page 3-13)**

Response 24: No wetland surveys specific to the site have been done. However, wetlands are not expected to be impacted by any groundwater remedial actions that might be taken. Section 3.8.1 will be revised to state that while wetland areas may be present on site (although not confirmed by a

survey), wetlands requirements are not ARARs for the proposed remedial action at the site. This is due to the fact that remedial actions will not take place within a wetlands area and are not anticipated to impact wetlands at the site.

Comment 25: **<u>Section 4.3.1 Long-Term Monitoring</u>. "Groundwater modeling indicates that COCs in Delaware Limestone bedrock groundwater in the PRRWP Area plume may migrate off site within 150 years." Reviewing the elevation of the top of the sump in the Wagner Quarry and the rate of ground water withdrawal there to keep the quarry dry, a more conservative view would be that the ground water contamination in the carbonates has been moving off site for years. The quarry was already in operation and pumping when the PBOW was built. (page 4-1)**

Response 25: These statements are not corroborated by the analytical data. No detections have been observed off site and only low and sporadic detections have been observed in onsite wells.

Comment 26: **"The monitoring well closest to the property boundary within the PRRWP Area plume is contaminated, although the nearest off-site well is not". Which well is that? Is that nearest off-site well in the correct location to intercept ground water moving off of the PBOW site towards the dewatering sump at the Wagner Quarry? (page 4-1)**

Response 26: The contaminated on-site well is BED-MW15. The nearest off-site well is BED-MW33, which is somewhat east of the path between BED-MW15 and the quarry. However, well BED-MW22 is located just within the boundary and is located directly between BED-MW15 and the quarry; TNT was detected at low (0.27 ug/L) levels in one sample from well BED-MW22.

Comment 27: **If PBOW is going to include long term monitoring in the remediation mix, there must be properly placed monitoring wells drilled deep enough to monitor ground water flow towards the Wagner Quarry. This monitoring route appears to be missing on Figure 1-2. (page 4-2)**

Response 27: Feasibility studies do not typically include site-specific details the reviewer is requesting. As part of any action at this site, a detailed work plan will be completed. This work plan will outline details for any other supplemental investigations or monitoring that is required to implement the preferred alternative. The comment concerning placement of a well at or near the quarry will be evaluated at that time.

Comment 28: **<u>Section 4.3.2 Monitored Natural Attenuation Effectiveness</u>. Plum Brook cannot use monitored natural attenuation for a remediation alternative because at least portions of the site are undergoing active**

dewatering by the Wagner Quarry. Plum Brook would have to be able to control and/or at least predict ground water flow off site. They can't because the quarry has control of at least the northern portion of the site with its dewatering activities. (page 4-2)

Response 28: The statement that monitored natural attenuation cannot be used for the site is without basis. The effectiveness of this alternative must be evaluated based on the current conditions at the site. As noted in the feasibility study, the conditions within the limestone bedrock appear to be ideal for the degradation of site contaminants. The rate at which they degrade must be determined but it is entirely plausible that natural attenuation will continue to occur regardless of the activities at the Wagner Quarry. Also see response to Comment No. 22 .

Comment 29: **<u>Implementability</u>. Before natural attenuation could even be considered at any point on the Plum Brook site, the full area impacted by dewatering at the NASA Reactor and at the Wagner Quarry will have to be determined. Only areas outside the area of influence of the dewatering operations could be considered for this application. (page 4-4)**

Response 29: Please see response to Comment No. 28 regarding the quarry. Even if the quarry has affected the groundwater flow at PBOW, the water level measurements do not indicate a steep gradient. Current data suggests that natural attenuation is occurring. We have seen no data to suggest that monitoring this natural attenuation is not reasonably possible. Once pumping is stopped at both the quarry and the reactor area, hydraulic gradients and hence flow velocities will decrease resulting in two possible effects: 1) concentrations in the bedrock could actually increase due to less dilution; or2) the slower groundwater velocities would allow more time for natural attenuation to degrade the nitroaromatics. It is important to note that ***monitored*** natural attenuation includes groundwater sampling on a regular basis to record any significant changes that may occur. Further, it is important to note from EPA guidance documents that decisions regarding selected alternatives can be revisited at any time in the process based on changes in site conditions, developments in new remedial technologies, etc. Thus, the selection of any remedial alternative is not the end of public involvement in this process.

Comment 30: **<u>Section 4.3.3 Groundwater Extraction Effectiveness</u>. At least portions of the Plum Brook facility are already undergoing a ground water extraction process and have been since the facility was in operation. Furthermore, it is not a static volume that can be calculated and be expected to remain the same over time. With the ongoing increase in depth and size of the Wagner Quarry over time as the quarried reserves are removed, that level of unplanned "ground water extraction" will continue to grow. (page 4-4)**

Response 30: Please see response to Comments 22 and 39. Also refer to the General Statement by the USACE at the beginning of these comments. Discussions with Ohio DNR suggested that the quarry likely will not expand greatly; regardless, the remedial design for groundwater extraction wells can account for potential variability in groundwater flow.

Comment 31: **<u>Implementability</u>. This scenario does not include the current impact of the Wagner Quarry or the NASA Reactor on the site either currently or over time. It also does not include the long-term plan of operations for either of these facilities and how those plans will impact this option over time. Without including those aspects, this option is not acceptable for the WARWP and especially not for the PRRWP which is considerably closer to the two identified dewatering sites in the region. (page 4-5)**

Response 31: Please see response to Comments 22 and 39. Also refer to the General Statement by the USACE at the beginning of these comments. As noted above, the systems can be designed to accommodate additional groundwater extraction for changing water levels. If groundwater extraction were to be included as part of the selected remedial alternative, monitoring of the systems would occur to ensure they are operating properly, and the systems would be modified as needed to address changing conditions. This is the purpose of the five-year reviews conducted at remediation sites that continually evaluate system performance. As noted previously in these comment responses, the preferred alternative can be modified at any point in the process based on changing site conditions or new information.

Comment 32: **<u>Section 4.3.6 In Situ Enhanced Bioremediation</u>. This alternative has to be reviewed against the active dewatering cones from the NASA Reactor and the Wagner Quarry. Active ground water movement may alter the amount of enhanced carbon substrate that needs to be added to the contamination plumes. (page 4-14)**

Response 32: Injection would be into the overburden/shale groundwater. Neither the reactor nor the quarry should affect the overburden/shale since this would be a one-time remedial event that occurs over a relatively short time frame. The ISEB cannot be effectively used in bedrock settings. Further, the objective of ISEB is to produce reducing conditions in the groundwater; the bedrock groundwater is already sufficiently reduced due to natural conditions at this site.

Comment 33: **<u>Section 4.3.7 In Situ Chemical Oxidation</u>. The impact of the reactor and the Wagner Quarry dewatering cones on the carbonate bedrock is not factored into this process. (page 4-17)**

Response 33: Injection would be into the overburden/shale groundwater. Neither the reactor nor the quarry should affect the overburden/shale.

Comment 34: **<u>Section 4.3.10 Groundwater Use Restrictions Implementability</u>. "Groundwater use restrictions are implementable at PBOW". No, they are not. Plum Brook is currently being actively dewatered by the NASA Reactor and, dominantly, by the Wagner Quarry. Therefore, regardless of what Plum Brook claims to have as a policy, they don't have control over the ground water flow and off-site migration of contaminants. (page 4-20)**

Response 34: Groundwater use restrictions for the off-site portions of the area would consist of a robust system of various options for protecting off-site receptors. This may include legal, data collection, monitoring, informational, response action, and reporting components. While it is understood that the Wagner Quarry is capturing groundwater, the restrictions proposed would only limit such things as installation of private water wells. Evaluation of the water quality at the Wagner Quarry is a necessary component of the process, but based on observed groundwater concentrations from site wells, it is unlikely there is any appreciable impact to the offsite workers or the ecological receptors in Plume Brook. Therefore, restrictions (other than use for potable water) will not necessarily be required for the Wagner Quarry.

Comment 35: **<u>Section 4.3.11 Apatite II</u>. Given the current "soluble phosphorus" crisis in western Lake Erie and the bays, any solution based on a phosphate process applied to water could have a significant negative public acceptance. (page 4-20)**

Response 35: Comment noted. The limited application of this technology to date has focused primarily on in situ stabilization of metals. The one study of this material cited in the text concerning its potential for remediation of nitroaromatic compounds was inconclusive, as there was significant removal of TNT in the control sample. The technology was not retained for further consideration in the development of remedial alternatives because there is no reliable evidence that it would be effective.

Comment 36: **<u>Section 5.1.5 Reduction of Toxicity, Mobility, or Volume (No Action)</u>. This alternative will potentially impact the environment and the community because of the carbonate bedrock flow to the Wagner Quarry sump. (page 5-3)**

Response 36: Reviewer offers an opinion that even if true would have no affect on the text.

Comment 37: **<u>Section 5.2.1 Description (Groundwater Monitoring and Institutional Controls)</u>. Regarding the remedial components. There already is off-**

site migration of contamination in the direction of the Wagner Quarry. The level of that contamination is unknown, however, because there are no monitoring wells installed, located and designed to intercept that ground water flow before it reaches the Wagner Quarry sump, and monitored on an on-going basis to determine the levels of contaminant transport off site. (page 5-4)

Response 37: The existing data do not support the opinion that off-site migration is occurring in the direction of the quarry as evidenced by no detections of nitroaromatics in off-site well BED-MW33 and off-site private wells. Also, only very low concentrations of nitroaromatics were found in on-site boundary wells BED-MW22 and BED-MW27, which have been abandoned because of nuisance odors due to naturally occurring sulfate.

Comment 38: **Plum Brook already has impacted off-site receptors, the quarry workers at the Wagner Quarry and the environmental receptors in the tributary of Pipe Creek which receives the dewatering flow from the sump pit. The contamination completion pathway is already in place. It is only the level of contamination, both historically and currently being received, that is unknown because the completion pathway is not being monitored. (page 5-4)**

Response 38: The existing data do not support the opinion that off-site migration is occurring in the direction of the quarry (see response to Comment No. 37). Even based on the maximum detections of nitroaromatics at abandoned on-site well BED-MW27, quarry workers would not be adversely affected. Please also see the response to Comment No. 3.

Comment 39: **Plum Brook cannot restrict what it cannot control. For at least the northern portions of the site, Plum Brook does not control the ground water flow off site, the Wagner Quarry does. (page 5-4)**

Response 39: If the USACE (or any other entity) were to implement land-use controls, there is no suggestion that any attempt would be made to "control" the flow regime. The groundwater flow regime at any site will always be subject to natural and/or human influences. The existence of the quarry and any influence that it may have on groundwater does not affect the implementability of land-use controls, as long as the health of those not subject to the controls is not exposed to an unacceptable risk.

Comment 40: **Where would the new wells be located and how deep would they be drilled? (page 5-4)**

Response 40: This type of information is typically not included in the feasibility study. This will be covered at the remedial design stage.

Comment 41: **Once a year monitoring is probably not sufficient for these monitoring wells, given the actual rate of ground water flow in the carbonates. (page 5-4)**

Response 41: Data collected to date does not suggest groundwater transport is occurring at a rate justifying more frequent sampling. Note that a frequency of once per year was used only to estimate costs associated with this alternative. If monitoring were to be included as a component of a selected remedial alternative, periodic reviews would be conducted and monitoring frequency or other components of the selected alternative would be modified as needed.

Comment 42: **<u>Section 5.2.2 Overall Protection of Human Health and the Environment</u>. No, it is not. Please see earlier comments. (page 5-5)**

Response 42: Please see responses to Comment Nos. 3 and 4.

Comment 43: **<u>Section 5.2.6 Short-Term Effectiveness</u>. There already are impacts to the environment and workers off site. The completion pathway exists. Only the amount of the impacts is yet to be defined. (page 5-7)**

Response 43: Please see the responses to Comment Nos. 3 and 4.

Comment 44: **<u>Section 5.2.6 Implementability</u>. The components of Alternative GW-2 are not administratively implementable because the PBOW does NOT control ground water flow on at least the northern portions of the site, the Wagner Quarry does. Plum Brook cannot implement what it cannot physically control. (page 5-7)**

Response 44: Institutional controls have been used at a number of sites where groundwater remediation is either cost prohibitive or technically impractical. Land-use controls are associated with groundwater access and potential use, not control of the flow regime. Please see the response to Comment No. 39.

Comment 45: **<u>Section 5.3 Alternative GW-3 – In Situ Enhanced Bioremediation/Pump and Treat for Mitigation/Protection of the Delaware Limestone Bedrock Aquifer</u>. This is an acceptable physical hydrogeological alternative as long as the Quarry's roll in off-site ground water flow is factored into the plan. (page 5-8)**

Response 45: Comment noted.

Comment 46: **A similar treatment is currently being implemented at the YSI clean-up site in Yellow Springs, OH. The bedrock formations are also carbonates and the glacial materials are similar but coarser-grained.**

This project is being reviewed by Ohio EPA Southwest District Office in Dayton. (page 5-9)

Response 46: Comment noted.

Comment 47: **<u>Section 5.3.1.2 P&T with Reinjection in Delaware Limestone Bedrock Aquifer – BED-MW27 monitoring well discussion, bottom of page 5-12</u>. The discussion of "a naturally occurring light nonaqueous-phase liquid (LNAPL) petroleum hydrocarbon" that ranges in thickness "from a sheen to as much as 0.5 feet on the surface of the groundwater" is completely at odds with the descriptions of the natural petroleum products intersected at the Wagner Quarry. The only petroleum products encountered there are thick and dense. The possibility exists that the LNAPL in BED-MW27 is from a man-made source. It needs to be fingerprinted as soon as possible to identify the source. There may be an on-site release of LNAPL materials that also needs to be remediated. (page 5-12)**

Response 47: NASA is currently conducting an evaluation of the LNAPL at PBOW. The authors of this FS report discussed the petroleum at this site with Ohio DNR personnel during preparation of the earlier RI report. An explanation as to the observation of the viscous petroleum at the Wagner Quarry is addressed in the response to the reviewer's general comment No. 2. Further discussion of this issue will be completed at a future date, pending receipt of the fingerprinting data.

Comment 48: **<u>Section 5.3.1.3 Groundwater Monitoring</u>. Where will the new wells be installed and which wells would be monitored? (page 5-13)**

Response 48: If monitoring were to be included as part of the selected alternative, this issue would be addressed at the remedial design stage. See response to reviewer's comment No. 27.

Comment 49: **<u>Section 5.3.1.4 Institutional Controls</u>. Plum Brook cannot apply institutional controls to ground water use because at least part of the site is being actively dewatered by the Wagner Quarry and Plum Brook does not have flow control. (page 5-14)**

Response 49: Land-use controls are associated with groundwater access, not control of the flow regime. Please see the response to Comment No. 39.

Comment 50: **<u>Section 5.3.2 Overall Protection of Human Heath and the Environment</u>. "Contaminated groundwater does not present a threat to ecological receptors or other environmental media, as impacted ground water does not discharge to surface water". This statement is not true. The pathway from Plum Brook to the Wagner Quarry sump to the tributary of Pipe Creek has been completed. The levels of**

contamination being transported have not yet been tested. Monitoring periods need to be significantly shorter than yearly because the time-of-travel in the carbonates is rapid. (page 5-14)

Response 50: It is true that USACE was denied access to sample surface water from the quarry. However, even if the maximum detected concentrations of COC from on-site boundary well BED-MW27 were to be discharged directly into the tributary to Pipe Creek, OEPA ecological criteria for the Lake Erie Basin would easily be met. BED-MW27 is the nearest on-site or off-site well to the quarry that shows detections of nitroaromatics. Please also refer to the response to Comment No. 4. Note that this section is not intended to address monitoring frequency; see the response to the reviewer's Comment No. 41 concerning monitoring frequency.

Comment 51: **<u>Section 5.4.1.3 Groundwater Monitoring</u>. Where will the wells discussed in this section be located? Monitoring the wells once a year is probably not often enough based on the active dewatering operations at the NASA Reactor and at the Wagner Quarry. (page 5-22)**

Response 51: This issue would be addressed at the remedial design stage. See response to reviewer's comment No. 27.

Comment 52: **<u>Section 7.2 Development and Evaluation of Remedial Alternatives</u>. Plum Brook cannot apply intuitional controls to ground water because at least on the northern portion of the site, they do not control the ground water flow, the Wagner Quarry does. (page 7-1)**

Response 52: Land-use controls are associated with groundwater access, not control of the flow regime. Please see the response to Comment No. 39.

Comment 53: **<u>Section 7.3 Recommendations for Additional Work</u>. I agree with all the work items listed. I recommend the expansion of the second item discussing "Groundwater flow within the Delaware Limestone" to include the following additional work efforts:**

a. Conduct a dye test of the carbonate wells on site to determine the time of-travel to the Wagner Quarry sump. Assistance can be requested from ODNR's Division of Water. They have experience with dyetesting these formations.
b. Create a new ground water model that more accurately represents the fractured bedrock setting. When running the new model, add the Wagner Quarry sump elevation and pumping rate and the measured 13 time-of-travel from the dye test to help in the model calibration. (page 7-4)

Response 53: The Army believes that any testing of the water at the Wagner Quarry should be restricted to site-related contaminants (i.e., nitroaromatics). This testing will first establish if there is any exposure risk at the quarry. This will also serve as a "tracer test" although it is recognized that it will not provide information on time of travel for advective flow, but would provide time required for migration of contaminants. Currently this type of information is not necessary to proceed with selection of a preferred alternative. The groundwater modeling as presented is sufficient to support the selection of a preferred alternative for this site. The intention of the modeling was to:

- determine if the soil remediation in the unsaturated zone was sufficient to protect groundwater;
- determine if residual overburden groundwater concentrations will migrate into the deeper limestone (regional) aquifer and result in unacceptable concentrations offsite; and
- provide basic information needed to evaluate treatment scenarios for the site.

The request for additional modeling will result in an unnecessary cost that the Army feels is not needed at this time.

Comment 54: **I concur with the importance on the last item on page 7-5. There has to be a carefully designed and installed off-site monitoring system to determine the levels of contamination migrating off site. There is no question that the contaminants are leaving the facility, the question is how completely they are diluted as they leave and do they still pose a threat at their diluted levels. (page 7-5)**

Response 54: BED-MW27 is the nearest boundary well at which detectable levels of nitroaromatics have been observed. These on-site concentrations are in the very low parts per billion, ranging from 1.2 to 2.6 ppb combined DNTs. The combined action level for DNTs is 1 ppb, meaning that exposure to 1 ppb in a home drinking water source used by an individual for 30 years would not result in unacceptable risk or hazard. The on-site boundary groundwater well nearly meets this criterion (and note that this water is not being used nor is it usable because of the sulfate and hydrogen sulfide content). The lower analytical reporting limit for the combined DNTs is 0.4 ppb. Therefore, it is possible that groundwater leaving the site does not exhibit detectable levels of DNT. If this is the case then any level of contamination that might be leaving the site may be minute and thus indeterminable. Please note that at the reporting limits, the DNT isomers do not represent an unacceptable risk or hazard to long-term, everyday users of groundwater as drinking water. Also, even at the maximum concentrations of DNTs detected at BED-MW27, human health risks to quarry workers would be de minimis (refer to the response to reviewer's Comment No. 3).

With respect to well placement, natural sulfur content is certainly an issue. Well BED-MW27 had to be abandoned due to complaint of nuisance odor hydrogen sulfide releases from this well to the air. Since submittal of the draft FS, on-site boundary well BED-MW22 had to be abandoned for the same reason. Also, this issue begs the question, "If this groundwater emits odors that irritate residents and has levels of sulfate so high that it cannot be used, why monitor at these locations?" Therefore, the recommendation to install additional monitoring wells in this area will be revisited in the Final FS.

Comment 55: **<u>Table 6-1</u>. This table has to be redeveloped after the off-site impact of the Wagner Quarry has been factored in to the evaluations.**

Response 55: Comment noted. The need for additional sampling at the Wagner Quarry will be addressed in future meetings.

Comment 56: **<u>Figure 1-1 PBOW Vicinity Map</u>. The Wagner Quarry has to be added to the large plain yellow area between US 205 and Columbus Ave., just north of Bogart Rd. The Quarry footprint will encompass most of the blanked out area.**

Response 56: Wagner Quarry will be added to Figure 1-1 as suggested.

Comment 57: **<u>Figure 2-2 Generalized PBOW Block Diagram</u>. This is a good visualization tool to understand the complexities of the site. As a first step to begin determining where the dewatering impacts of the Wagner Quarry are active, it would be useful to create a plan view map of bedrock monitoring wells where the water levels in the wells are below the bottom of the glacial overburden and/or shale units. Appendix A Groundwater Fate and Transport Modeling**

Response 57: The information requested has been presented in earlier reports. For example, the top of limestone bedrock was presented in the RI report (Shaw, 2005) along with all the water level data that had been collected to date.

Comment 58: **Previous Modeling. VLEACHSM allows for several different horizontal layers with different properties, but the input for the vertical hydraulic gradient requires the same matrix permeability in put parameter as the original VLEACH model did. This model assumes leaching flow from the matrix material only. This is not a good model to use in this setting where while there may be reservoirs of contaminants in the matrix, most all of the transport will be through the secondary fracture network. A better model for this site would be the USDA Root Zone Water Quality Model which allows modeling through the vadose zone and which also has a vertical fracture module which has been calibrated by USDA Agricultural**

Research Service soil scientists and agricultural engineers for Ohio soils. Leaching will probably occur more quickly than the VLEACHSM model predicts. Total leaching will depend on how much of the contaminants are stored in the matrix materials. (pages 1 & 2)

Response 58: The current modeling is sufficient to support selection of a preferred alternative for this site. The leaching model used in this FS used conservative estimates for soil properties and likely represents concentrations of leachate that are biased high.

Comment 59: **Both MODFLOW and MT3D are block-centered ground water flow models. They function on the assumption that the whole cell or block has the same properties. These kinds of models are very useful in sand and gravel settings or when calculating regional ground water recharge. The further away from that kind of setting the user gets the less useful and appropriate these models are. Modeling fastest time contaminant transport in fractured carbonate bedrock with well developed regionally controlled jointing structures and bedding plans is about as opposite an application as can be derived. The answers developed from these models will not represent closely the actual conditions at the site. There are far better fractured rock models available that would create more meaningful results. One of them should have been used here if meaningful results were anticipated. (page 2)**

Response 59: As previously stated, the intention of the modeling was to:

- determine if the soil remediation in the unsaturated zone was sufficient to protect groundwater;
- determine if residual overburden groundwater concentrations will migrate into the deeper limestone (regional) aquifer and result in unacceptable concentrations offsite; and
- provide basic information needed to evaluate treatment scenarios for the site.

The request for additional modeling will result in an additional cost that the Army feels is unnecessary at this time. Further, the data needs for fracture flow modeling are quite extensive and include determination of the location and continuity of the fractures, their orientation, and the fracture aperture or opening. As previously stated, the Army feels that the FS adequately provides enough information to determine a path forward for addressing the groundwater contamination at this site.

Comment 60: **Appendix B Evaluation for Monitored Natural Attenuation of Nitroaromatics in Bedrock 2.0 Geologic Controls on Contaminant Transport – Pages B-2 & B-3. A third scenario is that the dewatering at the Wagner Quarry results in rapid transport of the contaminants**

in the carbonates away from the discharge points and dilutes the contaminants as they travel towards the dewatering sump at the Wagner Quarry. (page B-3)

Response 60: The well elevation data collected to date do not suggest rapid transport. Conversely, the analytical data do indicate the presence of strongly reducing conditions that suggest the occurrence of natural attenuation. However, dilution is considered to be part of natural attenuation and will be described further in the text.

Comment 61: **A fourth scenario is that contaminants that may reside in the matrix of the overburden glacial materials and/or shales are only slowly released to the underlying carbonates by fracture flow during seasonal/annual recharge events. (page B-3)**

Response 61: Based on the data collected to date, the only places where contamination seems to consistently be found in the carbonates is at the Red Water Ponds. The dominant transport mechanisms likely include both desorption from the soil matrix and transport through soil fractures and through the soil pores themselves. Additional information regarding the potential for leaching during seasonally wet periods will be added to the text. However, it should be noted that this likely occurs only at the West Area and Pentolite Road Red Water ponds where there is a limited thickness of shale. Based on the data, the thickness of the shale in other parts of PBOW is sufficient to have prevented this from occurring to date

Comment 62: **<u>Geochemical Parameters – Page B-6</u>. Areas of the PBOW site where shale covers the carbonates will have naturally occurring hydrogen sulfide leached down from the overlying shale. The Plum Brook and Ohio shales were deposited in anaerobic conditions and are naturally higher in hydrogen sulfide. The Detroit River Dolostone has also been identified as having hydrogen sulfide in the formation. The lower levels have deposits of elemental sulfur. See Figure 3. In addition, both the Plum Brook and the Ohio shales are carbonaceous "oil shales" and so have their own natural "TOC" content. (page B-6)**

Response 62: Comment noted.

Comment 63: **"At TNTA-BEDGW-002, a 3.5-foot layer of free-phase hydrocarbon was encountered prior to sampling." This observation is so at odds with the observation of naturally occurring petroleum products at the Wagner Quarry that this material should be collected and fingerprinted to determine if it is from an alternative, man-made source. (page B-6)**

Response 63: NASA is currently collecting data for petroleum fingerprinting to address this issue. Please note the text incorrectly states the well as TNTA-BEDGW-002, this should be TNTA-BEDGW-001.

Comment 64: **There is no TNTA-BEDGW-002 on Figure 1-2. Is the well point missing from the map or is this label misidentified, typed in error, and the well is actually some other location? Please correct whichever way the correction needs to be made. (page B-6)**

Response 64: Please note the text incorrectly states the well as TNTA-BEDGW-002, this should be TNTA-BEDGW-001.

Comment 65: **There is no PB-BED-MW23 on Figure 1-2. There is a BED-MW23 northwest of PRRWP. Given the location of TNT-A and PRRWP on the site, is this well possibly mislabeled either on the map or in the text? Please correct. (page B-6)**

Response 65: The text will be revised to state "BED-MW23".

Comment 66: **There is not PB-BED-MW24 on Figure 1-2. There is a BED-MW24. Is this well mislabeled either on Figure 1-2 or in the text? If so, please correct. (page B-6)**

Response 66: The text will be revised to state "BED-MW24".

Response to comments in the June 1, 2007 memorandum from Julie Weatherington-Rice to Lisa Humphreys, USACE PBOW Coordinator, and others Titled "Amendments to the Technical Review for the RAB of the Shaw Environmental March 2007 Draft 'Feasibility Study for Groundwater TNT and Red Water Pond Areas' based on additional information provided at the May 31, 2007 RAB meeting"

Comment 1: **<u>Measurement of a Pumping and/or a Dewatering Cone of Influence</u>. Like Zeno's Paradox, the limits for cones of influence continue on forever. They are assumed to have reached equilibrium when either: a) They can no longer be physically measured separately from the natural static water levels of the area. This is assumed to be 0.1 inch. b) They can no longer be mathematically separated from the natural static water level. This is assumed to be 0.01 inch. The dewatering cone(s) of the Wagner Quarry, the Reactor sump, and/or any other pumping and/or dewatering cone at and/or near the PBOW site affect the time-of-travel of the ground water flow, which affects the time allowed for natural attenuation before the ground water leaves the facility boundaries, which affects how far the contaminants can move while they are still viable. Understanding these concepts will change the way we view the MODFLOW model output over time. It may also have major implications on which remediation techniques are chosen**

for the sites at PBOW. Therefore any portion of the PBOW site that has a physical impact of 0.1 inch as physically measured and/or 0.01 inch as mathematically measured on the natural static water level due to the dewatering cone of the Wagner Quarry and/or the Reactor sump and/or any other source, is within the cone(s) of depression of these sinks. Where are those boundaries?

This question does not immediately require remodeling the whole facility. It can be approximated by creating a (series of) cross section(s) of the water levels from the Wagner Quarry, the Reactor sump, and water levels in monitoring wells at the site. The Wagner Quarry sump elevation is fixed at about 460 feet above mean sea level. It should be possible to find the elevation of the Reactor sump. The water levels in the wells are measured on a regular basis. Where do the gradients change from well to well along the cross sections? Where are the static water levels steepened and where are they relatively flat?

Response 1: The influence of the Wagner Quarry is implicitly incorporated into the groundwater modeling for this site. As with any groundwater flow model, the model is calibrated against a known data set of water elevations. Both the on-site and off-site data used for calibration represent the groundwater elevation and flow of this site, as affected by the site hydrogeology as well as outside influences such as pumping at the quarry. Since the Wagner Quarry is outside the modeled domain, it is not explicitly included in the model. However, if the quarry is significantly drawing down water levels in the limestone, this drawdown would be reflected in the perimeter water levels. Therefore, the boundary conditions used in the model reflect the impacts of nearby off-site pumping. Travel time from the off-site well (BED-MW33) to the quarry is currently not a concern since we do not see any contamination in this area. Further, there is limited impact to the limestone bedrock, and only in close proximity to known sources. If there are concerns about the effects of the quarry dewatering activities on regional groundwater levels, it is more pertinent to address this issue with the Ohio DNR and the Wagner Quarry as the latter is responsible for this impact. Regardless, the Army believes that a remedial alternative can be selected at this time.

The PBOW specific groundwater elevation data is presented in numerous reports over the last few years. However, the change in hydraulic gradients across the site are readily observed on potentiometric maps included in the reports. The USACE sees no need at this time to compete additional cross sections to support the selection of a preferred alternative.

Comment 2: **<u>Using the Water Chemistry of the Ohio Shale for Background Chemistry</u>. Using the water chemistry of the Ohio and Plum Brook shales as the background for the "clean up" chemistry for the**

carbonates is simply NOT valid. It's like matching apples to meatloaf. If it was NOT possible to find background carbonate chemistry to the south and west on the PBOW site, wells should have been installed off site. USACE cannot allow Shaw to use the chemistry of the Ohio/Plum Brook shales to be used as the "clean" standard for carbonate wells in areas of thin and/or missing shale such as the Red Water ponds. The geochemical makeup of the two types of rock, their depositional conditions, and the chemistry of water within the formations are completely different. The shales are deposited in anaerobic/reducing conditions, not unlike the current Black Sea, which preserve the carbon, sulfur, and iron. The carbonates (at least the Delaware and Columbus limestones) are deposited in aerobic/oxidizing lagoon and reef conditions. The physical and chemical differences of these formations has historically been taught at Ohio State University in Geology 101, the introductory undergraduate course for geology majors. It is covered in the Ohio rocks laboratory and the field trip for the course.

Response 2: The reviewer has misinterpreted the data that has been collected and the manner in which it has been applied at this site. A more thorough review of the RI data and the subsequent BHHRA would have eliminated this concern.

The physical differences between the depositional environments for shale and carbonate units is understood. However, while the shale was indeed deposited under anaerobic conditions and the carbonates under aerobic conditions, one should not ignore the post-depositional processes that have occurred over the past 350 million years that transform the formation from sediment to bedrock. This includes lithification, uplift, fracturing, and geochemical changes resulting from interaction of the rocks with fresh water from precipitation as well as mobilization of petroleum from source rocks. If one uses only the depositional environment for the carbonates without considering post-depositional processes, the expected geochemistry of this unit at the site would be aerobic which clearly is not the case. We have extremely reducing conditions prevalent in the carbonates across the PBOW site and indeed in off-site locations as well. A review of the 2004 groundwater report indicates private wells in upgradient, crossgradient and downgradient areas having "sulfur" and "gas" present. The locations of these private wells are shown on Figure 2-1 of that report with the well details shown on Table 2-1. While the information from water well completion logs is anecdotal to some degree, the data contradict assertions of hydrogen sulfide being a site-related phenomenon resulting from spills and leaks of nitroaromatics and the raw products used in the manufacturing process.

The overburden/shale is the water-bearing unit that is contaminated with nitroaromatics. Only low and generally sporadic concentrations of

nitroaromatics have been detected in the limestone. The USACE thus considered it wise stewardship of public funding to focus its efforts on the overburden/shale unit. Accordingly, most of the wells that have been installed to gather information on background groundwater are completed in the shale unit. As described in the 2004 Groundwater Data Summary and Evaluation Report (Shaw, 2005a), these include the following seven wells: BG8-BEDGW-001, BED-MW20, BED-MW24, BED-MW25, BED-MW26, BED-MW28, and BED-MW29. Of these, only BED-MW24 was completed in the limestone; it was unexpectedly observed that BED-MW24, located on the western boundary of PBOW, is downgradient of PBOW and does not represent background. (Note that BED-MW20 was excluded from the background data set because of the presence of naturally occurring methane, but was judged suitable to use as a background comparison point for any site wells completed in the shale that likewise contain methane. BED-MW26 was replaced by off-site well BED-MW28 because of the low yield found at BED-MW26.)

The reviewer's statement that the background data obtained from the shale wells was being used "… as the background for 'clean-up' chemistry…" is inaccurate. The background data set was not used in the Feasibility Study for chemical considerations in developing any of the remedial alternatives. The background data set was used in the risk assessment (Shaw, 2006) as one of the screening tools for inorganics. As was previously agreed to by the USACE and OEPA, organic compounds (e.g., petroleum related compounds) were not screened out of the risk assessment regardless of their concentrations in background wells. Screening is typically performed early in the risk assessment process (e.g., EPA, 1989; 2000) to focus the efforts of the quantitative risk evaluation on those chemicals that may potentially (but not necessarily) be associated with human health risks or hazards. It was agreed (Shaw, 2005b; 2006) that inorganics would be screened in the PBOW groundwater risk assessment against the background data set. Use of this data set for risk screening can be justified because inorganics have not been identified as site contaminants in the soil investigation (other than lead contained in some of the building materials which affected surface soils only), nor have specific inorganics been identified at other former TNT manufacturing facilities.

Given the reviewer's apparent concerns, the risk assessment was revisited to see which specific inorganics were screened out using the background data set. Barium is the only inorganic that was screened out only on the basis of a comparison to background. Further, the maximum concentration of barium (marginally) exceeded the Safe Drinking Water Act Maximum Contaminant Level (EPA, 2006) of 2 milligrams per liter (mg/L) only in TNTC well PB-BED-MW13 (2.7 mg/L); the average concentration in this well was 1.6 mg/L. It is emphasized that barium is not used in the manufacture of TNT.

In summary, as the reviewer points out, a specific background data set does not exist for the limestone unit. The available shale background data set was used as a surrogate for screening of inorganic components in the groundwater risk assessment. Based on site history and observed inorganic concentrations, the topic of background inorganic conditions in the limestone aquifer is irrelevant with respect to any type of evaluation that impacts site remediation or close-out decisions. The development of a background data set specific to the limestone unit set at this time, as was suggested by the reviewer, would not in any way facilitate restoration of this groundwater or contribute in any discernible way to our understanding of the contaminant fate in groundwater underlying PBOW. Thus, the USACE team cannot logically or in good conscience recommend that limited public funding be used to develop a background data set specific to the limestone groundwater.

Comment 3: **<u>Dry Wells</u>. The Wagner Quarry is physically pumping over 1 million gallons per day out of the Quarry sump. The Delaware Limestone, the Columbus Limestone, and the Detroit River Group are considered and mapped as bedrock aquifers in Ohio by ODNR Division of Water, not aquitards. If a well is completed in the Delaware/Columbus/ Detroit River Group and it is completed below the dewatering cone of the quarry and it DOES NOT make water, it DOES NOT mean that the formations are aquitards, it means that the well was designed and constructed incorrectly for the hydrogeological setting. The most productive wells are located at the intersections of the two regional jointing systems, allowing water to travel to the well from both directions.**

Response 3: Labeling the carbonates in this area as "aquitards" seems to be a misinterpretation by the reviewer of the sitewide groundwater reports produced to date for the site. Groundwater investigation reports throughout the last 15 years for this site make no mention of the term "aquitard" for the carbonate units and indeed refer to these units as "aquifers" or "water-bearing zones" so the reviewer's reference to "aquitards" is puzzling.

In regard to well installation, undoubtedly the most productive wells would be found at the intersection of conjugate joints in the bedrock, a very basic premise of groundwater flow in carbonate settings. The key quite clearly is how to intersect these joints in a cost-effective manner. The design and construction of monitoring wells on PBOW follows OEPA and USACE guidance for well construction. The obvious key is the intersection of water-producing fractures and joints. Typically, borings are completed into the bedrock until a fracture is encountered that produces an adequate volume of water. Close monitoring of the drilling operations ensure that water producing fractures are noted prior to well

completion. In some cases, open boreholes have been used when numerous low producing fractures have been encountered.

Comment 4: **<u>Modification of the MODFLOW Model</u>. Depending on how the MODFLOW model was originally structured, the grid to the north can be simply modified with much bigger grid spacing. With the static water level information from the off-site monitoring well and the Wagner Quarry, two valid control points exist off-site. The cell for the Quarry can be as large as the Quarry itself (since the quarry occupies air space), as long as the sump is in the center of the cell so as not to violate the underlying rules of the model.**

This effort would still create an averaged time-of-travel instead of the fastest time-of-travel which is required for contaminant transport, but the Quarry sump should begin to drive the model IF the model was constructed correctly. As an interim step, historic and future water level maps for the carbonate bedrock for the site should be (re)generated with the Quarry sump as a constant at 460 feet above mean sea level. While the depth of the Quarry sump and its volume of pumping has changed in the last almost 100 years, the history of record of water levels at PBOW is relatively short and will not be significantly impacted by holding the quarry sump as a constant. Depending on how Shaw created these maps originally, this should be a fairly easy revision process by adding the locations and depths of the Wagner Quarry sump, the Reactor sump and any additional sumps and rerunning the static carbonate ground water surfaces through Surfer to see how the maps change with the new control points added. Once we can all view these new water level maps, we will have a much more useful place to continue this discussion of the site ground water remediation. Without this information, the accuracy of our decision making will have been limited by this critical lake of information.

Response 4: There is no additional groundwater modeling planned at this time. The model adequately simulated the groundwater flow processes both on site and in the immediate off-site areas and addresses the immediate needs for selection of a preferred alternative. Expanding the model grid to the north would require additional data well beyond the water levels from two data points. Certainly a modeling effort could be completed and adequate calibration obtained for the two points referenced, but there would be a great deal of uncertainty in the size of the capture zone of the quarry since water level data is lacking in most of the area, not to mention hydraulic conductivity data. Further, the effort proposed is an action either the Wagner Quarry or the Ohio DNR would have to undertake since the quarry is the responsible party for any dewatering.

The selection of a preferred alternative can be completed with the available data. The full remedial action process that occurs at

contaminated sites should be considered. Numerous guidance documents are available from state and federal regulatory agencies that address the full process. Under the CERCLA process, decision documents can be re-opened at any time after implementation of a remedial action if data suggest a change in site conditions or if developments in remedial technologies warrant a change in the remedy.

Comment 5: **<u>The Ohio Shale as an Oil Shale</u>. Mention was made last night about a deep rocket testing facility at the PBOW site where a large hole has been constructed in the bedrock formations under the facility and rocket engines are fired for testing. Firing a rocket creates heat, which must be dissipated from the test chamber. Mark Bohne located this test chamber on the PBOW site map for me.**

It is my understanding that the uppermost bedrocks at the site where it is located are the Ohio/Plum Brook shales. The Ohio Shale is an oil shale. In the late 1970s and early 1980s, when Ohio still had a Department of Energy (ODE), Dr. Dick McClish, recently retired from Ohio EPA Surface Water (mapping section ?), headed the geologic section for ODE. Gene Johnson, MS, Geology OSU, worked directly for Dick. They conducted oil extraction experiments on the Ohio Shale. The Ohio Shale, when heated, liberates high quality, light petroleum suitable for refining. This is a completely different product than the very thick petroleum that drips naturally out of the Columbus Limestone.

If there are physical operations at the PBOW site that generate significant amounts of heat and if that surplus heat comes into contact with the Ohio Shale, the oil fraction in the shale can be cooked out in place. It is also possible to liberate the oil fraction chemically. Once the oil is liberated, it will move with the local ground water flow pattern, floating on top of the water. When searching for the source of the free product light oil that has been located at several wells on the site, this rocket testing facility needs to be considered. Additionally, locations where volumes of transforming chemicals such as acids were spilled also need to be considered. This concludes my additional comments which were generated from information presented at the May 31, 2007 RAB meeting. Please distribute these technical comments to those who need them. If you have any questions and/or need further clarification on any portion of these additional comments, please feel free to contact me.

Response 5: The reference to rocket testing and heating of the bedrock not consistent with the actual testing conducted by NASA. According to NASA the B2 Rocket Testing Facility has an exhaust system that is designed with a deluge system comprised of a spray chamber. This spray chamber cools the exhaust with 1.7 million gallons of water. During the test the chamber

temperature only rises 1-4 degrees. Also the exhaust is extracted with a vacuum system to outside ejectors which are above ground. Further discussion of this subject can be addressed by NASA experts on the system, if necessary.

In reference to the leaching of the shale bedrock by acid spills, it is plausible that if acids were spilled in high quantities this acid may have been transported through the overburden with little or no neutralization. However, one must bear in mind that nitric and sulfuric acids, as well as toluene, were valuable and limited raw products for the production of TNT during World War II; leaks were likely addressed very quickly. Further, the lines transporting acids and other products were located above ground so any leaks would have been readily seen. Review of groundwater data at this site does not indicate any spills from acids, as with groundwater pH values are near neutral. It could be argued that the acids have been neutralized over the 65 years since operations ceased. However, extensive soil sampling at the Volunteer Army Ammunition Plant (VAAP) in Chattanooga, Tennessee along with soil pH testing did not indicate any impact to the soils by acids at any of the major process buildings (mono, bi, tri or wash houses). This plant operated in much the same manner as the PBOW facility, but for a much longer period (1942 through 1977). Hence, there were many more opportunities for spills at the VAAP site and the soils were, accordingly, heavily impacted with nitroaromatics. In addition, the soils at VAAP have little to no neutralization capacity as evident by low soil pH observed at the Acid Fume Recovery Buildings. This suggests that the spills at the main process buildings were not acidic which would rule out the leaching at most buildings.

The Acid and Fume Recovery Building likely did have some spills and each TNT manufacturing process area had two of these facilities, which essentially recycled acids from the manufacturing process. Because of this, the spent acids contained high concentrations of nitrotoluenes, dinitrotoluenes and to a lesser extent trinitrotoluene. During sampling of these buildings at PBOW, only limited concentrations of nitroaromatics were found, indicating that spills and leaks were minimal. Petroleum was found in well TNTA-BEDGW-001 on the extreme western edge of TNT Area A. This well is located at a wash house. As previously noted, soil pH data does not suggest that impacts by acidic wastes were significant at the wash houses. With that in mind, the petroleum, if from an anthropogenic source, had to be transported from the south-southwest, based on groundwater flow maps. The Acid and Fume Recovery Building is cross-gradient of the wash house which eliminates this building as a source (assuming of course that the hypothesis of acid leaching has merit). The petroleum fingerprinting being completed by NASA may further address this issue.

In all of the borings completed at PBOW, there is no observable evidence for acid leaching of soils. One would expect a noticeable change in lithology from acid leaching on a large scale; this is clearly not evident in any of the soils sampled at process buildings over the last 15 years at this site. At VAAP, leached soil was very evident from both color and textural changes in the soil. Also, one would expect that the oil would be present in the upper reaches of the limestone bedrock at least in some minimal quantities if it were coming from the overlying shale. As noted in the 2004 groundwater report, petroleum was observed on cores and hydrogen sulfide detected on a number of rock cores. It is clear from the summary table presented in that report (Table 2-6) that the observed staining does not begin at the top of the Delaware Limestone, it begins lower in the sections anywhere from 7 feet to 20 feet into the limestone. Further, staining was observed to depths of greater than 80 feet below the top of the limestone. Of importance to this evaluation, one should review the data for wells BED-MW24 and BED-MW30. Both of these wells are located along the west side of PBOW, separated from known sources of acids by a groundwater divide. Further, review of the geologic map indicates no shale units are present in this area. Yet in both of these borings, petroleum was evident in deeper portions of the rock core suggesting that there is a natural source for this contamination. To ensure review of this data, the table is attached to these comment responses.

In summary, there is no evidence to support either of the hypotheses that heating or leaching of the bedrock has mobilized petroleum. The major issue is that there were observations of very viscous petroleum at the Wagner Quarry which is not consistent with the observations on the PBOW site. A very basic fact seems to be overlooked in these observations. The Wagner Quarry has been dewatered, and the petroleum exposed to the elements. This would allow the volatilization of the lighter weight petroleum constituents such as benzene, toluene, ethylbenzene and xylenes, leaving behind heavier petroleum products. This does not occur in the subsurface. Most of the petroleum observed in PBOW wells is generally less viscous, but also limited in thickness. It is entirely plausible and perhaps likely that the differences observed are the result of natural evaporative processes occurring at the exposed rock surface in the quarry.

References for Responses to Julie Weatherington-Rice 6/1/08 Comments:

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U.S. Environmental Protection Agency (EPA), 2006, ***2006 Edition of the Drinking Water Standards and Health Advisories***, Office of Water, Washington, D.C., August, EPA 822-R-04-013.

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